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GEARING UP FOR GREATNESS

Talent identification and development in professional road cycling

Jens Voet

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Gearing up for greatness

Talent identification and development in professional road cycling

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de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
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CHAPTER 1

General introduction

The structure in and towards professional cycling

Professional male road cycling is restricted to the Union Cycliste Internationale (UCI) regulations for international competitions. The younger age categories (under-17 and younger) are regulated by the national federations and have different age cut-offs in various countries. The UCI is responsible for the international competitions starting from the under-19 (U19) category, which includes all the riders that turn 17 & 18 years old in a representative calendar year. Riders are not permitted to bypass the U19 category to already participate in the higher age categories. From the calendar year a rider turns 19 years old, the race categories are mainly based on level instead of age. Still multiple specific under-23 (U23) races exist, for example the World Championships, however, riders can be part of commercial teams of different levels and make transfers between them, as illustrated in Figure 1.1.

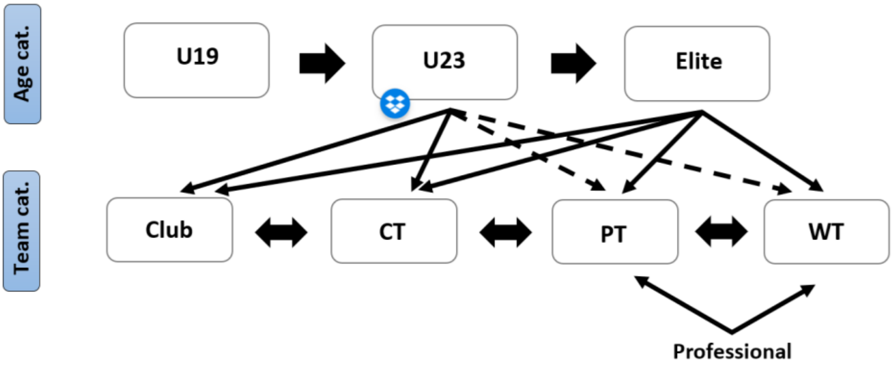

Figure 1.1. Schematic representation of age and team categories within male road cycling, according to the Union Cycliste Internationale (UCI). Straight lines: Most common team levels to be part of; Dotted lines: Less common, but still possible team levels to be part of. Abbreviations: U19, under 19; U23, under 23; CT, Continental; PT, Pro Tour; WT, World Tour; Cat, Category.

The commercial teams are taking part in races of different levels. The UCI Pro Tour (PT) and UCI World Tour (WT) teams are professional teams and only take part in professional races, i.e. at the .1, .PRO and .WT level races. The races on .WT level include the most famous stage races in professional cycling such as the Tour de France, Giro d’Italia and

Vuelta d’Espana, but also one-day classics such as the Tour of Flanders, Paris-Roubaix and Milano-Sanremo. The UCI continental teams (CT) are primarily acting just below this level and participate in races of .1, .2 and national level. Many CT level teams are functioning as development teams for the professional PT and WT teams and therefore consist mainly of U23 riders. These CT teams aim to bridge the gap between the U19 and professional level and could be defined as semi-professional teams as in most countries the riders receive minimal financial compensation. The riders are transferred into these teams from the U19 category or, when older, from club (amateur) level. These development teams are very often (but not always) integrated into the structure of professional cycling teams, for example Team Visma | Lease a Bike Development, UAE Team Emirates Gen Z and Soudal – Quick-Step Devo Team. These professional cycling ‘structures’ invest a lot of money and time in their development teams with the goal of developing the best new talents into professional cyclists. It should be mentioned that there are a few examples of riders immediately jumping from the U19 category to the professional level, including the Belgian Olympic Champion Remco Evenepoel as a well-known example. But, despite these exceptions, almost all other riders take an intermediate step within a development team, which is therefore an important part of the journey to becoming a professional cyclist.

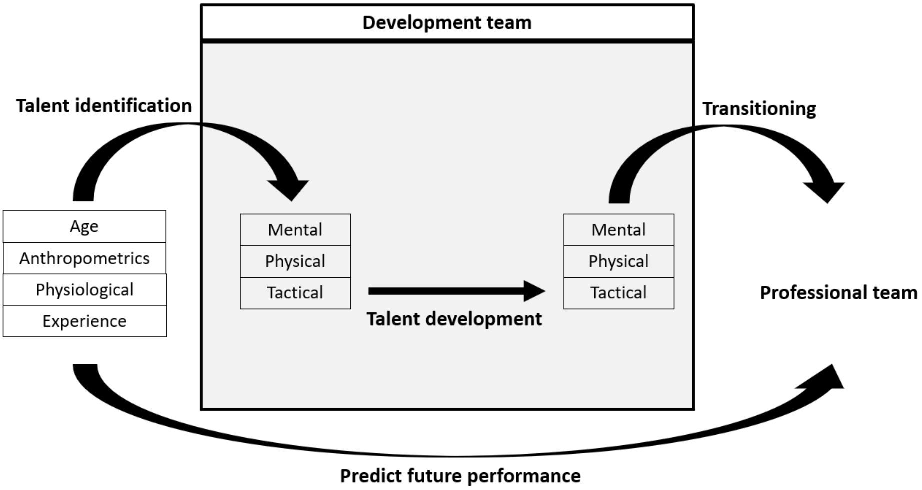

Figure 1.2. Schematic representation of a model to be used for talent identification and talent development practices relevant for development teams of professional road cycling teams.

This thesis focuses on these development teams, with the aim of improving talent identification and talent development practices, which include multiple aspects as illustrated in the model in Figure 1.2.

In the following paragraphs, this model will be further explained through the two main themes of this thesis: 1) talent identification, including transitioning between age categories and predicting future performance, and 2) talent development, including the comparison of age categories. It should be mentioned that the content of this thesis solely includes male road cycling.

Talent identification

The main objective of talent identification is to predict potential performance in elite competition, as the goal of talent development systems is to provide the necessary support and training to the athletes with the most potential [1]. However, essential for this is that there is a distinction between the performance level at the time of assessment and the capacity an individual has to develop [1]. Multiple studies investigated the ability to predict future professional road cycling performance based on race performance as a U19 cyclist, but these predictions show limited strength. Only 34% of the U19 World Championship participants later participated in major professional competitions [2]. Furthermore, only 1.6%, 8.3% and 25% of the top-10 riders in the Italian youth U16, U18 and U23 categories went on to finish in the Italian top-10 in the UCI World-Tour rankings [3]. However, it seems to be possible to have at least an estimate of potential based on U17 and U19 category results, as is shown that each additional top-10 result in these categories was associated with 3-6% higher odds of reaching professional level at adult age in Belgium [4]. Similar results were found in Italy, showing that with every additional point in success score in Italian U17, U19 and U23 cycling races there is a 4-10% higher odds to turn professional later [5]. Also, in Norway, future WT cyclists (assessed at the age of 23) have already placed significantly better at the U19 national road championships compared to CT, club and retired cyclists [6]. Recently, the use of machine learning models has also been applied to scouting practices, using results in the U19 and U23 categories to predict performance in the first years as a professional rider [7] and/or to identify races that strongly influence the predictions [8]. Using machine learning models could therefore be a helpful tool to predict future talent or finding the races where a good result could indicate a promising future.

Looking further than solely race results, Menaspa *et al.* [9] studied the predictive capacity of 'traditional' performance defining factors in road cycling: peak oxygen uptake (VO_{2peak}) and oxygen consumption (VO_2) at the respiratory compensation point (RCP). These measures were able to differentiate in competitive level in the U19 category, but they were not able to predict future success as a professional cyclist. Similar results were found within Norwegian cyclists, showing that the maximal oxygen uptake (VO_{2max}) and threshold power at the age of 18 were not predictive of later success as a professional rider. However, the maximal aerobic power, both absolute (W) and relative ($W \cdot kg^{-1}$), could differentiate between performance levels 5 years later [6].

The study of Hovorka *et al.* [10], which focused solely on the selection process for and the transition to the U23 development teams, retrospectively investigated the differences between U19 riders who were selected for UCI licensed U23 development teams and those who were not selected. The riders who were selected showed higher work rate and VO_2 relative to body mass ($W \cdot kg^{-1}$ or $L\ O_2 \cdot min^{-1} \cdot kg^{-1}$) at the gas exchange threshold (GET) and RCP, while also a superior peak power output (PPO) and VO_{2peak} both relatively to body mass ($W \cdot kg^{-1}$ or $L \cdot min^{-1} \cdot kg^{-1}$) when compared to riders who were not selected [10]. Using a similar research design but assessing the transition from the U23 category to professional level, it has been shown that U23 riders selected for a professional team showed higher absolute 2-, 5-, 12-min and CP power outputs (W), both when assessed as fresh MMPs and as MMPs after 2000 kJ of previous work done [11]. However, no difference was found when the power outputs were normalised to body mass ($W \cdot kg^{-1}$) [11]. In addition, the annual training volume and the UCI points scored in races in the year before transitioning was higher for the riders transitioning into professional level compared to the ones that did not [11]. The study by Valenzuela *et al.* [12] assessed the performance of U23 cyclists and showed the predictive value of endurance indicators such as the ventilatory threshold (VT), RCP, PPO, VO_{2peak} and 8-min time trial (TT) performance for reaching professional level after the U23 category. However, no predictive value was found for muscle strength/power indicators [12].

Research on factors beyond physical or race performance that can have an influence on talent identification in professional road cycling is scarce. The studies of

Gallo *et al.* [5] and Mostaert *et al.* [4] included the relative age effect (RAE), which is defined as a biased distribution of the birthdates of elite athletes towards the beginning of the competitive year, originating from the youth categories where cut-off dates are used to distinct between ages. They concluded that the RAE only has an effect on success in the U15 category [4, 5] and the first year of the U17 category [5], but not in older age categories (U17, U19 and U23). However, it should be mentioned that the sample sizes in these studies were limited to only Belgian [4] or Italian [5] cyclists and therefore it is difficult to generalise the conclusions made in these studies to other countries. Furthermore, studies in other sports have shown that also other factors such as anthropometric characteristics, psychological skills, motivational orientations, personality traits, birthplace and support from family and coaches can be important information in the identification of talent [13]. However, there are currently no specific studies investigating this in professional road cycling.

Talent development

Comparison of age categories

For practical reasons, there is just a limited amount of research focusing on the long-term development of training and performance of elite/international and world-class athletes (so not even solely focusing on road cyclists) [14]. Studies focusing on this should contain a longitudinal research design, which is often more time-consuming and expensive compared to other research designs, such as cross-sectional designs. In order to have guidelines for talent development, several studies have focused on comparing different age categories to see the development and standards in race demands and physical capacities from age to age. The most important change in race demands is the increase in race duration from U19 to U23 to professional level, with the average race length increasing from 2.4 (U19) to 3.1 (U23) to 3.9 (professional) hours and from 94 (U19) to 124 (U23) to 150 (professional) km [15]. Race demands of the so called “Monuments” are even greater, with an average length of 6.8 hours and 268 km [16]. Also, the yearly number of race days increases from an average of 36 (U19) to 42 (U23) to 77 (professional) [15], with a larger part of the professional calendar existing out of multi-day races, including the 3 grand tours (Giro d’Italia, Tour de France, Vuelta a España) as the longest races, consisting of 3 weeks of racing.

Based on the external demands of the races in the different age categories, it can be concluded that absolute (W) and relative ($W \cdot kg^{-1}$) power outputs from 1 to 60 seconds duration are similar between U19, U23 and professional races, but for durations longer than 5 minutes, power outputs are higher at professional level [15, 17]. Relatively similar results can be seen within the final sprint, with similar absolute peak and average sprint power when comparing U23 with professional riders, but a higher intensity in the last 10 minutes leading up to the sprint at professional level [18]. Contradictory, the internal demands of U19 races are higher compared to U23 and professional races with a higher Edwards training impulse (eTRIMP)$\cdot$hour^{-1} score and more time spent in higher heart rate zones [15]. In line with this, higher eTRIMP and eTRIMP$\cdot$km^{-1} scores and more time spent in higher heart rate zones were found for U23 compared to professional cyclists participating in the same race [19]. Similar results have also been found within standardised testing protocols, as no differences in 6, 15, 30 and 60 sec tests between junior, U23 and professional cyclists were shown, while 12- and 30-min efforts improved by 18±16 and 37±33 W respectively, from junior to senior cyclists [20]. In addition, W_{max} during an incremental test to exhaustion and the power output at 2 and 4 $mmol \cdot L^{-1}$ during a blood lactate profile test improved from junior to senior cyclists [20]. Laboratory-based endurance indicators also seem to improve from U19 to U23 to professional level, seeing VO_{2max}, PPO, RCP, the VT and an 8-min TT effort improve, as studied by Alejo *et al.* [21]. This was accompanied by changes in body composition, with a decrease in fat percentage and an increase in muscle mass, despite no significant changes in body mass. However, no differences were found between age groups in strength/power indicators [21].

When comparing U19 with U23 and professional cyclists, there appears to be a particular improvement in performance after certain accumulated loads, which is also defined as physiological resilience and/or “durability” [22]. This was demonstrated in the study by Leo *et al.* [19], who showed that professional cyclists had similar mean maximal power (MMP) values in the professional multi-day race “Tour of the Alps” compared to U23 cyclists. However, after certain levels of external workload (1000-3000 kJ) the U23 cyclists had a larger drop in MMP values compared to the professional cyclists, which suggests an important role for the resistance to fatigue and, thereby the maintenance of performance towards the end of a cycling race when developing towards higher categories. Similar to these findings, higher percentages of decrease in record power outputs were found for U19 compared to U23 and professional cyclists and for U23 compared to professional cyclists after workloads of 20 to 50 $kJ\cdot kg^{-1}$ when assessing the record power outputs of those cyclists within a full year [17]. The 5-min mean power output after a fatiguing protocol also improves from junior to U23 to senior cyclists, while the energy spent in the fatiguing protocol before this 5-min test even increased [20]. To summarise the comparison of race demands between U19, U23 and professional cyclists, there is especially a growth in the duration of the races, asking for a better endurance capacity, which is reflected in an increase in power output over longer durations and an improvement in durability.

Talent development in cycling and other sports

Multiple factors play a role in the development of ‘expert’ (i.e. professional sports) performance, such as training, teaching/coaching, parental support, enjoyment, recovery, age, psychological skills and attributes and innate abilities [23]. To investigate how these factors affect performance development over multiple years, a longitudinal study design that tracks long-term development would be required. There are a limited number of relevant studies, particularly in professional road cycling, investigating long-term development in elite/international or world-class athletes [14]. The study by Pinot and Grappe [24] monitored the training and development of a top-10 grand tour cyclist from the age of 18 to 24. During this period, the total annual duration of training increased from 526 to 943 hours and the rider improved his record power outputs between 5 min and 4 hours with 12.5 to 31.6%. The increase in training volume and the improvement in the cyclist’s aerobic potential (5 min to 4 hours power outputs) were significantly correlated, whereas the stochastic change in anaerobic potential (1 to 60 sec power output) was not. Notable was the strong increase in training load in the first three years (62%); however, while it continued to increase, the rate slowed down in the last three years (9%). Although this was a case study and the results of this cannot be generalised, a similar conclusion could be drawn from studies concerning other sports. Multiple studies are showing a non-linear increase in training volume, which plateaus at the elite/international and world-class level [14]. This increase in training volume was mainly caused by an increased volume of low-intensity training, while this varied for medium- and high-intensity training [14]. The results of this case study [24] are also in line with the earlier discussed changes in race demands from U19 to the professional level, demanding a better endurance capacity, which is induced by a higher training volume as shown in this study.

More specifically focused on the U23 development teams (Figure 1.2), two related studies have shown the relationship between training characteristics and performance improvement in U23 cyclists within a competitive season [25, 26]. From pre- to early-season, an increased training load (work (kJ) and work$\cdot$h^{-1} (kJ$\cdot$hr^{-1})) resulted in a decrease in 2-, 5- and 12-min MMPs. In addition, from early- to mid-season, an increased training time below VT1 was positively correlated with improvement on 2 and 12 min MMP and an increased training time above VT2 was positively correlated with improvement in CP [26]. The study by Spragg *et al.* [25] used data from the same participants, but the analysis focused specifically on durability and MMPs after 2000 kJ of accumulated load. It was concluded that a shift towards a polarised training distribution was correlated with an improved power profile after accumulated load. However, it should be noted that both studies were not examined based on a standardised testing protocol but on MMPs, which raises the question of whether the effort was really the maximal performance of the athlete at the given moment in time.

As stated above, there are many more factors than solely training that have an influence on the development of a cyclist. But, to the author's knowledge, similar to talent identification, there are currently no studies published that focus on other aspects of talent development (outside of training) specifically targeting road cycling. However, studies focused on other sports can give valuable insights applicable to the suggested model (Figure 1.2) for development teams in professional cycling. Using the 'four stages model' (Sampling, Specialising, Investment and Maintenance years) as proposed by Durand-Bush & Salmela [23], the years being part of a development team can be classified as the stage 'Investment years': "The period in which the athletes generally focused on the sport in which they eventually became World and Olympic champions. At this level, they sacrificed many personal and extracurricular activities to concentrate on deliberate training and competitions" [23]. Next to physical training, tactical and mental training are also important parts of the development in this period. Self-confidence, motivation and competitiveness are seen as important personal characteristics that help athletes get through this stage, and most athletes use post-competition evaluation, imagery, relaxation, and self-talk to perform optimally [23]. However, next to the athlete, there is also an important role for the supportive environment of the athlete, which can in the line of this thesis be specifically adjusted to the development teams in cycling (Figure 1.2). Family members are still important in this phase, but less actively involved compared to when the athletes were younger. A more important role will be there for valuable people in their developmental environment, such as strength trainers, nutritionists, sport psychologists, but especially their individual coaches, which were motivating but also demanding for them to help them develop the optimal skills to perform [23]. A good example of the importance of the coach can be seen in the study of Talsnes *et al.* [27], investigating the effects of a 6-month cross-country ski specific training period by comparing high- vs. low-responders. From both the side of the coach, as well as the side of the athlete, the coach-athlete relationship was perceived as a very important requisite for a high training response [27]. Coaches are expected to be highly knowledgeable and to be able to transfer this to the athlete and strive for perfection [28], and the effectiveness of coaches depends on a unique fit between the characteristics of the coach and the personality of the athlete [13]. Therefore, the coach will play a highly important role in the development of talent in professional road cycling. A strong mutual understanding between coach and cyclist is crucial, as effective communication can significantly enhance performance and development [29]. Further exploration of this coach-cyclist relationship could optimise coaching strategies for talent development in professional road cycling.

Aim and Outline of the thesis

There is limited knowledge about talent identification and talent development in professional cycling, especially in the development team trajectory, as outlined in Figure 1.2. As professional road cycling teams invest a lot of money and resources in the identification and development of new talents, a better understanding of how to do this in the most optimal way could be very beneficial. Therefore, the aim of this thesis is to extend the knowledge as identified in the model of Figure 1.2, focusing specifically on the development teams acting at semi-professional level, with the aim to develop young talents in the U23 category into professional cyclists. This thesis will consist of 5 studies, with a short outline given below.

Chapter 2: The role of the relative age effect on talent identification in professional road cycling

There is limited knowledge about the relative age effect in professional road cycling and if this has an influence on talent identification for development teams and future success at professional level. This chapter will explore the presence of the relative age effect within (the road to) professional cycling.

Chapter 3: Are professional road cycling countries selecting their talents based on anthropometric characteristics which suit the countries' terrain?

Professional cycling races are held on a variety of terrains, which asks for a variation in anthropometric characteristics for optimal performance. As countries differ in terrain, there could be a selection bias towards cyclists with the weight and height that are beneficial for the terrain of their home country. Validation of this hypothesis may assist in the identification of talent and will be explored in Chapter 3.

Chapter 4: Durability and underlying physiological factors, how do they change throughout a cycling season in Semi-Professional cyclists?

Durability, also known as the performance after accumulated load, has been shown to be an important performance indicator for professional road cycling. Durability could therefore possibly be an interesting measurement tool in the identification and development of an U23 cyclist. The aim of Chapter 4 is to show how durability changes over the course of a cycling season, as well as the proposed underlying physiological factors (gross efficiency and substrate oxidation), all measured in a standardised test protocol.

Chapter 5: Training characteristics related to (the changes in) durability in semi-professional cycling

There are a limited number of studies exploring a dose-response relationship between training and performance in high-level cyclists. An improved understanding of this relationship can assist an U23 cyclist and his coach to ensure optimal physical development. Chapter 5 will investigate this relationship based on both fresh and fatigued (after accumulated load) performance. It is hypothesised that especially a polarised training distribution will have a positive effect on the improvement of durability and that more individualised training load variables (TSS, sRPE) will show a larger dose-response relationship with performance improvements.

Chapter 6: Differences in execution and perception of training sessions as experienced by (semi-)professional cyclists and their coach

A coach designs a training program with the aim of balancing overload and recovery in order to reach optimal training adaptations for the cyclist. A mismatch between the coach's training plan and the cyclist's execution of that plan could potentially lead to reduced performance adaptations. This chapter investigates whether the intended training program by the coach is also executed and perceived similarly by the cyclist.

CHAPTER 2

The role of the relative age effect on talent identification in professional road cycling

Jens G. Voet, Robert P. Lamberts, Jos J. de Koning & Teun van Erp

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Abstract

This study aims to investigate the presence of the relative age effect (RAE) in (semi-) professional cycling, especially within selecting cyclists for Continental (CT) development teams. Data were collected from www.procyclingstats.com (PCS). Cyclists out of the top-25 countries of the PCS ranking that were part of a CT team between 2005 and 2016 and born between January 1986 and December 1997 were included ($n = 2854$). Distributions of cyclists in different birth quarters (Q1, Q2, Q3 and Q4) as well as for different starting years at CT level ($U23_{year1}$, $U23_{year2}$, $U23_{year3}$ and $U23_{year4}$) and reaching professional level or not were investigated using the Chi-square goodness-of-fit test. A RAE was found for cyclists that did not reach professional level, which can be explained by cyclists starting at CT level $U23_{year1}$ and $U23_{year2}$ (19 and 20 years old). Meaning that for cyclists at 19 and 20 years old, there is a selection bias towards relatively older (Q1) cyclists at the expense of relatively younger (Q4) cyclists. Within the cyclists that reached professional level, no RAE was found, indicating that the RAE diminishes at professional level. This study provides insight into possible selection errors while selecting cyclists for CT development teams.

Introduction

Professional male cycling consists of different competitions for different age groups. Based on the Union Cycliste Internationale (UCI), cyclists are classified based on age as: ‘under 19 years’ (U19), ‘under 23 years’ (U23) or as ‘elite’ (>23 years) riders. In addition to age categories, teams are ranked based on performance level to either: ‘Club’ [amateur], ‘Continental’ (CT [amateur]), ‘Pro Tour’ (PT [professional]) or ‘World Tour’ (WT [professional]) level (see also Figure 2.1). Professional cycling teams (i.e. PT and WT) tend to scout for talents at CT level. Furthermore, most professional teams also have their own development team on CT level with the majority of their cyclists being U23 years old (U23 category). These CT (development) teams, on their turn, tend to scout most of their riders from cyclists competing in U19 category or on Club level.

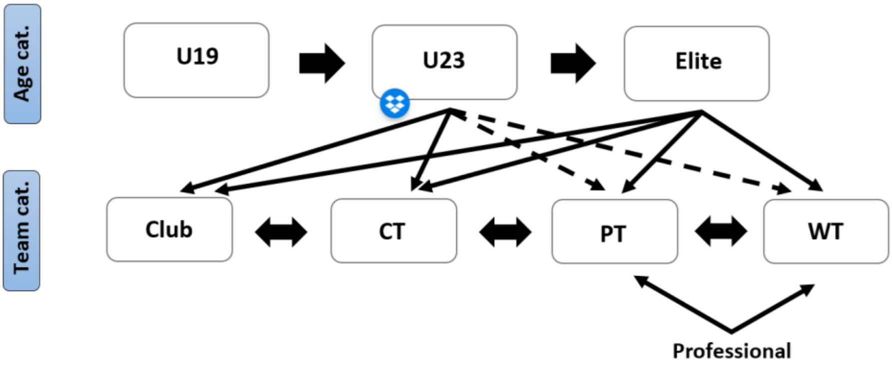

Figure 2.1: Schematic representation of age and team categories within cycling, according to the Union Cycliste Internationale (UCI). Abbreviations: U19, under 19; U23, under 23; CT, Continental; PT, Pro Tour; WT, World Tour; Cat, Category

Cyclists in the U19 category compete with other cyclists born within the 2 consecutive calendar years (January – December) before they turn 19 (17 and 18 years old). Due to this, the age difference between riders in the U19 category can be 2 years between the oldest (born in January) and youngest (born in December). This 2 years difference in age may result in physical advantages for the relatively older cyclists, born at the beginning of the year (quarter 1 [Q1]), due to advanced growth and maturation [30]. This effect is known as the relative age effect (RAE) and has been studied extensively in team sports such as soccer [31-35], ice hockey [36-38], basketball [31], baseball [35, 36], volleyball [35] and handball [39]. Most of these studies report a relatively high number of athletes born in Q1, at the expense of athletes born in quarter 4 (Q4), suggesting that the RAE might play a role in becoming successful in team sports. In line with these findings in team sports, similar outcomes were found for individual sports such as track and field [35, 40], swimming [40], tennis [41], and alpine skiing [42]. As maturation differs the most between young children, the RAE is the most substantial in the junior categories [34, 37, 39, 42, 43]. However, although differences in maturation status become smaller with age, the RAE could still be found in senior categories for some sports [33, 35, 36, 38, 41]. The influence of the RAE in senior categories is most likely caused by the effect of getting more facilities (i.e. coaches, materials or the possibility of combing school with sport) early in the development [44], competing against higher-level athletes at a younger age [44] and a higher motivation because of success experiences [45].

Helsen *et al*. [34] showed that, although there were small differences, the RAE was present in youth soccer in all observed countries across Europe in their study. In addition, de la Rubia *et al*. [39] showed that the RAE was present in handball in all continental federations except Oceania. It could therefore be suggested that the RAE is present in various countries and continents and does not depend on the birth country of the athlete. The RAE could not only affect sports participation at elite level, but as previously found in NHL hockey, the RAE could also influence performance, as relatively younger players performed better in the long-term [46] and maintained longer careers [38]. Although the cause for this effect is not known, a lower risk for injuries [38] and an ‘underdog’ effect [46] for relatively younger players were suggested. Despite various studies in different sports, the impact of the RAE in professional cycling is relatively unknown. It could be that this is different because the peak performance age in endurance sports is relatively high [47], so therefore the development of cyclists also starts at a relatively older age.

To the best of the author’s knowledge, only a few studies have previously investigated the RAE in professional cycling. A recent study by Mostaert *et al*. [4] showed that RAE influenced the success rate of Belgian cyclists in the U15 and to a lesser extent in the U17 category, but not in the U19 category. Similar results were shown by Gallo *et* *al.* [5], showing that the RAE did not influence the success rate of Italian cyclists in the U17, U19 and U23 categories. However, as both studies only investigated one country, it is still unknown if their findings are generalizable or not. In addition, it is unclear if the RAE influences future success/performances at professional cycling level as found in other sports [38, 46]. Also, the influence of the RAE on being selected for a development team is not yet determined. Therefore, the current study aims to determine 1) if the RAE is presence in (semi-)professional cycling, 2) if there is a selection bias towards relatively older cyclists (e.g. born in Q1) for CT teams, 3) if the potential RAE differs between countries and 4) if the RAE has an impact on performance in case of reaching professional level (minimal 1 year in PT or WT team).

Methods

Subjects

Data of the cyclists was collected from the open-source website www.procyclingstats.com (PCS) [48], while the data of the general birth of the population of the representative countries was collected from UN data [49]. Inclusion criteria for the cyclists were: 1) born in a country that was in the top-25 of the PCS ranking at the end of 2020, 2) born in a country of which the general birth of the population was accessible 3) had been part of a UCI CT team between 2005 and 2016 and 4) were born between January 1986 and December 1997.

Research design

Based on a script written in Python (Python Software Foundation, www.python.org), the following data was captured from the PCS website: date of birth, nationality, years on CT, PCT and WT level, starting year at CT level and PCS points. From the UN database, representative date of birth from the general population was collected for all present years in the database between 1986 and 1997.

Firstly, to investigate the RAE within (semi-)professional cycling, all cyclists were allocated to either: Q1 (January, February, March), Q2 (April, May, June), Q3 (July, August, September) or Q4 (October, November, December), based on their date of birth. In addition, it was noted if the cyclist reached professional level or not, which was defined as being part of a PT or WT team for at least one year, being part of a professional team as a trainee was therefore not considered as being professional.

Secondly, to investigate if relatively older cyclists (i.e. born in Q1 and Q2) were more often selected for a CT team, for every rider the starting year at CT level was determined based on the four calendar years (19, 20, 21 and 22 years old) that every rider is part of the U23 category. The first year that a cyclist was part of a CT team was noted as the starting year at this level, so cyclists were divided into four groups: $U23_{year1}$, $U23_{year2}$, $U23_{year3}$ or $U23_{year4}$. Thus, when a cyclist started at age 19 in a CT team he was classified as $U23_{year1}$, for age 20 this was $U23_{year2}$, for age 21 this was $U23_{year3}$ and for age 22 this was $U23_{year4}$. Cyclists that started at CT level after 4 years in the U23 category (thus at an age of 23 or older), were excluded from further analyses because they were likely not seen as talented cyclists in the U23 category as they were not selected for a CT team.

Thirdly, to investigate if the potential RAE differs between countries, the influence of the RAE was investigated for the top-25 countries in the world for cyclists reaching professional level as well as cyclists that did not reach professional level.

Lastly, to investigate if the performances of cyclists who made it to professional level were associated with a RAE, multiple performance parameters were defined: the absolute PCS_{points} that a cyclist collected in his career, PCS_{points} relative to the length of his career ($PCS_{points/year}$), the length of his professional career (years in a PCT or WT team) and the length of years being part of a WT team.

Statistics

To investigate the RAE, the difference between expected and observed frequencies of birth months in each quarter was studied using the Chi-square (χ^2) goodness of fit test. For a representative analysis, the minimum expected frequency for each quarter must be 5, countries with less than 20 participants in total were therefore excluded from further analyses (i.e. Ecuador). The expected distribution was based on the date of birth of the general population of representative countries. If this data was not present, participants of these countries were excluded for further analyses (i.e. Columbia and South-Africa). The W coefficient was used to measure the effect size for the χ^2. The W coefficient was calculated as the square root of χ^2 divided by the total number of frequencies (n) [50] (see equation 1):

(Equation 1)

$$W = \sqrt{\frac{\chi 2}{n}}$$

The W was considered as a: ≤0.1 small, 0.1 – 0.3 medium, and >0.3 large effect [23]. When the χ^2-test revealed a significant result (or tendency), the standardized residual for each quarter was calculated based on equation 2 [51] to investigate which birth quarters were under- or overrepresented.

(Equation 2)

$$\frac{observed\ frequency - expected\ frequency}{\sqrt{expected\ frequency}}$$

Based on Sharpe [51], a standardized residual higher than 2.0 or lower than -2.0 was considered significant. Differences in performance between various quarters were investigated using a one-way ANOVA. All statistical analyses were performed with the use of SPSS (IBM SPSS Statistics version 27, IBM Corporation, Armonk, NY, USA). A p-value <0.05 was considered statistically significant, a p-value >0.05 and <0.10 was considered a tendency.

Results

In total, 2720 cyclists from the top-25 cycling countries globally met the inclusion criteria. The average number ± SD of cyclists per country was 124 ± 82. Data of Ecuador was excluded for further analyses, due to not meeting the minimum criteria of 20 cyclists. For the total dataset, an expected distribution of 24,5% (Q1), 25,2% (Q2), 26,1% (Q3) and 24,3% (Q4) was used based on the date of birth of the general population of concerned countries.

RAE in (semi)-professional cyclists

A RAE with a medium effect size was found for the complete dataset (all 2720 cyclists) (χ^2 =37.915, p<0.001, W=0.12), with an overrepresentation in Q1 (z = 4.73) and an underrepresentation in Q4 (z = -3.81). When distinguishing between cyclists who reached professional level or not, no RAE was found for cyclists that reached professional level (χ^2=2.041, p=0.564, W=0.06). However, a RAE with medium effect size was found for cyclists that did not reach professional level (χ^2=38.969, p<0.001, W=0.14), with an overrepresentation in Q1 (z = 4.75) and an underrepresentation in Q4 (z = -3.93) (Figure 2.2).

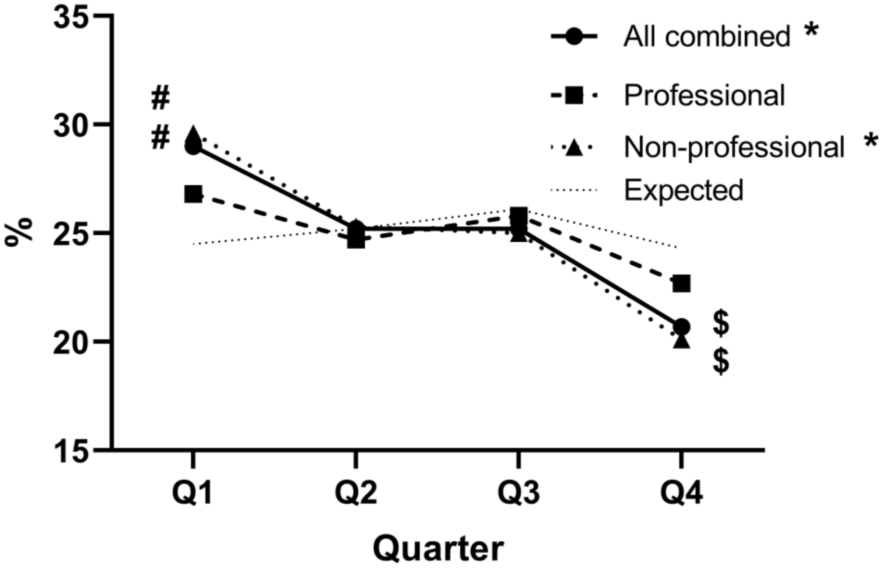

Figure 2.2: The birth month distribution of the total dataset of cyclists, the cyclists who did reach professional level and cyclists who did not reach professional level. Expected distributions based on birth dates of the general population of concerned countries were plotted for illustration. Q1: January-March, Q2: April-June, Q3: July-September, Q4: October-December. *Significantly different (p<0.05) from expected distribution. $^{\#}$post-hoc analysis indicated an overrepresentation, $^{\$}$post-hoc analysis indicated an underrepresentation

RAE and being selected for a CT team (U23)

For cyclists that did reach professional level, no RAE was found for cyclists starting at $U23_{year1}$ (χ^2=1.243, p=0.743, W=0.07), $U23_{year2}$ (χ^2=0.756, p=0.860, W=0.07), $U23_{year3}$ (χ^2=2.699, p=0.440, W=0.15) and $U23_{year4}$ (χ^2=0.345, p=0.951, W=0.06) (Figure 2.3A). For cyclists that did not make it to professional level, a RAE with medium effect size was found for $U23_{year1}$ (χ^2=34.981, p<0.001, W=0.20) and $U23_{year2}$ (χ^2=16.53, p<0.001, W=0.18), but not for $U23_{year3}$ (χ^2=2.042, p=0.564, W=0.07) and $U23_{year4}$ (χ^2=1.498, p=0.683, W=0.07) (Figure 2.3B). In both $U23_{year1}$ as $U23_{year2}$ Q1 was overrepresented (z = 4.71 & z = 2.88) and Q4 was underrepresented (z = -3.55 & z = -2.37).

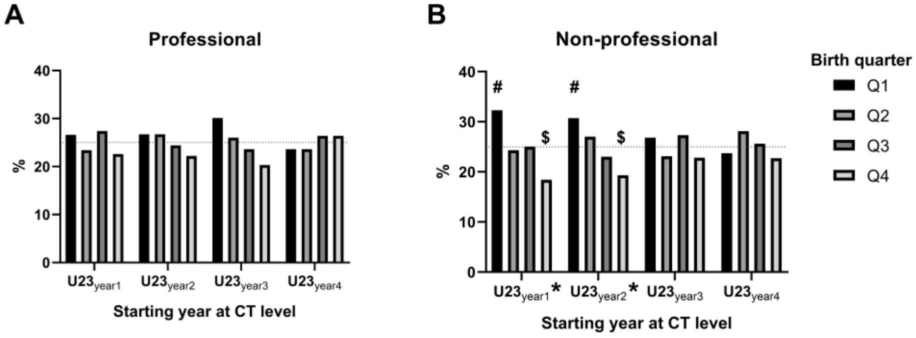

Figure 2.3: The birth month distribution of cyclists that started on Continental level as a $U23_{year1}$, $U23_{year2}$, $U23_{year3}$ and $U23_{year4}$ for cyclists that reached professional level (A) or did not reach professional level (B). *Significantly different (p<0.05) from expected distribution in Non-professional $U23_{year1}$ and $U23_{year2}$. $^{\#}$post-hoc analysis indicated an overrepresentation, $^{\$}$post-hoc analysis indicated an underrepresentation

RAE within different countries

Different RAE's were found within the different countries, as presented in Table 2.1. Among cyclists who made it to professional level, cyclists born in Q1 in Denmark (z = 2.83) and United States (z = 2.21) were overrepresented. Also, a RAE was found for cyclists that made it to professional level out of Italy, but post-hoc analysis showed no under- or overrepresentation for any of the birth quarters. In contrast, no RAE was found in any of the other 19 countries in cyclists who made it to professional level.

Within cyclists who did not make it to professional level, an overrepresentation of cyclists born in Q1 was found in Austria (z = 2.40), England (z = 2.29), Germany (z = 2.27), Kazakhstan (z = 2.71) and Russia (z = 2.29), while an underrepresentation for cyclists born in Q4 in Kazakhstan (z = -2.36) and Russia (z = -3.13) was found. No RAE was found in any of the other 16 countries in cyclists who did not make it to professional level.

Table 2.1: Birth month distribution of all top-25 countries divided into cyclists that did reach professional level or not.

	Professional					Non-professional				
	Q1	Q2	Q3	Q4	χ^2	Q1	Q2	Q3	Q4	χ^2
Australia	11	11	14	10	0.78	28	30	31	20	2.74
Austria	4	5	2	5	-	37	21	23	19	8.00*
Belgium	14	19	16	24	3.11	66	58	62	62	0.52
Colombia	9	9	10	11	2.92	17	5	18	17	8.05*
Czech	4	4	3	3	-	27	27	32	25	0.96
Denmark	16	4	7	5	11.25*	41	23	35	30	5.42
England	7	4	8	8	1.59	29	15	13	20	7.94*
France	7	11	8	7	1.30	12	12	12	5	3.59
Germany	11	12	8	14	1.67	89	60	73	60	8.07*
Ireland	1	0	2	1	-	7	5	9	4	2.36
Italy	9	6	13	2	8.67*	22	26	30	13	6.98#
Kazakhstan	6	2	3	3	-	20	13	7	3	15.33*
New Zealand	4	3	2	0	-	9	12	3	8	1.62
Norway	5	7	7	5	0.67	30	29	28	16	5.00
Poland	7	2	3	4	-	33	27	17	19	6.83#
Portugal	1	0	3	2	-	11	8	4	9	3.25
Russia	12	16	10	5	5.84	34	30	15	7	22.37*
Slovakia	2	0	0	2	-	12	9	8	11	1.00
Slovenia	2	3	3	3	-	20	15	24	20	2.06
South Africa	2	2	4	3	-	9	4	7	7	1.89
Spain	10	11	11	9	0.27	10	12	11	8	0.85
Switzerland	1	5	3	3	-	10	9	7	5	1.90
The Netherlands	13	15	22	19	2.83	50	53	55	35	5.11
United States	17	11	10	5	6.77#	27	40	28	24	5.00

*Significant (<0.05), #(<0.10) with Chi-squared goodness of fit test. Dark grey = significant overrepresentation of birth quarter, light grey = significant underrepresentation of birth quarter.
- = No statistics applied if total number of cyclists was lower than 20

RAE and performance in professional cyclists

No differences in performance characteristics (i.e. $\text{PCS}_{\text{points}}$, $\text{PCS}_{\text{points/year}}$, professional years and years in WT) were found between cyclists born in the different quarters for riders who managed to become professional cyclists (Table 2.2).

Table 2.2: Performance of cyclists (mean ± SD) that were part of a Continental team in U23 category and reached professional level compared between different quarters in which they were born.

	$\text{PCS}_{\text{points}}$	$\text{PCS}_{\text{points/year}}$	Professional years	Years in WT
Q1	962 ± 2154	95 ± 188	4.5 ± 2.9	2.6 ± 3.2
Q2	1214 ± 2119	108 ± 164	4.9 ± 3.4	2.9 ± 3.7
Q3	1107 ± 1823	105 ± 143	5.1 ± 3.2	2.8 ± 3.2
Q4	1034 ± 1666	97 ± 130	4.9 ± 3.2	3.0 ± 3.3
p	0.704	0.855	0.479	0.649

Abbreviations: SD, standard deviation; U23, under 23; $\text{PCS}_{\text{points}}$, total ProCyclingStats points; $\text{PCS}_{\text{points/year}}$, ProCyclingStats points relative to the length of the professional career of the cyclist; WT, World Tour; Q1, cyclists born in January, February or March; Q2, cyclists born in April, May or June; Q3, cyclists born in July, August or September; Q4, cyclists born in October, November or December

Discussion

The aims of this study were four-fold, firstly to investigate if the RAE was present in (semi-) professional cycling, secondly if there was a selection bias towards relatively older cyclists (born in Q1 and Q2), thirdly if the RAE differs per country and fourthly to investigate the relation between RAE and performance in professional cyclists. The main finding of this study was that a RAE was found for cyclists who have been part of a CT team, but did not reach professional level, which was caused by cyclists starting at CT level as $\text{U23}_{\text{year1}}$ and $\text{U23}_{\text{year2}}$ (i.e. at 19 and 20 years old). This means that among these 19 and 20 years old cyclists, there is a selection bias towards relatively older cyclists born in Q1, at the expense of relatively younger cyclists born in Q4. However, cyclists born in Q1 did not have a higher chance of becoming a professional cyclist, as this study did not find a RAE in cyclists that became professional. Also, when data was analyzed for each country independently, only a RAE for cyclists that did not reach professional level was found for Austria, England, Germany, Kazakhstan and Russia. In addition, our results indicated that there is no influence of the RAE on performance at professional level.

This study shows that the RAE is present within (semi-)professional cycling at CT level. This is in contrast with recent studies indicating that the RAE does not affect the performance of Belgian cyclists in the U19 category [4] and Italian cyclists in the U19 and U23 categories [5]. These different conclusions could be caused as both of these studies investigated success rate rather than being selected for a CT (development) team and therefore have different criteria of success. In addition, both of these studies assumed a uniform distribution between the birth quarters, while the current study compared with a distribution based on the birth dates of the general population. Also, the current study has a substantial larger sample size which could have an effect on the results. And lastly, it seems that both studies [4, 5] do not make a distinction between cyclists that reach professional level or do not reach professional level when looking into the distribution of the cyclists in the different birth quarters. When only investigating the cyclists that did not reach professional level (but were present in the database so they were more or less successful in the youth categories), same conclusions as in the current study could be made when also using the Chi-square (χ^2) goodness of fit test. Namely, a RAE for cyclists that did not reach professional level with an overrepresentation in Q1 [5] and/or an underrepresentation in Q4 [4, 5]. Similar to the current study, no RAE was present anymore at professional level.

The present study also shows that cyclists born in the first quarter have a higher chance of being selected for a CT team at the age of 19 and 20 (i.e. $U23_{year1}$ and $U23_{year2}$), while this effect was not found in 21 and 22 year old cyclists (i.e. $U23_{year3}$ and $U23_{year4}$). This can possibly be explained by how talents are scouted for CT teams at the age of 19 and 20 years. When this is mainly done based on performance outcomes, this can lead to a selection bias, as relatively older cyclists (born in Q1) are more likely to perform better in the U19 category (and the 1st year in the U23 category) because they are further in growth and maturation statuses than cyclists born in Q4 [30]. This selection bias could result in not selecting relatively younger cyclists (born in Q4), although the ability to perform in the future could be equal. In addition, more relatively older cyclists (born in Q1) are selected although our results show that they are not overrepresented at professional level later in their career, as our analysis did not reveal unequal distributions between birth quarters for all cyclists that reached professional level. Being aware of this selection bias could result in improved talent selection with equal chances for cyclists in the different quarters and reducing investments in the development of 'incorrectly' selected relatively older cyclists. Possible solutions for this selection bias could be varying the age group cut-off dates within the competition year or quotas for youth teams based upon chronological age as was suggested by Passfield & Hopker [52]. In addition, it could also be suggested to structure age groups based upon biological age rather than chronological age.

In this study, relatively older cyclists (born in Q4) had a higher chance of being selected for a CT team at $\mathrm{U23}_{\mathrm{year1}}$ and $\mathrm{U23}_{\mathrm{year2}}$ (age 19 and 20 years old). Although this did not result in a higher chance of becoming a professional cyclist because no RAE was found for cyclists reaching professional level. This is in line with several studies also not finding a RAE at senior level in volleyball [35], basketball [35, 36, 38], badminton [35], golf [36], football [38] and handball [39]. However, this is in contrast with studies finding a RAE at senior level in a variation of sports, such as soccer [33, 35], baseball [35, 36], track and field [35], hockey [38] and tennis [41]. These differences can possibly be explained by characteristics (e.g. peak performance age, age at which development starts, the popularity of the sport, physical/psychological characteristics of the sport) of the several sports as these characteristics could be factors in the RAE [44]. Cycling is a sport that is mainly dependent on physical capacities. It could be suggested that being selected at a younger age and therefore getting more facilities (e.g. coaching, playing against higher-level opponents) has fewer long-term advantages for physical sports such as cycling, compared to technical sports such as soccer and hockey.

When data was analyzed for each country independently, the general trend was still visible with an absence of RAE for cyclists at professional level and a RAE for cyclists that did not reach professional level. However, there was some variation present between the different countries. In total, 5 countries (Austria, England, Germany, Kazakhstan and Russia) showed a significant RAE with an overrepresentation in Q1 and/or an underrepresentation in Q4 for cyclists that did not reach professional level. This is in contrast with other studies, which found RAE's in (almost) all investigated countries [34, 39], however, these studies were done in more technical sports which could explain the differences with this study in professional cyclists as mentioned before. In addition, one of the previous studies [39] used an expected uniform distribution, while the current study based the expected distribution on the birth rate of the general population. The wide range of results between countries could also be caused by the small sample size for various countries resulting in biased effects. Furthermore, countries such as Spain, Italy and France have a high number of professional cyclists, but a different development structure. In these countries, most development teams with young, talented cyclists are at club level instead of CT level. Fewer cyclists are therefore selected for CT teams at $U23_{year1}$ and $U23_{year2}$ (age 19 and 20 years old), leading to, again, small sample size and potentially biased effects. Another explanation for the wide range of results across countries could be the popularity of the sport in each country. As previously suggested by Much & Grondin [44], the RAE is influenced by the competition (how many athletes are available for how many places) for obtaining a place in a development program, which depends on the popularity of a given sport in a given country. It could also be suggested that talent scouting in some countries is more focused on possible future performances instead of current performance. Future research could be focused on how talent scouting is organized within cycling, the differences between countries and how this could be improved to better guide future performers.

For the cyclists that did reach professional level, no differences were found in various performance parameters between cyclists born in different birth quarters. This is in contrast with results in ice hockey, where longer career lengths [38] and better long-term performances [46] were found for relatively younger players (i.e. players from Q4). It is suggested that this was caused by fewer injuries [38] or an ‘underdog’ effect [46] in favour of relatively younger players. It could be suggested that these explanations are not valid for cycling because it is, as previously mentioned, a sport largely dependent on physical (so, almost no technical) capacities. Furthermore, the results found in this study were in line with other results found in handball [39], basketball and football [38], where no differences in performance parameters were found between born quarters.

There are some limitations to this study that should be taken into account when interpreting the results of the performance characteristics of the professional cyclists. Some of the cyclists in the database were still active on professional level and could therefore still gain additional points in their career. Although, the general trend still clearly shows no differences between the different birth quarters.

Practical applications

The results of this study contribute to a better understanding of selecting talented cyclists for CT teams. For the ones responsible for talent scouting, it could provide valuable information about possible selection errors. This study found that scouting on performance at 19 or 20 years old could lead to a bias of choosing relatively older cyclists (Q1) at the expense of relatively younger cyclists (Q4). Instead of focusing on present performance, it should be the aim to focus on future performances and how to detect these at 18 or 19 years old. It could also raise the question of re-evaluating the current structure of age categories by the UCI, especially in the youth categories. For example, structuring the age categories based on biological age instead of chronical age could be suggested. Both would probably result in fewer selection errors within talent scouting in cycling. Especially, talent identification in Austria, England, Germany, Kazakhstan and Russia could gain more attention as the current study shows that, especially in these countries, a RAE exists. In addition, our results show that the RAE diminishes at professional level, indicating that the RAE is mostly important while selecting talented cyclists for CT (development) teams and of less importance for selecting cyclists for professional teams.

Conclusion

To conclude, relatively older cyclists (Q1) are more often selected for CT teams as $U23_{year1}$ and $U23_{year2}$ (19 and 20 years old) compared to relatively younger cyclists (Q4). Specifically, this RAE was present within the cyclists that did not reach professional level. Therefore, relatively younger cyclists (Q4) have a smaller chance of becoming professional, as they are less selected by CT teams. Within the cyclists that reached professional level, the RAE was not present anymore. The RAE found for cyclists who did not reach professional level is not present in all countries. It was outside the scope of this study to investigate why these differences between countries occur, but this could be an interesting topic for future research. At professional level there is no difference in performance between the cyclist born in different birth quarter

CHAPTER 3

Are professional road cycling countries selecting their talents based on anthropometric characteristics which suit the countries' terrain?

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Abstract

Background: This study investigates if countries are more focussed on certain specialisations (one day, climb, sprint, time trial (TT) and grand tour (GC)) in male professional road cycling and if this is possibly linked to the countries landscape (for example, does a mountainous country have more climbers?) and anthropometric characteristics (does the mountainous country also have lighter cyclists?) of their cyclists.

Methods: Body weight, height, procyclingstats (PCS) points per speciality were gathered from 1810 professional cyclists out of 15 countries, as well as the elevation span of those countries. To compare the anthropometric differences between different countries, height was normalized based on the average height of the countries' population, while BMI was used as a correction for body weight.

Results: The average anthropometrics (body weight and height) of professional cyclists in a country are related to the relative number of PCS points collected in GC, sprint and climb races. This means that when a country has shorter and lighter cyclists, they score relatively better in GC and climb races and vice versa for sprint races, which indicates that countries are focused on certain specialities. However, these relationships were not found for TT and one day PCS points. In addition, countries with larger cyclists have a less mountainous (elevation span) landscape compared to countries with lighter cyclists.

Conclusions: The results suggest a selection bias towards smaller/lighter or taller/heavier cyclists in various countries, probably caused by the terrain of their home country, leading to missed opportunities for some cyclists to reach professional level.

Introduction

Male professional road cycling is a highly demanding sport in which competition can vary from a one day [53] to a multi-day stage race (2-10 days) [54]. The most demanding races in professional road cycling are the Grand Tours which consist of 21 race days interspaced with only 2 or 3 rest days [55-58]. As cycling races are held on public roads and in different places around the world, their race profiles are different because of the variation in distance, duration, road conditions and elevation gain [53]. Based on the profile, cycling races or stages can be categorised as “flat”, “semi-mountain”, “mountain” or a Time Trial (TT), which require different decisive qualities to win a race [59]. This leads to different specialties among professional cyclists such as climbers, sprinters, general classification specialists (GC), time trialists (TT) and one day specialists.

As the racing conditions and therefore decisive qualities to win a cycling race differ between these different race types it is known that the optimal anthropometrics vary for different race types and specialties (i.e. one day specialists, climbers, sprinters, TT and GC specialists) [60-63]. Male professional cyclists, therefore, show a wide range of anthropometric characteristics [64] and only excel in one or two of these different race types (i.e. flat, semi-mountain, mountain and TT) [57, 58]. Within these different specialisms, different resistances are playing a role. For example, when riding on flat terrain, air resistance is the primary resistance, which places taller cyclists at more advantage as they have a lower frontal area/body weight (muscle mass) ratio which gives them an advantage against smaller cyclists when riding on flat terrain. The opposite occurs when cycling uphill, as the primary resistance to overcome is gravity. This places smaller cyclists into an advantage over taller cyclists as they have a relatively higher VO_2/body weight ratio resulting in higher power output relative to body weight [65]. As a result of this, anthropometric characteristics have been shown to be related to certain specialisations within professional cycling. Climbers seem to be smaller [60, 61] and have a lower body weight [60-62] and Body Mass Index (BMI) [60] compared to flat terrain specialists. In addition, GC specialists seem to be smaller and have lower body weight and BMI compared to TT specialists [63], sprinters are taller and have higher body weight and BMI compared to climbers [60] and GC specialists [63] and one day specialists were found to be smaller than TT specialists [63].

To become a professional cyclist, a young cyclist must, amongst other things, show that he can perform on the professional level by winning amateur level races, for example in the U19 or U23 category as categorised by the UCI. Recent studies show that results of road cycling races in the U19 and U23 category in Italy [5] and Belgium [4] may provide an indication of the probability of becoming a professional cyclist. In general, young cyclists are primarily racing in their own or coextensive countries. Because countries differ in dominant terrain, it can therefore occur that talented cyclists must perform at a race type that does not optimally fit their anthropometric characteristics. For example, Spain's terrain can be classified as hilly or mountainous and therefore it might be difficult for a talented sprinter (mostly relatively heavier) to show his talent as he will need to win or perform well in mainly hilly races. In contrast, if he had been growing up in the Netherlands, where most races are flat, it potentially would be a lot easier to showcase his talent as a sprinter. The opposite could occur for a lighter, climber typed cyclist in the Netherlands where taller, heavier cyclists have an advantage on the mostly flat and windy terrain. Therefore, the terrain of a country, such as hilly or flat, might influence a young cyclists' chances to show his talents and thus increase his chance of making it into a professional cycling team. Therefore it could appear that, within different countries, there might be a selection bias towards cyclists that do well in the environmental condition of their home country and thus talent for the non-prevalent terrain in a country could be lost. To our knowledge, no study to date has specifically investigated this.

As described above, one of the most important factors for being selected for a development program or a professional career in male professional road cycling is achieving good race results. However, since riders primarily compete in their own or coextensive countries, these race results could be influenced by the terrain of the country. Therefore, the aims of this study are twofold. Firstly, this study aims to investigate if there is a relationship between the specialisation of male professional road cyclists and their home country, as well as their anthropometric profile. The second aim was to determine if different countries indeed tend to have a selection bias toward cyclists that match the countries' environmental conditions.

Methods

Data collection

The data for this study was extracted from an open-source website, namely www.procyclingstats.com (PCS) [48]. The dataset included all male cyclists born in the top-25 countries of the PCS ranking. This PCS ranking for nations is based on a summation of the 100 best results of a country over a 12-month period [48]. These results could include multiple performances by the same cyclist and were limited to the 100 best results so not only the quantity of riders out of a specific country, but also the quality of them was taken into account. From this list of 25 countries, all male cyclists that rode at the professional level between 2005 and 2020 were included. Professional level was defined as being part of a Union Cycliste Internationale (UCI) Pro Tour (PT) or World Tour (WT) team for at least one year. Being part of a PT or WT team as a trainee was not considered as ‘professional’. To avoid the effect of skewed averages, countries with less than 30 cyclists in the database were excluded. This resulted in a database of 1810 professional cyclists from 15 countries.

Research design

Based on a script written in Python (version 3.10.3, Python Software Foundation), body weight, body height and nationality were collected from the PCS website at the end of 2020.

In addition, PCS points per specialty (one day, climb, sprint, TT and GC) were collected based on scores from PCS. The PCS scoring system is based on ranking each race on type (TT or mass start, one day or multi day), level (i.e. World Tour, 1.1 or 1.2) and giving every race a profile score based on the number, length and steepness of climbs in a race. This scoring system is more extensively described and used by Miller and Susa [63]. The total amount of points for each specialty were calculated in various ways. One day: for every one day race, the PCS points based on the race result were summated. Climb/Sprint: points were classified on a special point scale, taking the race profile and the race result into account of both one day races as well as individual stages in a multi-day race. TT: for every TT, the PCS points based on the result were summated. GC: the

PCS points based on the result in the final GC standings were summated. This all resulted in a total PCS points per race type (one day, climb, sprint, TT and GC) for each rider.

To investigate if cyclists from certain countries are more specialized in certain race types and if this is related to the terrain and the anthropometric characteristics of the cyclists in this country, the PCS points per specialty (one day, climb, sprint, TT and GC) were summed for all cyclists. The total PCS points per specialty for a country were divided by the total number of PCS points, to create a relative score per specialty for each country (see Equation 1 for an example). This method was used to define in which specialty a country excelled relatively the most.

(Equation 1)

$$Relative\ One\ day\ score = \frac{Total\ of\ One\ day\ PCS\ points\ per\ country}{Total\ of\ PCS\ points\ per\ country} * 100\%$$

Furthermore, for all cyclists belonging to a specific country, the anthropometric values (i.e. body height and body weight) were averaged. The elevation span (see Equation 2) was used as a measure of the terrain of the country.

(Equation 2)

$$Elevation\ span = highest\ point\ in\ the\ country - lowest\ point\ in\ the\ country$$

To investigate if countries with a more mountainous terrain also have lighter cyclists and vice versa, the elevation span of the 5 countries with the largest average weight and height of their cyclists was compared to the elevation span of the 5 countries with the smallest average height and weight of their cyclists.

As a second aim, to investigate if a countries’ terrain results in a selection bias (i.e. that a relatively mountainous country selects lighter cyclists and vice versa for a relatively flat country), the average body weight and height of the countries’ cyclists were analysed. To fairly compare countries, corrected height based on the average country was calculated. This is done because when the whole male population of a country is relatively tall, it would be logical that the cyclists are also relatively tall compared to cyclists from a country with a relatively small male population. The average body height of the male population per country, as part of this calculation, was based on NCD-RisC [66] for all analyzed countries, using the age cohort of 1996. The average body height of all these countries was again averaged, resulting in a total average body height. The difference between the total average body height and the average body height of the male population for a country was used as a correction, of which an example can be seen in Equation 3:

(Equation 3)

Correction Australia = Average body height of male population of all included countries – Average body height male population in Australia

Although this method is, to our knowledge, not previously used, we designed it to make it possible to compare countries with each other and to investigate a potential selection bias in certain countries towards taller or shorter cyclists based on the country's terrain.

A similar approach could, unfortunately, not be used to calculate a corrected weight as the mean weight of a country is not representative of professional cyclists as they are much leaner. Corrected body weight was therefore based on Body Mass Index (BMI), as then the body height was no longer influencing the comparison in body weight between countries. BMI was calculated, based on the actual body weight and height, according to equation 4:

(Equation 4)

$$BMI = \frac{body\ weight}{body\ height^2}$$

Statistics

Prior to analysis, normality assumption was verified by using Shapiro-Wilk W test and by visual inspection of Q-Q plots. The relationships between body height, body weight, and the PCS points per specialty were assessed by Pearson's correlation coefficient. Interpretation of the strength of the correlation coefficients was based on the following criteria: 0-0.09 *trivial*; 0.1-0.29 *small*; 0.3-0.49 *moderate*; 0.5-0.69 *strong*; 0.7-0.89 *very* *strong*; 0.9-0.99 *almost perfect*; 1.00 *perfect* [67]. Differences in elevation span between the 5 countries with the largest and lowest average weight and height were investigated with an independent samples t-test. Differences between countries in corrected body weight and height were investigated using a one-way ANOVA with a Bonferroni post-hoc. Differences between the average body height of the cyclists with and the average body height of the male population in a country were investigated with a one sample t-test and a paired samples t-test. Effect size is reported as the standardised Cohen's d, with the following criteria based on the guidelines provided by Hopkins *et al*. [67]: 0-0.19 *trivial*, 0.20-0.59 *small*, 0.6-1.19 *moderate*, 1.20-1.99 *large*, ≥2.00 *very large*. All statistical analyses were performed with the use of SPSS (IBM SPSS Statistics version 27, IBM Corporation, Armonk, NY, USA), figures were created with GraphPad Prism (version 8.01, GraphPad Software, La Jolla California, USA) and a p-value <0.05 was considered as statistically significant.

Results

Cyclists from 15 countries were included in this study with on average 121 ± 85 riders per country, resulting in a total of 1810 professional cyclists analyzed. Significant *strong* to *almost perfect* correlations were found between the average body weight of the cyclists per country and the relative number of collected climb ($r = -0.93$, $p < 0.001$), sprint ($r = 0.76$, $p = 0.001$) and GC ($r = -0.73$, $p = 0.002$) PCS points for that country (Figure 3.1). However, no significant correlations were found between the average body weight of the cyclists per country and the relative number of one day and TT PCS points (Figure 3.1). In addition, significant *strong* to *almost perfect* correlations were found between average body height per country and relative number of collected climb ($r = -0.91$, $p < 0.001$), sprint ($r = 0.65$, $p = 0.009$) and GC ($r = -0.62$, $p = 0.013$) PCS points for that country (Figure 3.1). However, no significant correlations were found between average body height per country and the relative number of one day and TT PCS points (Figure 3.1).

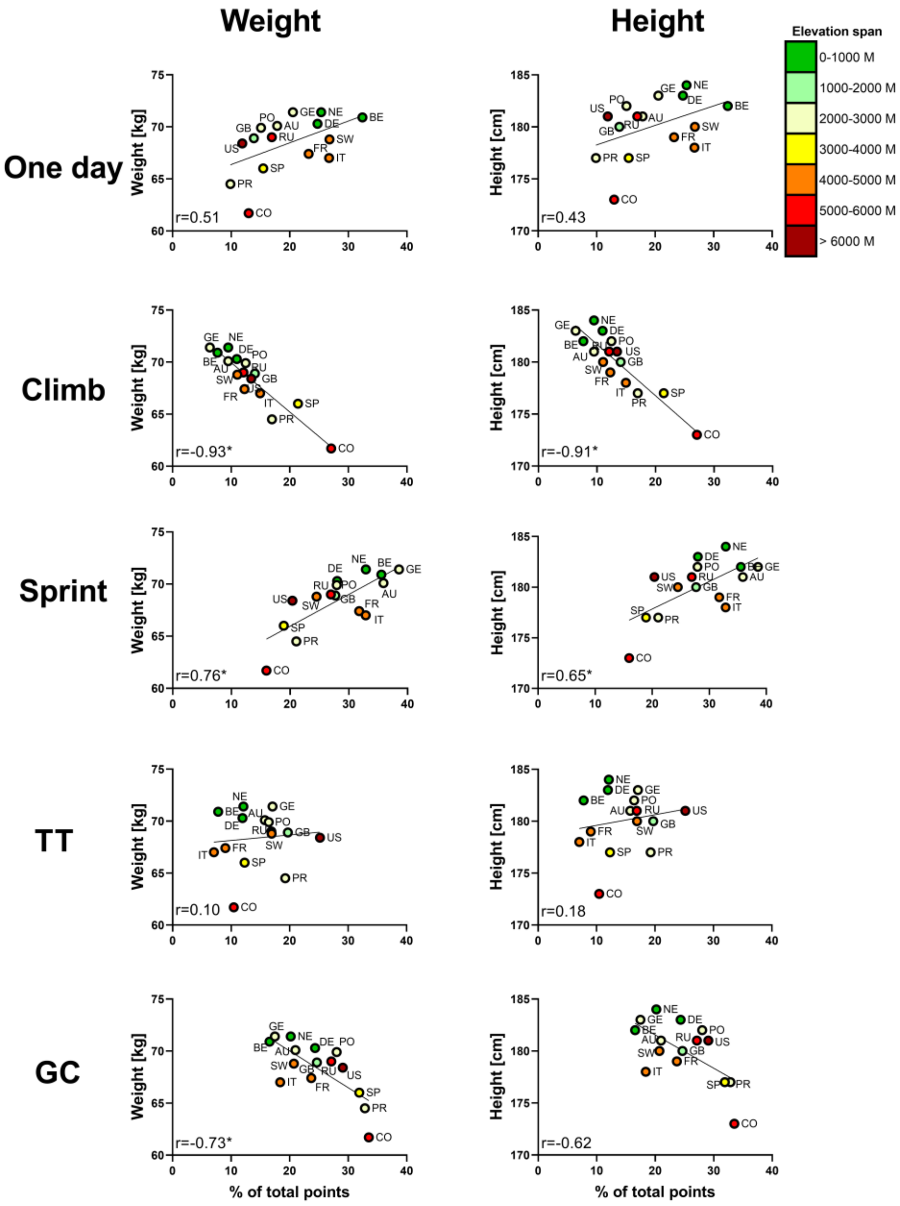

Figure 3.1: The relation between the average body weight and height of the cyclists per country and the percentage of collected One day, Climb, Sprint, TT and GC procyclingstats points of these countries. The elevation span for each country is shown to give a measure of terrain of the country. *Sig. correlation (p<0.05). Abbreviations: GC, General Classification; TT, Time Trial; AU, Australia; BE, Belgium; CO, Colombia; DE, Denmark; FR, France; GE, Germany; GB, Great Britain; IT, Italy; NE, The Netherlands; PO, Poland; PR, Portugal; RU, Russia; SP, Spain; SW, Switzerland; US, United States of America

The elevation span of the 5 countries with the largest average weight (Germany, the Netherlands, Belgium, Denmark and Australia) was significantly smaller compared to the elevation span of the 5 countries with the lowest average weight (Colombia, Portugal, Spain, Italy and France) (1396 m vs 4280 m, p = 0.006). Also, the elevation span of the 5 countries with the largest average height (the Netherlands, Denmark, Germany, Belgium and Poland) was significantly smaller (1447 vs 4280 m, p = 0.007) with a *very large* effect size (d = -2.26) compared to the elevation span of the 5 countries with the lowest average height (Colombia, Portugal, Spain, Italy and France).

To detect possible selection biases towards smaller/lighter or taller/heavier cyclists, this study investigated if cyclists from different countries differ in body weight and height, when corrected for the average height in a country. Differences were found between countries when comparing BMI (Supplementary Table 3.1) and corrected body height (Supplementary Table 3.2).

Table 3.1: The average body height in a country compared with the average body height ± SD of the professional cyclists for that country.

Country	Average height in the country [cm]	Average height cyclists [cm]	Difference [cm]
Australia	175.6	180.6 ± 5.7	5.0*
Belgium	178.6	181.9 ± 5.9	3.3*
Colombia	170.6	173.0 ± 5.6	2.4*
Denmark	180.4	183.3 ± 6.4	2.9*
France	174.1	179.1 ± 5.9	5.0*
Germany	175.4	182.6 ± 6.4	7.2*
Great Britain	175.3	180.5 ± 6.8	5.2*
Italy	176.5	178.2 ± 6.1	1.7*
Netherlands	180.8	183.7 ± 5.7	2.9*
Poland	178.7	181.7 ± 6.2	3.0*
Portugal	173.9	177.4 ± 5.8	3.5*
Russia	176.4	180.9 ± 6.0	4.5*
Spain	173.1	177.3 ± 13.1	4.2*
Switzerland	175.4	180.0 ± 7.0	4.6*
United States	175.3	181.1 ± 5.4	5.8*
Mean ± SD	176.0 ± 2.7	180.1 ± 2.8	4.1 ± 1.5$^{\$}$

*Sig. difference ($p<0.05$) with a one-sample t-test, $^{\$}$Sig. difference ($p<0.05$) with a paired samples t-test

When analysing the results, it was additionally found that the professional cyclists were on average significantly taller with a *large* effect size compared to the average male in their country of origin (d = 1.45, p<0.001), which was found in each of the included countries (Table 3.1).

Discussion

This study aimed to investigate if the terrain of a specific country causes selection bias towards cyclists with specific anthropometric characteristics that suit the landscape of the country. This was done by investigating the anthropometric characteristics of male professional road cyclists in the top 25 countries of the PCS ranking from which 15 countries were included in this study. The most important results of this study showed that the average anthropometrics (body weight and height) of male professional road cyclists in a country are related to the relative number of PCS points collected in GC, sprint and climb races. This means that when a country has shorter and lighter cyclists, they score relatively better in GC and climb races and vice versa for sprint races. This is also related to the terrain of the country as the 5 countries with the largest average weight and height had a significantly lower elevation span compared to the 5 countries with the smallest average weight and height. In addition, the differences between the professional cyclists of countries in body weight and height, also when corrected for the average body height in the country (corrected body height) or the body height of the cyclist (BMI) are presented. The results suggest a selection bias towards smaller/lighter or taller/heavier cyclists in specific countries. Besides that, in all investigated countries, the average body height of male professional road cyclists was taller than the average male body height in the country.

The current study showed that the average body weight and height of professional cyclists in a country are related to the number of PCS points the country scores relatively in GC, sprint and climb races. This means that countries with a higher number of smaller/lighter cyclists are more successful in GC and climb races while countries with more taller/heavier cyclists are more successful in sprint races. This is in line with previous research which found that GC specialists and climbers are lighter/shorter compared to road cyclists specialised in sprinting [60, 63]. The current study found *almost perfect* relationships between anthropometric measures and performance in climb races while this relationship was weaker although still *strong* to *very strong* for GC contenders. This is probably caused by performing in a GC means performing more all-round because stage races can exist out of various race types (i.e. flat, semi-mountain, mountain and TT) resulting in different optimal anthropometrics. The current study did not find a significant relationship between anthropometric measures and relative TT points. Previous research about the anthropometrics of TT specialists was not conclusive as results suggested that performing in TT's is related to taller cyclists [63], although not in every study [61]. It could be reasoned that performing in TT's is a very specialistic part of cycling, which needs a lot of attention in training and optimising aerodynamics [68] and therefore being taller or heavier does not directly result in better TT performance. Also, no significant correlations were found between anthropometric measures and PCS points collected in one day races. As one day specialists could only be distinguished from TT specialists previously [63], this would also be expected, probably because one day races could range between Flemish classics such as 'Ronde van Vlaanderen' or 'Paris-Roubaix' and more climber typed races such as 'Giro di Lombardia' and 'Clasica San Sebastian'. Previous research showed that only the 'Monuments' already variate substantially within them, which is clearly visible in the large standard deviation in total elevation gain (1300 m) of these races [16], therefore it is likely that there are various optimal anthropometrics to win these races. It should, however, also be noted that the p-value was only $p = 0.0504$ for the correlation coefficient between weight and relative one day PCS points, suggesting a tendency that a higher average weight results in relatively more one day PCS points.

From the results discussed above it seems that certain countries have a selection bias towards either lighter/smaller or heavier/taller cyclists. However, this bias could be caused by a combination of nutrition and socio-economic factors [69], which affects the body height (and indirectly also body weight) of the population in the country. In general, the wealthier countries are therefore expected to have taller (and indirectly also heavier) cyclists. Therefore, to answer the question if countries have a real bias towards certain anthropometric measures, we corrected this by correcting the cyclists' body height with the average body height of the male population of their country of origin. Although, also when the body height and body weight were corrected, still some differences between countries were found, which suggests that these countries have a selection bias towards cyclists with certain anthropometrics. After correction, the cyclists born in Germany, Australia and Belgium are on average heavier compared to the cyclists born in Spain, Colombia and Portugal. In addition, after correction, the cyclists from Germany seem to be taller than cyclists in other countries (Belgium, Colombia, Denmark, Italy, Netherlands and Poland) and the cyclists from Italy seem to be smaller than cyclists in other countries (Australia, France, Germany, Great Britain, Spain, and United States). This is possibly caused by the terrain of these countries. As Germany, Australia and Belgium are mostly flat countries and their cyclists relatively score most PCS points in sprint races and relatively less in climb races there is a tendency towards selecting cyclists that fit the optimal anthropometrics for this specialty and the landscape of the country. The opposite can be suggested for Italy, Colombia, Spain and Portugal with more mountainous geography and a relatively higher success rate in climb races and GC, and less in sprint (although Italy is an exception in sprints) races which could be caused by the relatively smaller and lighter professional cyclists. So, it could be suggested that in all those countries (Germany, Australia, Belgium, Italy, Colombia, Spain and Portugal) there is a selection bias towards cyclists with the anthropometrics that fit the specialty and geography of the country, which are probably influencing each other (more hilly country, more specialised in climbing and vice versa). This possibly results in deselecting other talented cyclists in those countries with anthropometrics that fit other specialties. This suggestion is strengthened by our results that show that the 5 countries with the largest average height for their cyclists have a significantly lower elevation span compared to the 5 countries with the smallest average height for their cyclists. However, not in all countries such selection bias was found. For example, no selection bias was found in the Netherlands, although this is also a country with a mostly flat landscape. Possibly, the scouting and development system in this country is better organised compared to the countries with a selection bias. The results of this study suggest that practicians involved in talent identification should investigate more qualities than only being able to win a race on home soil and should give young cyclists the possibility to ride on all variations of terrain or give them other ways to show that they can excel on terrain which favours their anthropometrics.

When analysing the results, it was surprisingly found that, although there is some variation between countries, the common trend is that the average cyclist is taller than the average male from the same country. To the best of our knowledge, there is currently no study that investigated if these differences in anthropometrics between athletes and nonathletes are present in other sports. It could be suggested that, as cycling is a quite expensive sport (buying bicycles and equipment, travelling to races), this is primarily practiced by the more wealthy population of the country. It is known from previous research that body height is related to nutritional and socio-economic factors [69] and thus this could be a reason why cyclists are taller compared to the average population.

Practical applications

This study shows that within male professional road cycling there is (in some countries) a selection bias towards cyclists that are specialised in racing on the terrain of home soil. This means that in these countries cyclists with anthropometric characteristics that do not suit these home races are not selected and supported and therefore miss the opportunities to develop themselves in becoming a professional cyclist. It should therefore be the aim within talent identification to focus on multiple aspects of the cyclist and not only on race results. Talent identification based solely on race results probably caused multiple talents to miss out on their chances of becoming a successful professional because they didn’t have the anthropometric build to be specialist enough to excel in their home countries' terrain.

Conclusion

The average anthropometrics (body weight and height) in a country are related to the relative number of PCS points collected in GC, climb and sprint races but not TT and one day races. This relationship is probably influenced by the terrain of the various countries. These relationships also result in differences between countries in body weight and height of their cyclists. When correcting for the average body height in the country, or correcting body weight for body height (BMI), still some differences between countries occur, suggesting a possible selection bias in some countries towards taller/heavier or smaller/lighter cyclists. In addition, the average body height of cyclists is taller than the average male body height in the same country in all investigated countries.

Limitations

The riders weight was collected from the PCS database, this data is collected from various sources, including self-reported information and team websites. This means that mostly race weight is collected which can deviate from the average weight of a rider during the season as riders are periodizing their weight towards certain race goals. In addition, the mentioned elevation span is not the ideal measure of the terrain of a country, however, in the opinion of the authors, this was the best measure that was available for all included countries. This made it available to at least indicate the terrain of the included countries. Also, it should be mentioned that the current study is done retrospectively and therefore no direct link between anthropometric characteristics and the terrain of a country with talent selection can be made.

Supplementary Table 3.1: Mean differences in BMI (as an estimate for corrected body weight, in kg/m²) between countries investigated with one-way ANOVA

	N	**BMI [kg/m²]**	**SD**	Australia	Belgium	Colombia	Denmark	France	Germany	Great Britain	Italy	Netherlands	Poland	Portugal	Russia	Spain	Switzerland	United States
Australia	90	21.5	1.5	X														
Belgium	270	21.4	1.2	0.1	X													
Colombia	71	20.6	1.3	**0.9***	**0.8***	X												
Denmark	53	20.9	1.3	0.6	0.5	0.3	X											
France	274	21.0	1.3	0.5	**0.4***	0.4	0.1	X										
Germany	95	21.5	1.4	0.0	0.0	**0.9***	0.6	0.5	X									
Great Britain	51	21.1	1.5	0.4	0.3	0.5	0.2	0.1	0.3	X								
Italy	254	21.1	1.5	0.4	0.4	0.5	0.2	0.1	0.4	0.1	X							
Netherlands	150	21.1	1.3	0.4	0.3	0.5	0.2	0.1	0.3	0.0	0.1	X						
Poland	57	21.2	1.3	0.3	0.3	0.6	0.3	0.2	0.3	0.0	0.1	0.0	X					
Portugal	42	20.5	1.2	**1.0***	**1.0***	0.1	0.4	0.5	**1.0***	0.7	0.6	0.7	0.7	X				
Russia	60	21.1	1.3	0.5	0.4	0.4	0.2	0.1	0.4	0.1	0.0	0.1	0.1	0.6	X			
Spain	220	20.8	1.1	**0.7***	**0.7***	0.1	0.1	0.2	**0.7***	0.4	0.3	0.4	0.4	0.3	0.3	X		
Switzerland	54	21.2	1.3	0.3	0.2	0.6	0.3	0.2	0.3	0.0	0.1	0.0	0.0	0.7	0.1	0.4	X	
United States	69	20.8	1.4	0.7	0.6	0.2	0.1	0.2	0.6	0.3	0.2	0.3	0.3	0.4	0.2	0.1	0.3	X

*Sig. difference ($p < 0.05$) between countries with Bonferroni post-hoc. In addition, sig. differences were shown as **bold**

Supplementary Table 3.2: Mean differences in corrected body height (based on average body height of the male population in the country, in cm) between countries investigated with one-way ANOVA

	N	Corrected Height [cm]	SD	Australia	Belgium	Colombia	Denmark	France	Germany	Great Britain	Italy	Netherlands	Poland	Portugal	Russia	Spain	Switzerland	United States
Australia	90	181.0	5.7	X														
Belgium	270	179.3	5.9	1.7	X													
Colombia	71	178.4	5.6	2.6	0.9	X												
Denmark	53	178.9	6.4	2.1	0.4	0.5	X											
France	274	181.0	5.9	0.1	1.8	2.7	2.1	X										
Germany	95	183.1	6.4	2.2	**3.9***	**4.8***	**4.3***	2.1	X									
Great Britain	51	181.2	6.8	0.2	1.9	2.8	2.3	0.2	2.0	X								
Italy	254	177.7	6.1	**3.3***	1.6	0.7	1.2	**3.4***	**5.5***	**3.5***	X							
Netherlands	150	178.9	5.7	2.1	0.4	0.5	0.0	**2.2***	**4.3***	2.3	1.2	X						
Poland	57	178.9	6.2	2.0	0.3	0.6	0.1	2.1	**4.2***	2.2	1.3	0.1	X					
Portugal	42	179.5	5.8	1.5	**0.2***	1.1	0.6	1.6	3.7	1.7	1.8	0.6	0.5	X				
Russia	60	180.5	6.0	0.5	1.2	2.1	1.6	0.6	2.7	0.7	2.8	1.6	1.5	1.0	X			
Spain	220	181.0	5.4	0.0	1.7	2.6	2.1	0.1	2.2	0.2	**3.3***	2.1	2.0	1.5	0.5	X		
Switzerland	54	180.6	7.0	0.3	1.4	2.3	1.8	0.4	2.5	0.6	3.0	1.8	1.7	1.2	0.2	0.3	X	
United States	69	181.8	5.4	0.8	2.6	2.4	2.9	0.8	1.3	0.6	**4.1***	2.9	2.9	2.3	1.3	0.8	1.2	X

*Sig. difference ($p < 0.05$) between countries with Bonferroni post-hoc. In addition, sig. differences were shown as **bold**

CHAPTER 4

Durability and underlying physiological factors, how do they change throughout a cycling season in semi-professional cyclists?

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Abstract

Purpose: To investigate how cycling time trial (TT) performance changes over a cycling season, both in ‘fresh’ state and ‘fatigued’ state (durability). Additionally, the aim was to explore whether these changes are related to changes in underlying physiological factors such as gross efficiency (GE), energy expenditure (EE) and substrate oxidation (FatOx and CarbOx).

Methods: 16 male semi-professional cyclists visited the laboratory on three occasions during a cycling season (PRE, START, IN) and underwent a performance test in both fresh and fatigued state (after 38.1±4.9 $KJ \cdot kg^{-1}$), containing a submaximal warm-up for the measurement of GE, EE, FatOx and CarbOx and a maximal TT of 1 (TT1min) and 10 minutes (TT10min). Results were compared across states (fresh vs fatigued) and periods (PRE, START, IN).

Results: The average power output (PO) in TT1min decreased ($p<0.05$) from fresh to fatigued state across all observed periods, whereas there was no change in the PO in TT10min. Over the course of the season, the PO in TT1min in fatigued state improved more compared to the PO in TT1min in fresh state. Furthermore, while EE did not significantly change, there was an increase in FatOx and a decrease in CarbOx towards the fatigued state. These changes diminished during the cycling season (IN), indicating a greater contribution of CarbOx in the fatigued state.

Conclusions: TT1min performance is more sensitive to fatigue compared to TT10min. Also, during a cycling season, durability improves more when compared to fresh maximal POs, which is also observed in the changes in substrate oxidation.

Introduction

Professional road cycling races often feature decisive moments in the latter stages of the race when the cyclists have already completed significant workloads. It has been shown that the mean maximal power output (PO) values (MMPs) that cyclists can produce after accumulated load, also called durability, are a better predictor of success rather than maximal PO values only [19, 70-72]. To gain a better understanding of performance in professional road cycling, it is therefore suggested to assess performance variables (for example in an exercise test), not only when the cyclists are in a fresh state but also in a fatigued state (i.e. after accumulated load) [73]. Multiple physiological factors have been proposed to underlie durability in various endurance sports. In cross-country skiing double-poling performance, for instance, a decrease in submaximal gross efficiency (GE) after prolonged exercise has been related to the decrease in performance [74]; furthermore, in cycling a decrease in GE has been related to a decrease in the 5-min time trial PO [75] and to the PO at the moderate-to-heavy intensity transition [76]. A decrease in GE has also been associated with an increased whole-body fat oxidation (FatOx) rate [76], which indirectly suggests glycogen depletion may be related to durability. Nutrition intake also plays an essential role in these changes in substrate oxidation, subsequently affecting performance decrement [77]. It is therefore likely that after prolonged exercise, both GE and carbohydrate oxidation (CarbOx) decrease, while FatOx increases, which are likely related to durability.

The studies regarding durability discussed above assessed performance at a single point in time. However, it might be even more interesting to evaluate how durability and the related physiological parameters (GE, FatOx and CarbOx) change over the course of a cycling season to observe the influence of training and racing on durability. A professional cycling season generally consists of multiple phases, including 1) a rest phase, to recover from the previous season (REST), 2) a pre-season phase, containing mostly training sessions to prepare for the new season (PRE), and 3) a race-season phase, containing both races and training sessions (RACE). Performances in exercise tests have been shown to vary between these cycling season periods, with exercise thresholds (both ventilatory and lactate thresholds) [78], GE [79], and 20 min time trial (TT) PO [80] improving from REST to PRE to RACE. Looking specifically at durability, Spragg *et al.* [25] showed that MMPs investigated after accumulated load vary more throughout the

RACE phase than when investigated in a fresh state [25, 81], suggesting that durability has a different change compared to maximal POs. However, research based on MMPs could raise the question of whether the cyclists' effort was really an all-out effort, both in the fresh and the fatigued state. To the best of our knowledge, durability measured as (a decrease in) PO has not yet been investigated using a standardized testing protocol in different phases of the season (i.e. REST vs PRE vs RACE), including an investigation of possible underlying factors (GE, CarbOx and FatOx) for the likely decrement in performance after prolonged exercise.

The current study aims to answer the following two questions: 1) How does TT performance, in fresh state and after accumulated load (defined as fatigued state), change throughout a cycling season? and 2) how do underlying physiological characteristics for durability change from fresh to fatigued state and throughout a cycling season? As the decrement in W', the work capacity above critical power (CP), has been shown to be larger than the decrement in CP [82], we expect shorter duration efforts to be more influenced by accumulated load than longer duration efforts; therefore TTs of both shorter (1 min) and longer (10 min) duration will be investigated.

Methods

Participants

In total, 16 male semi-professional cyclists (mean±SD: age: 21±3 years, height 184±6 cm, body mass 72.7±5.5 kg) participated in this study. All participants were part of a UCI Continental team (3rd level in professional cycling) and had a 1st Lactate Threshold (LT1) of 297±24 W, a 2nd Lactate Threshold (LT2) of 346±28 W and a maximal 10 min PO of 379±22 W. The participants would fall into either tier 3 (Highly trained/National level) or tier 4 (Elite/International level) within the participant classification framework [83]. The study protocol was approved by the local ethics committee and followed the principles as set out in the Declaration of Helsinki.

Research design

All participants visited the lab on three occasions during one cycling season: (1) In December at the start of pre-season after the participants (± 2 weeks) restarted training following an off-season break (PRE), (2) in February just before race-season started (START), and (3) in July halfway into race-season (IN). Time points of measurement were chosen so that both the changes after a training period (PRE to START) as well as after a racing period (START to IN) could be investigated. Testing days included: an incremental exercise test, a performance test in fresh state, an outdoor endurance ride in order to achieve an accumulated load, and a performance test after this accumulated load, defined as the fatigued state, as illustrated in Figure 4.1A. All tests (incremental exercise test and performance tests) were executed in a controlled environment (temperature: 17.0±2.4°C, humidity: 52±9%) and completed on a standardized laboratory cycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, the Netherlands), heart rate was captured by using a Polar heart rate monitor (Polar Electro Oy, Kempele, Finland), while respiratory gas exchange was collected breath-by-breath by using open-circuit spirometry (Quark CPET, Cosmed SrI, Rome, Italy).

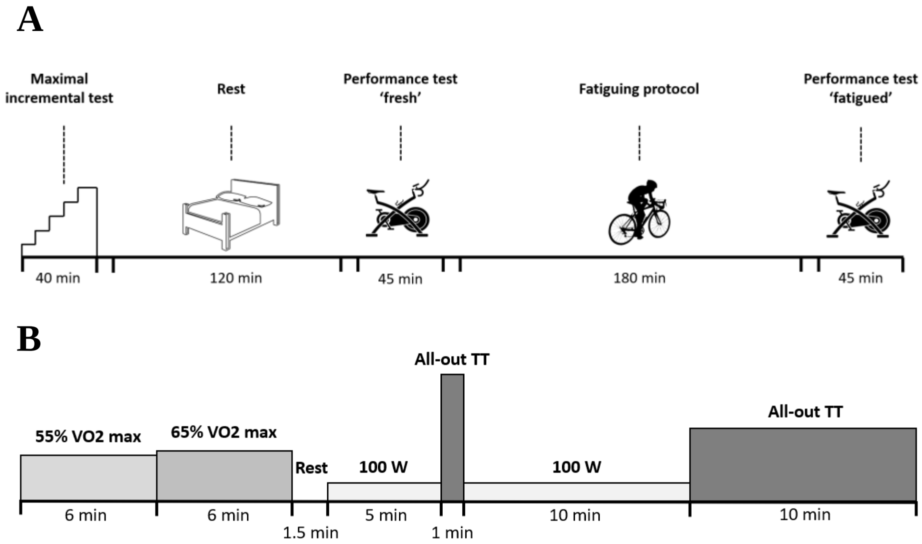

Figure 4.1: Design of the testing days (A) and the performance test (B)

Maximal incremental test

The maximal incremental test started with a warm-up of 3 min at 100 W, after which the PO was increased to 170 W and increased stepwise with 35 W every 5 min. Participants were instructed to maintain a pedalling frequency of ~90 rpm during the complete test and continued until volitional exhaustion. PO at VO_{2max} ($POVO_{2max}$) was calculated as:

(Equation 1)

$$POVO_{2max} = PO_{final} + (\frac{t}{300} * 35)$$

Where PO_{final} is the power output of the final completed stage in watts and t is time spent in the final uncompleted stage in seconds. At the end of each step, capillary blood was drawn from the fingertip and analyzed with the Lactate Pro 2 analyzer (Laktate; Busimedic S.L, San Sebastian, Spain). LT1 was determined as the intensity at which blood lactate concentration increased 0.5 above baseline values, LT2 was determined with the Log-Log Modified D_{max} method: The intensity at the point on the third order polynomial regression curve that yielded the maximal perpendicular distance to the straight line formed by the intensity associated with the log-log LT and the final lactate point [84].

Performance test

The performance test consisted of three parts: (1) a submaximal warm-up during which gas exchange data was collected, (2) a 1 min all-out time trial (TT1min), and (3) a 10 min all-out time trial (TT10min) (Figure 4.1B). Part 1 consisted of two constant PO steps of 6 min: step 1 at 55% (mean±SD: 216±17 W) and step 2 at 65% (mean±SD: 256±20 W) of $POVO_{2max}$. Gas exchange data were collected to calculate gross efficiency (equation 2), FatOx (equation 3) [85], CarbOx (equation 4) [85] and EE (equation 5) [86] from 3.5 min until 5.5 min in step 2 (65% of $POVO_{2max}$). For a correct determination of GE, data were only included if the respiratory exchange ratio (RER) was below 1.0 [87]. The rating of perceived exertion (RPE) was collected at the end of the step. The warm-up was followed by 90 seconds of passive rest and 5 min of cycling at 100 W before continuing with part 2 of the performance test.

(Equation 2)

$$GE\ [\%] = \frac{Power\ Output}{\frac{VO_2}{60} * (4940 * RER + 16040)} * 100$$

(Equation 3)

$$FatOx\ (\frac{g}{\mathrm{min}}) = 1.695 * VO_2 - 1.701 * VCO_2$$

(Equation 4)

$$CarbOx(\frac{g}{min}) = 4.210 * VCO_2 - 2.962 * VO_2$$

(Equation 5)

$$EE(\frac{kcal}{\mathrm{min}}) = 3.941 * VO_2 + 1.106 * VCO_2$$

During part 2 and 3, the ergometer was set on a resistance based on the body mass of the participant. This resistance was set so that the mostly used cadence range would widely cover the expected POs, as indicated by pilot measurements and field data on mean maximal POs of the participants over included durations. During both time trials, the participants were only able to see the elapsed time, with exception of the first min of TT10min (part 3), during which the participants could see the PO, to exclude a pacing effect. During TT10min (part 3) the participants were restricted to seating, while during TT1min (part 2) both seated and standing positions were allowed. An active rest period of 10 min at 100 W was interspersed between TT1min and TT10min.

Fatiguing protocol

After the performance test, the participants immediately changed clothes and started an endurance ride, which was executed outdoors on flat terrain with an average temperature of 13.5±7.4 °C. This endurance ride was used as a fatiguing protocol and participants were instructed to ride on a PO of 3.2 $W{\cdot}kg^{-1}$. Together with the load of the fresh performance test, this resulted in a load of 38.7±3.7 KJ·kg^{-1} before starting the fatigued performance test, which was executed immediately after coming back in the laboratory from the endurance ride and was an exact replication of the fresh performance test.

Nutrition

The participants were instructed to refrain from strenuous exercise the day before the testing sessions, to follow their normal sleep cycle, to not consume alcohol the 24 h prior to the test, to not consume caffeine within 3 h preceding the beginning of the testing sessions and to prepare for the test with a breakfast as comparable to a race day and to keep this breakfast the same between different testing days. During the complete testing day (maximal incremental test, fresh performance test, endurance ride and fatigued performance test) the participants were given 60 grams of carbohydrates per h in the form of gels and energy bars to minimise the possibility that energy depletion would influence the fatigued performance test.

Data analysis

All data were analysed and formatted using Python software (version 3.10.3, Python Software Foundation), statistical analyses were performed using R software (version 4.2.2, R Foundation for Statistical Computing, Vienna, Austria). Normal distribution was assessed using Shapiro-Wilk's test. Data were reported as mean ± standard deviation. Mean differences (MD) were reported with a 95% confidence interval (CI).

GE, EE, FatOx, CarbOx, average PO in TT1min (PO1) and average PO in TT10min (PO10) were examined using a mixed-effects multilevel model. This statistical test corrected for missing data (due to injuries/illnesses or deficiencies with data collection) within the repeated measures. Test (fresh vs fatigued) and period (PRE vs START vs IN) were used as the within-participant factors for the outcomes of the performance test. Where a significant main effect was found, Bonferroni post-hoc tests were performed for pairwise comparisons. Relationships between the Δ change (fresh – fatigued) of the various parameters (GE, FatOx, CarbOx, PO1 and PO10) were assessed with Pearson's correlations (r). Interpretation of the strength of the correlation coefficients was based on the following criteria: 0-0.09 *trivial*; 0.1-0.29 *small*; 0.3-0.49

moderate; 0.5-0.69 *strong*; 0.7-0.89 *very strong*; 0.9-0.99 *almost perfect*; 1.00 *perfect* [67]. Significance level was set at $p<0.05$.

Results

The results of the performance test in fresh and fatigued state in the 3 different periods are shown in Table 4.1.

Table 4.1: Mean (±SD) or median [interquartile range] values out of performance test both in 'fresh' and 'fatigued' state in 3 different periods of a cycling season

		Fresh		**Fatigued**		**Δ Fresh - Fatigued**	
		Mean (SD)	*N*	**Mean (SD)**	*N*	**Mean (SD)**	*N*
TT1min (W)	PRE	671 ± 68	12	601 ± 67*	12	-70 ± 35	12
	START	693 ± 53	16	623 ± 73*	15	-69 ± 52	15
	IN	667 ± 72	13	629 ± 73*	13	-37 ± 16$^{\$}$	13
TT10min (W)	PRE	355 ± 29	12	346 ± 27	12	-10 ± 18	12
	START	379 ± 22$^{\$}$	16	370 ± 28$^{\$}$	16	-10 ± 20	16
	IN	390 ± 31$^{\$}$	13	387 ± 33$^{\$}$	12	-4 ± 12	12
GE (%)	PRE	21.5 ± 0.7	12	21.2 ± 0.8	12	-0.4 ± 0.5	12
	START	22.8 ± 0.8$^{\$}$	13	22.0 ± 0.9	16	-0.7 ± 1.2	13
	IN	23.2 ± 1.1$^{\$}$	10	22.8 ± 1.7$^{\$}$	11	0.0 ± 0.8	10
EE [kcal·min^{-1}]	PRE	16.6 ± 1.2	12	16.3 ± 1.1	12	0.3 ± 0.4	12
	START	16.4 ± 1.3	13	16.9 ± 1.5	16	0.6 ± 0.9	13
	IN	17.0 ± 1.3	10	16.7 ± 1.4	13	0.0 ± 0.8	10
FatOx (g·min^{-1})	PRE	0.46 ± 0.15	12	0.75 ± 0.16*	12	0.28 ± 0.16	12
	START	0.33 ± 0.19	13	0.65 ± 0.19*	16	0.36 ± 0.21	13
	IN	0.37 ± 0.17	10	0.51 ± 0.16$^{\$}$	13	0.11 ± 0.15$^{\#}$	10
CarbOx (g·min^{-1})	PRE	2.93 ± 0.41	12	2.34 ± 0.33*	12	-0.59 ± 0.38	12
	START	3.20 ± 0.47	13	2.67 ± 0.56*	16	-0.70 ± 0.54	13
	IN	3.23 ± 0.40	10	2.94 ± 0.31$^{\$}$	13	-0.24 ± 0.35	10

*Sig. (<0.05) different from fresh state, $^{\$}$Sig (<0.05) different from PRE period. $^{\#}$Sig (<0.05) different from START period. Abbreviations: TT1min, power output during 1 min all-out time trial; TT10 min, power output during 10 min all-out time trial; GE, gross efficiency; FatOx, Fat oxidation; CarbOx, Carbohydrate oxidation

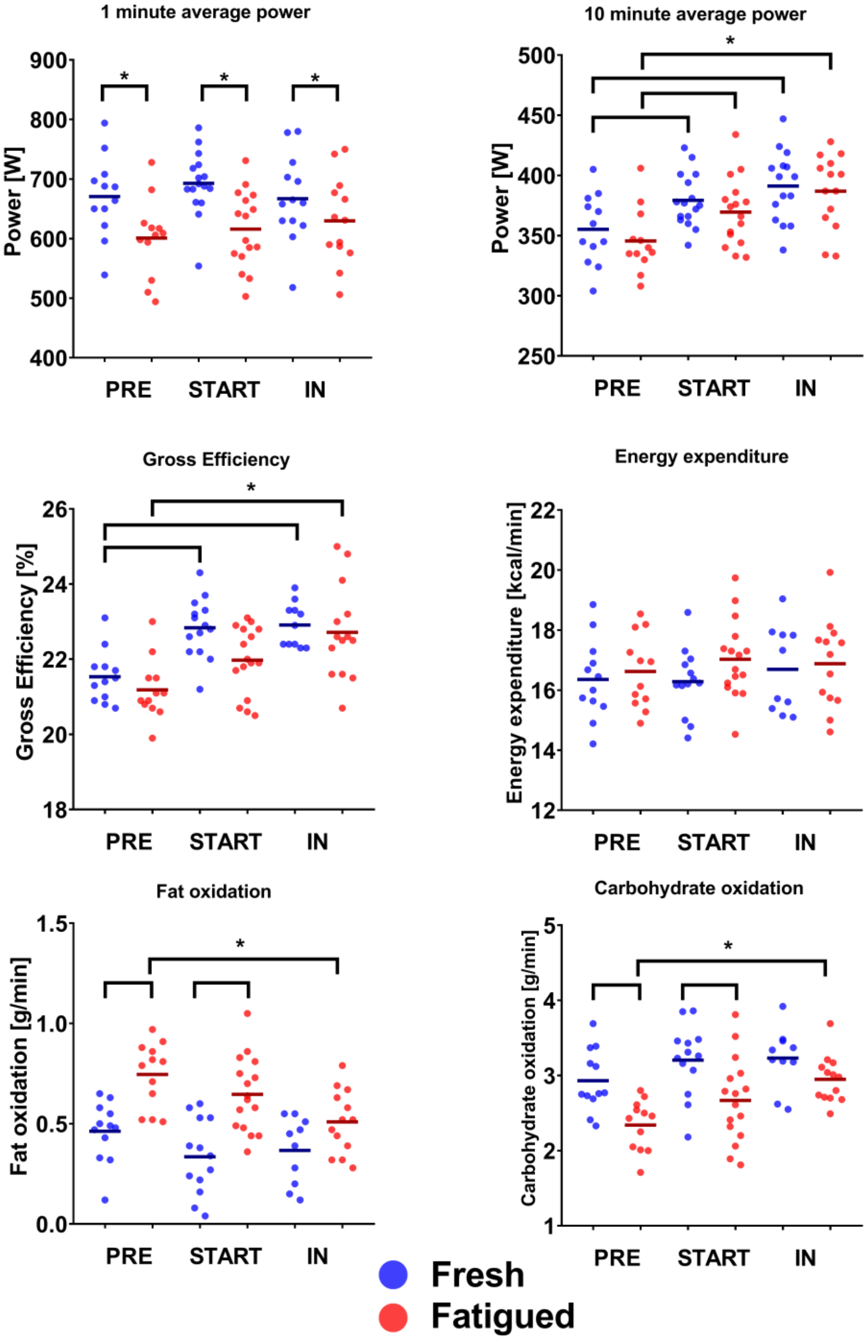

Figure 4.2: Results of the performance test compared from 'fresh' to 'fatigued' state and different phases of a cycling season. Individual data points are displayed alongside a horizontal line to show mean values.

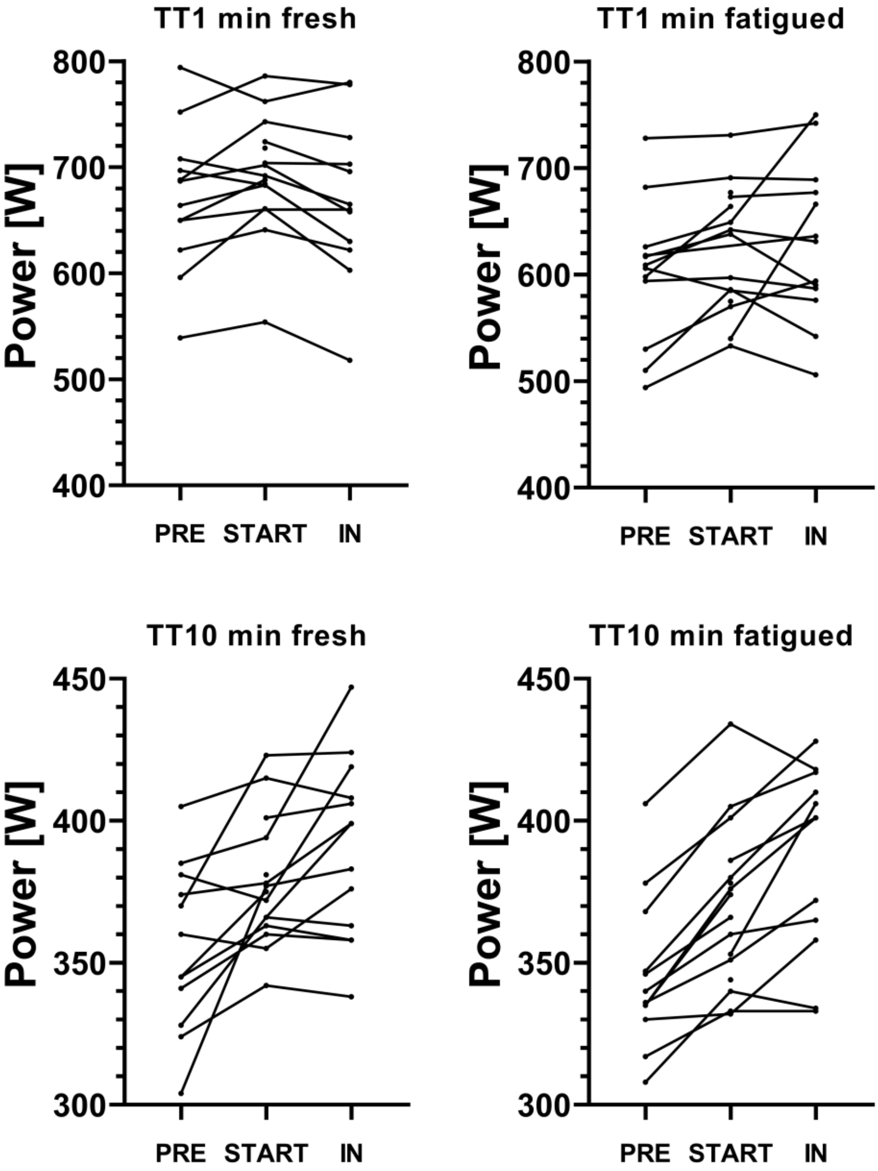

Figure 4.3: Individual seasonal changes in performance during TT1min and TT10min in 'fresh' and 'fatigued' state.

Power output

Average PO in TT1min was lower in the fatigued test compared to the fresh test at PRE (MD [CI] = -70 [-103, -35] W, $p<0.001$), START (MD [CI] = -69 [-99, -39] W, $p<0.001$) and IN (MD [CI] = -37 [-69, -5] W, $p = 0.01$). However, no differences were found for the average PO in TT1min between PRE, START and IN for either the fresh test or the fatigued test. In addition, no significant interaction effect was found in the average PO in TT1min for test*period ($p = 0.054$) (Figure 4.2). Individual seasonal changes in the average PO in TT1min are shown in Figure 4.3.

The average PO in TT10min was not different in the fatigued test compared to the fresh test at PRE ($p = 1.000$), START ($p = 0.79$) and IN ($p = 1.000$), while the average PO in $\text{TT10min}_{\text{fresh}}$ and $\text{TT10min}_{\text{fatigued}}$ were higher at START (Fresh: MD [CI] = 23 [6, 39] W, $p = 0.002$; Fatigued: MD [CI] = 23 [6, 39] W, $p = 0.002$) and IN (Fresh: MD [CI] = 33 [16, 51] W, $p<0.001$; Fatigued: MD [CI] = 39 [21, 56] W, $p<0.001$) compared to PRE. No significant interaction effect was found in the average PO in TT10min for test*period ($p = 0.767$) Figure 4.2). Individual seasonal changes in the average PO in TT10min are shown in Figure 4.3.

Gross Efficiency @ 65% POVO$_{2max}$

GE was not different in the fatigued compared to the fresh test at PRE ($p = 1.000$), START ($p = 0.351$) and IN ($p = 1.000$). GE_{fresh} was higher for START (MD [CI] = 1.3 [0.1, 2.4] %, $p = 0.022$) and IN (MD [CI] = -1.6 [0.3, 2.8] %, $p = 0.005$) compared to PRE, while $\text{GE}_{\text{fatigued}}$ was only higher for IN compared to PRE (MD [CI] = 1.6 [0.4, 2.7] %, $p = 0.001$). No significant interaction effect occurred in GE for test*period ($p = 0.542$) (Figure 4.2).

Energy expenditure @ 65% POVO$_{2max}$

Energy expenditure was not different in the fatigued compared to the fresh test at PRE ($p = 1.000$), START ($p = 0.534$) and IN ($p = 1.000$). Also, no differences were found between periods (PRE vs START vs IN) ($p = 0.349$), as well as no interaction effect occurred for test*period ($p = 0.514$) (Figure 4.2).

Substrate oxidation @ 65% POVO$_{2max}$

FatOx was higher in the fatigued test compared to the fresh test at PRE (MD [CI] = 0.28 [0.10, 0.47] g·min^{-1}, $p<0.001$) and START (MD [CI] = 0.32 [0.15, 0.49] g·min^{-1}, $p<0.001$) but not at IN ($p = 0.582$). CarbOx was lower in the fatigued test compared to the fresh test at PRE (MD [CI] = -0.59 [-1.02, -0.15] g·min^{-1}, $p = 0.002$) and START (MD [CI] = -0.57 [-0.98, -0.17] g·min^{-1}, $p = 0.001$) but not at IN ($p = 1.000$).

FatOx$_{fresh}$ was not different between periods, while FatOx$_{fatigued}$ decreased from PRE to IN (MD [CI] = -0.23 [-0.41, -0.04] g·min^{-1}, $p = 0.007$). In line with this, CarbOx$_{fresh}$ was not different between periods, while CarbOx$_{fatigued}$ increased from PRE to IN (MD [CI] = 0.58 [0.15, 1.02] g·min^{-1}, $p = 0.002$). No significant interaction effect for test*period was found for both FatOx ($p = 0.087$) and CarbOx ($p = 0.210$) (Figure 4.2). The contribution of FatOx and CarbOx to the total substrate oxidation throughout the season are shown in Figure 4.4.

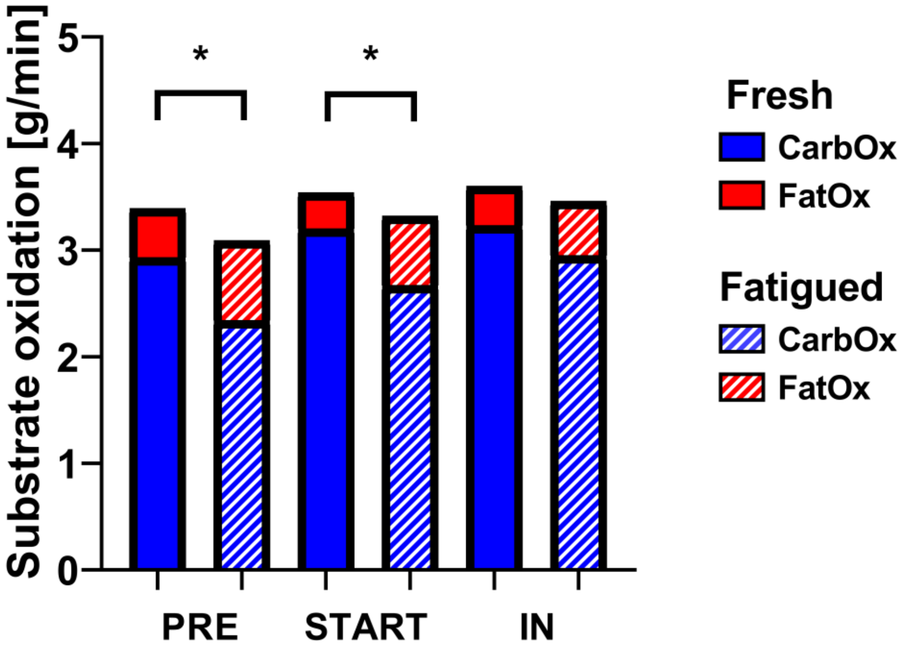

Figure 4.4: Changes in substrate oxidation in different phases of a cycling season as measured in a submaximal bout at 65% of POVO$_{2max}$ before and after a fatiguing protocol.

Relationships with the Δ change in performance

The Δ change in PO1 from fresh to fatigued state showed a *strong* correlation with PO10 in PRE, FatOx in START and a *moderate* correlation with CarbOx in RACE. All other correlations were shown to be *trivial* to *small* (Figure 4.5).

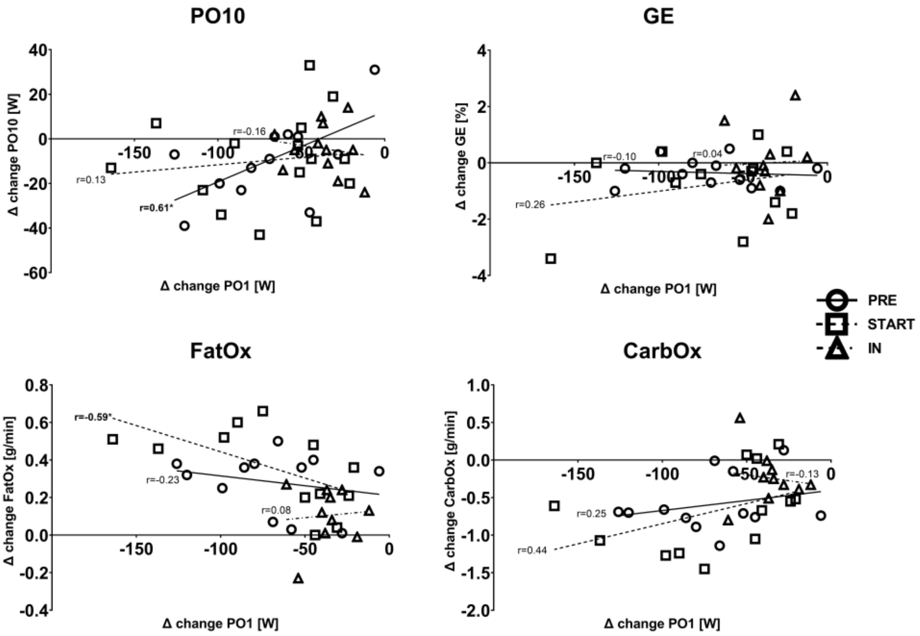

Figure 4.5: The relationship between Δ change in PO1 from fresh to fatigued state and Δ change in PO10, GE, FatOx and CarbOx during different phases (PRE, START and IN) of the season as assessed with pearson's correlations (r).

The Δ change in PO10 from fresh to fatigued state showed a *strong* correlation with PO1 in PRE and a *moderate* correlation with CarbOx in START. All other correlations were shown to be *trivial* to *small* (Figure 4.6).

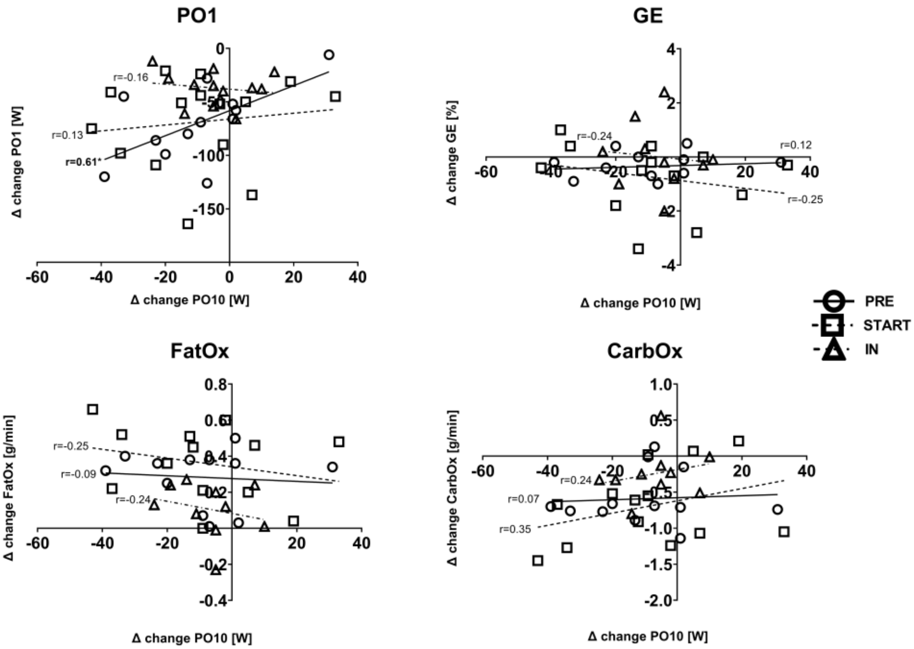

Figure 4.6: The relationship between Δ change in PO10 from fresh to fatigued state and Δ change in PO1, GE, FatOx and CarbOx during different phases (PRE, START and IN) of the season as assessed with pearson's correlations (r).

Discussion

The aims of the current study were to investigate how TT performance and underlying physiological (GE, FatOx and CarbOx) characteristics change from fresh to fatigued state and throughout a cycling season. This was done by investigating 16 semi-professional cyclists during one cycling season. The most important results show that the average PO in a 1 min TT is affected by accumulated load (~6-10% decrease), while the average PO in a 10 min TT is not significantly affected after accumulated load (~1-3% decrease). Also, the PO in the 1 min TT after accumulating load (i.e. durability) improved more during a cycling season than maximal fresh POs during the 1 min TT. Lastly, while energy production at a submaximal intensity of 65% of $POVO_{2max}$ did not change from fresh to fatigued state and throughout the season, substrate contribution differed. FatOx increased and CarbOx decreased from fresh to fatigued state. However, these changes diminished as the season progressed, ultimately leading to a greater contribution of carbohydrates to the total energy production in the fatigued state as illustrated in Figure 4.4.

The current study shows that the average PO in a 1 min TT is affected by accumulated load, while the average PO in a 10 min TT is not affected by accumulated load. These results are in line with previous studies showing that W' is more affected by accumulated load than critical power [77, 82, 88]. A possible explanation for this could be related to the metabolic fatigue associated with intensities above critical power, which includes glycogen depletion that has previously been shown to be related to a reduction in W' [89]. Although we did not measure glycogen depletion in the current study, the reported reduction in carbohydrate oxidation at 65% of $POVO_{2max}$ supports this suggestion. *Moderate* to *Strong* correlations were found between the Δ change in PO1 from fresh to fatigued state and the Δ change in fat and carbohydrate oxidation in the START period. Also, at the IN period, the decline in carbohydrate oxidation from fresh to fatigued state was not significant anymore (where it was at PRE and START), when at the same time also a smaller decline in the PO in the TT of 1 min was present, both suggesting an important role for carbohydrate contribution in this decline. The effect of carbohydrate oxidation could have been different for the 10 min TT compared to the 1 min TT as maximal efforts of 1 min have an aerobic energy contribution of ± 45% whereas maximal efforts of 10 min have an aerobic energy contribution of ± 90% [90]. Higher glycogen breakdown rates are found for exercise intensities at a relatively higher percentage of VO_{2max} [91], showing the differences in energy contribution to performance. Another explanation for the differences in the decline in PO between a maximal effort of 1 and 10 min could be that the magnitude of neuromuscular fatigue is intensity dependent and, therefore, found to be higher after a 1 min TT of compared to a 10 min TT [92]. Although we did not measure neuromuscular fatigue in the current study, this could be partly explained by the fact that excitation contraction coupling is affected by glycogen concentration in the muscle fibre. Glycogen depletion leads to lower Ca^{2+} release in the sarcoplasmic reticulum and may therefore contribute to muscle fatigue [93, 94]. Exercises with higher rates of glycogen depletion (1 min TT) could therefore lead to a larger magnitude of neuromuscular fatigue. Future research should further investigate the effect of neuromuscular fatigue on durability performance.

This study also shows that durability (i.e. TT performance after accumulating load) improved more throughout the season than fresh performance parameters. This was observed in the 1 min TT, but also a trend was present in the 10 min TT. These improvements in durability were especially the case when comparing the measurements during a training period (PRE and START) compared to a race period (IN), showing the different effects training and racing have on fresh performance parameters compared to performance after accumulated load. The study of Spragg *et al*. [25] already showed that POs after accumulated load out of race and training data varied more within the race season compared to fresh POs, which is relatable to our findings. However, this is the first study investigating durability in a standardized testing protocol on multiple occasions in a cycling season while also measuring physiological variables such as substrate oxidation. Multiple reasons could be suggested why durability improves in a different way than fresh performance parameters. The participants in this study were relatively young (21±3 years) and part of a development team. As the study of Gallo *et al*. [17] demonstrated that professional cyclists could be distinguished from U23 cyclists by a better durability (and not by fresh maximal POs), it could be argued that the change was long-term with the durability level of the participants increasing closer towards professional level rather than a seasonal change. Another explanation was previously suggested by Jones [22], who suggested that regular exposure to a situation wherein durability is challenged may be effective according to the assumption that the specificity of a stimulus is important. This could be a reason why durability still improved from START to IN, while fresh POs did not, as the participants took part in lots of races (27 ± 5 race days); situations wherein durability was constantly challenged. As the testing protocol used in the current study is designed to replicate cycling races as much as possible, the races that the participants took part in during the season could have been a good stimulus to improve durability and therefore also the performance in this test. In addition to this, it was shown that the intensity of racing is quite different to that of training [95], probably leading to different adaptations. Further research should investigate the mechanisms of how durability could be improved with specific training sessions and/or racing.

The improvements in durability over the course of the season are accompanied by changes in physiological parameters as measured during a submaximal bout at 65% of $POVO_{2max}$. An increased FatOx in fatigued state was seen in the current study. At the beginning of the season, FatOx increased and CarbOx decreased in fatigued compared to fresh state despite similar energy expenditures as measured at 65% of POVO$_{2max}$, which is in line with previous research [76, 88]. However, these differences in substrate oxidation almost diminished throughout the season, attenuating the decrease in CarbOx. Based on these results it could be suggested that a metabolic shift towards higher CarbOx in a fatigued state could be a preferential adaptation in order to mitigate a GE decrease [76]. However, within the current study we couldn't show a direct correlation between an increase in CarbOx and a decrease in GE. In addition, it is plausible to consider that, although not measured, higher glycogen sparing can be seen throughout the season in the fatigued state, which has been shown to be beneficial for performance after accumulated load [88]. Moreover, a greater sympathetic activation (potential neuromuscular adaptation or resilience to fatigue) could have been maintained to keep high glycogenolysis and glycolysis rates [96]. In fact, analyses of metabolomics have previously demonstrated that the best cyclists across a World Tour team are able to maintain a higher glycolytic capacity and lactate dynamics in relation to performance [97] and have an improved mitochondrial function that is explained by a greater capacity to oxidise glucose (through lactate) and fatty acids [98]. To summarize this, here we described for the first time that metabolic adaptations to greater load (throughout a season) and acute fatigue in semi-professional cyclists are explained by a metabolic shift towards a more efficient and preferable substrate oxidation (carbohydrates [99]), which adds a contemporary insight to understand metabolic adaptations in cycling and might be different to previously reported.

Caution in the interpretation of the results of the current study must be made, as a high inter-individual variability in the decline of performance after accumulated load was found, as shown in Figure 4.3 and as in line with previous studies [77, 82, 88]. Also, the participants were given 60 grams of carbohydrates per h in this study, whereas also a higher intake of carbohydrates has been recently reported [100]. However, not all participants were used to these carbohydrate intakes, which also need nutritional training [101]. A reduced carbohydrate consumption was therefore selected. As fuelling alters the metabolic response, this should be taken in mind when interpreting the results. However, in all conditions the same intervention was used, and it replicates the minimal fuelling that is given in races and/or training sessions. Furthermore, previous research [102, 103] has shown that not only the magnitude of the accumulated load but also its intensity plays a role in durability. However, in this study, an endurance ride was used as the fatiguing protocol. While it is expected that more pronounced declines in performance would occur with a higher-intensity protocol, the one currently used was already mentally demanding for our participants and we aimed to prevent any loss of motivation among the participants. These statements also show that durability is difficult to standardize and understand, as there are multiple mechanisms that play a role. Durability could therefore be seen as an independent physiological determinant of endurance performance [22]. Although assessing the performance on multiple days (i.e. TT1min and TT10min fresh and fatigued on 4 different days) would give more reliable results, this was logistically not possible with the current level of the participants, as this would interfere too much into training schedules and race programs, showing the difficulties of doing research with high-level athletes. In addition, in this study, a total of 16 participants participated; however, not all participants were able to take part in every test during this longitudinal study due to injuries and illnesses. Additionally, there was some missing data during several measurements due to equipment malfunctions. Table 4.1 provides information on the number of participants included for each measurement. While having consistent data for each measurement would be ideal for reliability, we chose to include all available data to prevent data loss. We also took the missing data into account when applying our statistical methods.

Practical applications

The findings of this study contribute to a better understanding of durability among high-level cyclists. The study shows that for a maximal 10-min effort no significant decline in PO was found after accumulated load. This suggests that there might be a limited necessity of repeating this test after accumulated load in addition to a standard fresh test. However, for shorter maximal efforts (i.e. 1 min) there is stronger evidence supporting the repetition of the test in a fatigued state, as this study shows distinct performance changes between the test in a fresh and fatigued state. Furthermore, the results of the study suggest that assessing FatOx and CarbOx during submaximal efforts in a fatigued state might provide valuable insights into durability performance and development. This approach would be easier to replicate compared to maximal efforts and can therefore be more easily integrated into a cyclist's training schedule.

Conclusion

To conclude, the average PO in a 1 min TT for semi-professional cyclists is affected by an accumulated load of 38.1±4.9 $KJ\cdot kg^{-1}$, while the average PO in a 10 min TT remains unaffected. Durability performance improves more during a cycling season than the maximal fresh POs in the 1 min TT. Furthermore, as determined at a submaximal intensity of 65% of $POVO_{2max}$, FatOx increased while CarbOx decreased from the fresh to fatigued state with energy production remaining constant. However, these changes in substrate contribution diminished as the season progressed, ultimately leading to a higher proportion of carbohydrates contributing to the total energy production in the fatigued state. Both FatOx and CarbOx have been found to exhibit the same trend as the average PO in the TTs, demonstrating the suitability of these measures for tracking durability

CHAPTER 5

Training characteristics related to (the changes in) durability in semi-professional cyclists

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Abstract

Purpose: To provide insights into a dose-response relationship between training and time trial (TT) performance, as assessed in both a ‘fresh’ and ‘fatigued’ state (durability), including proposed underlying factors for durability: gross efficiency (GE) and substrate oxidation (FatOx and CarbOx).

Methods: 10 male semi-professional cyclists underwent a performance test in both ‘fresh’ and ‘fatigued’ state (after 38.6±4.6 $kJ \cdot kg^{-1}$) before and after an 8-week training period, containing the measurement of GE, FatOx, and CarbOx at submaximal intensity and a maximal TT of 1 (PO1) and 10 minutes (PO10). Relationships were assessed with the sRPE, KJ spent, LuTRIMP, Training Stress Score, Polarisation Index, and Time spent in 3 zones in the intervening period.

Results: No significant relationship was found between higher training load and performance on PO1 and PO10, with a large variation between assessed training load measures and individual participants. However, CarbOx showed a *strong* correlation with training volume in the ‘fresh’ state and with time spent below LT1 intensity in the ‘fatigued’ state. Also, the relationship between training load and change in performance between tests showed different trends for ‘fresh’ compared to ‘fatigued’ state, especially for FatOx and CarbOx.

Conclusions: As no clear relationships between dose (training) and response (TT performance) were shown in this study, it shows that a single load measure is not able to predict performance improvements after an 8-week training period. However, the current study shows that the same training can have a different effect on ‘fresh’ versus ‘fatigued’ performance, having implications for the design of training plans.

Introduction

As part of their preparation for races, professional road cyclists must undertake a considerable amount of training to prepare for professional road cycling races [24, 104]. As the largest gains in training status are achieved by maintaining a healthy balance between training load and recovery, it is important to monitor training load and recovery in professional road cyclists [105]. A mismatch in the balance between training load and recovery can lead to undertraining or overtraining [106], resulting in a suboptimal performance outcome. Within professional cycling, there are a variety of measures (e.g. power output [PO], heart rate, and the rating of perceived exertion [RPE]) that are used to monitor training intensity and load [104, 107].

Although multiple studies investigated the load imposed by training session and competitions on (semi-)professional cyclists [16, 55, 58, 95, 104, 108-111], only a few studies have investigated the direct dose-response relationship between training load (dose) and performance (response). Sanders et al. [112] studied the relationship between training dose and performance over an 8-week period in competitive cyclists and suggested that the dose-response relationship was more pronounced with individual measures of training load (e.g. individualised training impulse score [iTRIMP] and Training Stress Score [TSS]). In line with this, Vermeire et al. [113] studied the relationship between training dose and performance during an 8-week training period in physically active males with various sports backgrounds. They concluded that different training load measures can not be used interchangeably as they evolve differently.

To the best of our knowledge, no study to date has studied the dose-response relationship specifically in (semi-)professional cyclists using a standardised approach in the laboratory. As multiple (at least 2) performance measurements are needed to investigate such a dose-response relationship and most professional cyclists of the same cycling team live far apart from each other, it is challenging to plan and execute multiple performance tests within a cycling season in professional cyclists. As a result of this difficulty, multiple studies have investigated the relationship between training load and performance in professional cyclists, using mean maximal PO (MMP), measured with bicycle-mounted power meters, from training sessions and races. These studies showed a relationship between MMPs and training load in the preceding 4-8 weeks [114], between changes in MMPs and changes in training load between different season periods (early, mid, and late) [26], and between the annual increase in MMPs and the average weekly training load [24]. All the above-named relationships between training and performance are based on MMPs. However, as cycling races are won at the end of a race, recent research has highlighted the importance of maximal POs after a considerable amount of accumulated load, which is referred to as durability, and is seen as a strong predictor of success in professional cycling races [19, 70-72]. Spragg et al. [25] investigated the relationship between changes in training characteristics in 3 season periods (early, mid, and late), and changes in MMPs after accumulated load in subsequent periods. They stated that a tendency towards more polarised training should be beneficial for improving MMPs after accumulated load. However, the use of MMPs raises the question of whether the PO over the obtained periods is really the maximal performance the rider could achieve at that moment. To avoid this, it is preferable to use more standardised testing protocols to investigate a dose-response relationship between training and performance (in a ‘fatigued’ state) over a certain period.

A recent study of our group [115] showed the improvement/decline throughout a cycling season in 1-min and 10-min time trial (TT) PO, as well as changes in substrate oxidation and gross efficiency (GE). This study was executed with semi-professional cyclists performing a standardised testing protocol, both in a ‘fresh’ state and after accumulated load. The results of this study showed that a 1-min TT is more affected by accumulated load compared to a 10-min TT and that with training the semi-professional cyclists had a lower drop in performance after accumulated load. Secondly, the drop in performance in the 1-min TT was related to changes in substrate oxidation. As mentioned before, there is currently a lack of studies that investigate the dose-response relationship between training and performance in high-level cyclists, as measured in a standardised test protocol. The current study aims to analyse the training undertaken in the 8-week training period between the first 2 test moments in our previous study [115], thereby providing insights into the dose-response relationship between training and performance and into the improvement of durability.

Methods

Participants

In total, 10 male semi-professional cyclists (mean±SD: age: 22±4 years, height 183±6 cm, bodyweight 71.0±6.4 kg) participated in this study. All participants were part of a UCI Continental team (3rd level in professional cycling) and had a 1st Lactate Threshold (LT1) of 299±23 W; 4.2±0.3 $W\cdot kg^{-1}$, a 2nd Lactate Threshold (LT2) of 347±30 W; 4.9±0.3 $W\cdot kg^{-1}$ and a maximal 10-min PO of 379±23 W; 5.3 ±0.4 $W\cdot kg^{-1}$. The participants would fall into either tier 3 or tier 4 within the participant classification framework [83]. The study protocol was approved by the local ethics committee and followed the principles as set out in the Declaration of Helsinki.

Research design

All participants were observed during an 8-week training period in the pre-season of 2022, lasting from December 2021 to February 2022. During this period, the participants were preparing for the new cycling season and did not participate in any races. The study was observational, so no interventions were made in the training of the participants, as they followed the plan of their coach. 5 of the 10 participants were trained by the same coach, the other 5 participants had different coaches. Participants underwent a performance assessment at the beginning and the end of the training period.

Performance assessment

The performance assessment consisted of four parts: (1) a maximal incremental exercise test, (2) a performance test in ‘fresh’ state, (3) a 3-hour endurance ride as a fatiguing protocol to achieve an accumulated load and (4) a performance test after this accumulated load, defined as the ‘fatigued’ state, as illustrated in Figure 5.1[A]. All tests (incremental test and performance tests) were executed in a controlled environment (temperature: 15.7±1.6°C, humidity: 48±10%) and completed on a standardised laboratory cycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, the Netherlands) and gas exchange data was collected breath-by-breath using open-circuit spirometry (Quark CPET, Cosmed SrI, Rome, Italy).

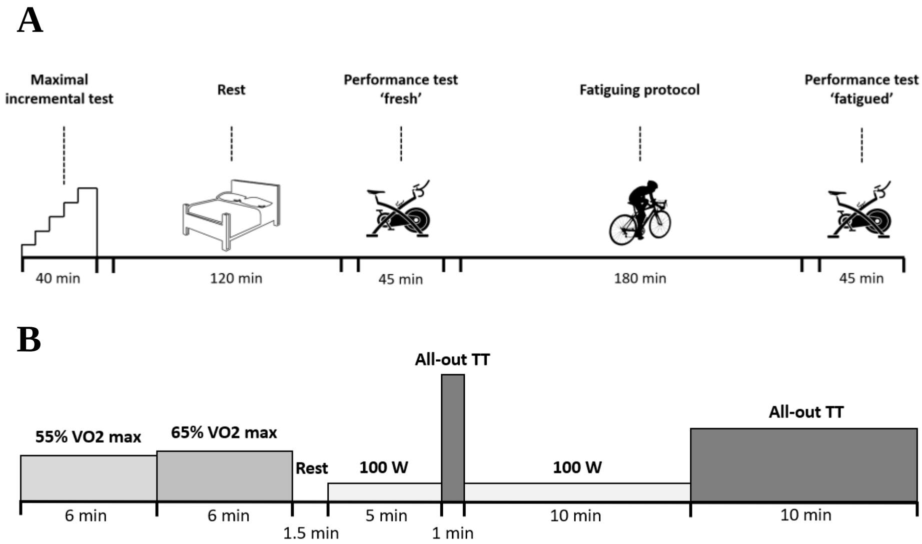

Figure 5.1: Design of the testing days (A) and the performance test (B)

Maximal incremental exercise test

The maximal incremental test started with a warm-up of 3 minutes at 100 W, after which the PO was increased to 170 W and increased stepwise with 35 W every 5 minutes. Participants were instructed to maintain a pedalling frequency of ~90 rpm and continued until volitional exhaustion. PO at VO_{2max} (PVO_{2max}) was calculated as:

(Equation 1)

$$PVO_{2max} = PO_{final} + (\frac{t}{300} * 35)$$

Where PO_{final} is the PO of the final completed stage in W and t is the time spent in the final uncompleted stage in seconds. Capillary blood samples were obtained from fingertips at the end of each step and analysed for lactate determination with the Lactate Pro 2 (Arkray, Kyoto, Japan). The first lactate threshold (LT1) was determined as a rise of 0.5 mmol/L above baseline lactate levels and the second lactate threshold (LT2) with the Log-Poly-ModD$_{max}$ method, which is shown to be most closely related to the maximum lactate steady state [84].

Performance test

The performance test consisted of three parts: (1) a submaximal warm-up during which gas exchange data was collected, (2) a 1-min all-out TT (TT$_{1min}$), and (3) a 10 min all-out TT (TT$_{10min}$) (Figure 5.1^{B}). Part 1 consisted of two constant PO steps of 6 minutes: step 1 at 55% (211±17 W) and step 2 at 65% (249±21 W) of PVO$_{2max}$. Gas exchange data were used to calculate gross efficiency (GE, Equation 2), FatOx (Equation 3) [85] and CarbOx (Equation 4) [85] from 3.5 minutes until 5.5 minutes in step 2 (65% of PVO$_{2max}$). For a correct determination of GE, data was only included if RER < 1.0 [87]. RPE was collected at the end of the step. The warm-up was followed by 90 seconds of passive rest and 5 minutes of active rest before continuing with part 2 of the performance test.

(Equation 2)

$$GE\ [\%] = \frac{Power\ Output}{\frac{VO_2}{60} * (4940 * RER + 16040)} * 100$$

(Equation 3)

$$FatOx\ (\frac{g}{\mathrm{min}}) = 1.695 * VO_2 - 1.701 * VCO_2$$

(Equation 4)

$$CarbOx(\frac{g}{min}) = 4.210 * VCO_2 - 2.962 * VO_2$$

During parts 2 and 3, the ergometer was set on a resistance based on the weight of the participant. This resistance was set so that the mostly used cadence range would widely cover the expected POs, as indicated by pilot measurements and field data on mean maximal POs of the participants over included durations. During both TTs, the participants were only able to see the elapsed time, except for the first minute of TT$_{10min}$

(part 3), during which the participants could see the PO, to exclude a pacing effect. During TT_{1min} (part 2) both seated and standing positions were allowed, while during TT_{10min} (part 3) the participants were restricted to seating. An active rest period of 10 minutes was interspaced between TT_{1min} and TT_{10min}. PO was averaged over TT_{1min} and TT_{10min}, resulting in PO1 and PO10.

Fatiguing protocol

After the performance test, the participants immediately changed clothes and started with an endurance ride, which was executed outdoors on a flat terrain with an average temperature of 7.9 ± 1.4 °C. This endurance ride was used as a fatiguing protocol and participants were instructed to ride at a steady pace at a PO of 3.2 $W \cdot kg^{-1}$. Together with the load of the 'fresh' performance test, this resulted in a load of 38.6 ± 4.6 $kJ \cdot kg^{-1}$ before starting the 'fatigued' performance test, which was executed immediately after the endurance ride and was an exact replication of the 'fresh' performance test.

Nutrition

The participants were instructed to refrain from strenuous exercise the day before the testing sessions, to follow their normal sleep cycle, to not consume alcohol the 24 hours before the test, to not consume caffeine within 3 hours preceding the beginning of the testing sessions and to prepare for the test with consuming a 'normal' race-day breakfast and to keep this breakfast the same before different testing days, which was monitored by the investigators. During the complete testing day (maximal incremental test, 'fresh' performance test, endurance ride, and 'fatigued' performance test), the participants had to consume 60 grams of carbohydrates per hour from gels and energy bars to exclude the effect of energy depletion during the 'fatigued' performance test.

Training load

Various methods were applied to calculate the training load, either based on PO or RPE. Participants were only included if >80% of the training sessions contained PO or RPE. All training load measures were described as an average training load per week. sRPE was calculated based on the RPE of the training session on a 10-point scale [116], obtained 30 minutes after the session and based on the question: ‘How hard was your workout?’. To calculate the sRPE, the RPE score was multiplied by the duration of the session in minutes. The PO data were collected using a 4iiii power meter (4iiii; 4iiii Innovations Inc, Cochrane, Canada) and calibrated according to the manufacturer’s instructions before every training session. The total mechanical energy spent (kJ) was summated for each session and the Training Stress Score (TSS) was calculated according to Equation 5 [117].

(Equation 5)

$$TSS = \left(\frac{t * NP * IF}{FTP * 3600}\right) * 100$$

(Equation 6)

$$NP = \sqrt[4]{\frac{1}{N}\sum_{i=1}^{N} Pi^{4}}$$

(Equation 7)

$$IF = \frac{NP}{FTP}$$

Where t is the duration of the session (sec), NP is the normalised PO as calculated with Equation 6, where Pi is the floating mean PO for 30 seconds time segments and N is the total number of time segments. IF is the intensity factor as determined by Equation 7. FTP, the Functional Threshold Power [117], which was determined as the PO at LT2 [118], Lucia’s training impulse (LuTRIMP) was calculated based on the time spent in each PO zone (zone 1: below LT1, zone 2: between LT1 and LT2, and zone 3: above LT2) multiplied by a coefficient relative to each intensity zone, see Equation 8 [55].

(Equation 8)

$$LuTRIMP = (duration[min]\ in\ zone\ 1 * 1) + (duration[min]\ in\ zone\ 2 * 2) + (duration[min]\ in\ zone\ 3 * 3)$$

This is an adjusted approach compared to the original LuTRIMP, which was based on heart rate and used ventilatory thresholds to calculate the three zones [55]. In addition to this, also the percentage (%) of time in each zone (1, 2, and 3) was calculated relative to the total time of the training sessions of the total training period. Furthermore, the polarisation index (PI) was also calculated according to Equation 9 [119].

(Equation 9)

$$PI = log_{10}(\frac{\%Zone\ 1}{\%Zone\ 2} * \%Zone\ 3 * 100)$$

Data analysis

All data were analysed and formatted using Python software (version 3.10.3, Python Software Foundation), and all statistical analyses were performed using R software (version 4.2.2, R Foundation for Statistical Computing, Vienna, Austria). Normal distribution was assessed using Shapiro-Wilk's test ($p>0.05$) and data were reported as mean ± standard deviation. Mean differences (MD) were reported with a 95% confidence interval (CI). Relationships were examined between dose (training load measures) and response (change in test measures) using Pearson's correlations. The change in test measures was defined as a percentage according to Equation 10.

(Equation 10)

$$\text{Change in test measures (\%)} = \frac{value\ test\ 2 - value\ test\ 1}{value\ test\ 1} * 100$$

Interpretation of the strength of the correlation coefficients was based on the following criteria: 0-0.09 *trivial*; 0.1-0.29 *small*; 0.3-0.49 *moderate*; 0.5-0.69 *strong*; 0.7-0.89 *very strong*; 0.9-0.99 *almost perfect*; 1.00 *perfect* [67]. Significance was set at $p<0.05$.

Results

Descriptive values for training characteristics are shown in Table 5.1. Due to some technical issues with power meters and/or incomplete RPE data of the observed period, not all measures are included for every participant. Resulting in 9 out of 10 complete datasets for both RPE and PO. Table 5.2 shows the descriptive values of the changes in test performance from test 1 (pre-training period) to test 2 (post-training period), which is also visualised in Figure 5.2.

Table 5.1: Descriptive values of training characteristics averaged per week presented as mean ± SD. (n=9)

Total Time [hours]	16.7 ± 1.4
RPE	
sRPE [AU]	4562 ± 1356
Power output	
KJ	12353 ± 1210
LuTRIMP	1230 ± 153
TSS	957 ± 143
Polarization Index	1.81 ± 0.27
Time < LT1 (%)	80.7 ± 8.0
Time LT1 – LT2 (%)	11.3 ± 6.7
Time > LT2 (%)	8.0 ± 2.4

Abbreviations: RPE, Rating of Perceived Exertion; kJ, KiloJoules; LuTRIMP PO, Lucia's training impulse; TSS, Training Stress Score; LT1, lactate threshold 1; LT2, lactate threshold 2

Table 5.2: Descriptive values of the changes in test performance variables from PRE to POST training period measured in ‘fresh’ and ‘fatigued’ state, presented as mean [95% CI]

	Fresh		*Fatigued*	
	Abs	*Relative [%]*	*Abs*	*Relative [%]*
PO1 [W]	16 [1 to 31]	2.5 [0.4 to 4.5]	20 [5 to 36]	3.6 [0.8 to 6.4]
PO10 [W]	21 [8 to 34]	6.4 [2.1 to 10.7]	25 [18 to 33]	7.3 [5.2 to 9.5]
GE [%]	0.9 [0.5 to 1.4]	4.9 [3.0 to 6.9]	1.0 [0.3 to 1.6]	4.7 [1.5 to 7.8]
FatOx [g·min^{-1}]	-0.12 [-0.27 to 0.03]	-22.4 [-51.4 to 6.6]	-0.08 [-0.21 to 0.06]	-4.4 [-10.6 to 1.8]
CarbOx [g·min^{-1}]	0.29 [-0.04 to 0.63]	11.3[-2.0 to 24.7]	0.22 [-0.17 to 0.61]	12.4 [-5.8 to 30.5]

Abbreviations: PO1, average power output in time trial of 1 minute; PO10, average power output in time trial of 10 minutes; GE, gross efficiency; FatOx, fat oxidation at 65% peak power output; CarbOx, carbohydrate oxidation at 65% peak power output

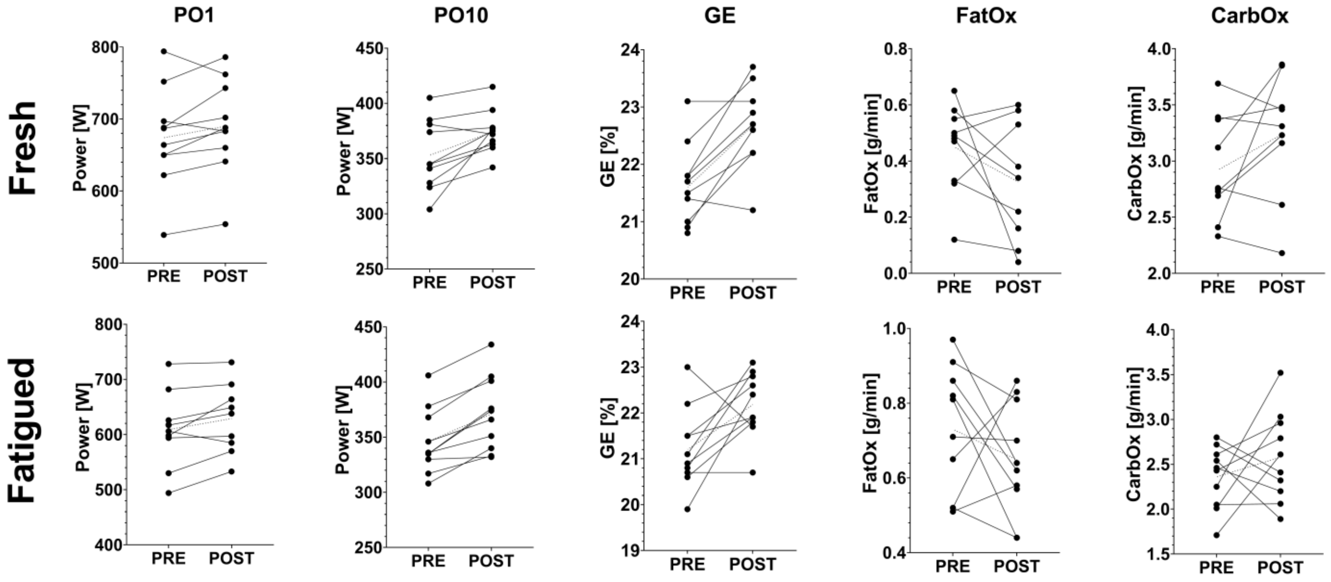

Figure 5.2: Descriptive values of the changes in test performance variables from PRE to POST training period measured in ‘fresh’ and ‘fatigued’ state. The dotted line displays the mean. Abbreviations: PO1, average power output on a 1-minute all-out time trial; PO10, average power output on a 10-minute all-out time trial; GE, gross efficiency; FatOx, Fat Oxidation at 65% peak power output; CarbOx, Carbohydrate oxidation at 65% peak power output

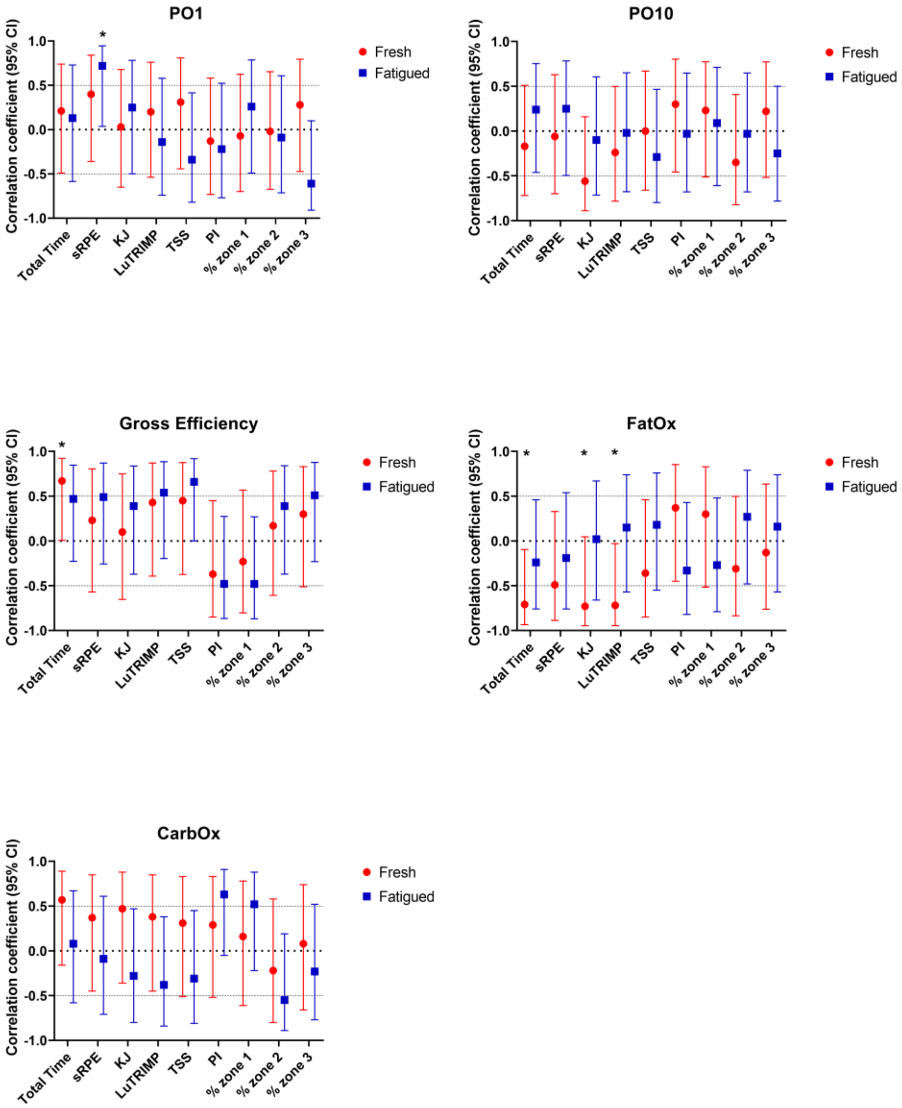

Figure 5.3: Correlations between the change in performance from PRE to POST and the training load variables during an 8-week training period of semi-professional cyclists. *Significant Pearson's correlation ($p < 0.05$). Lines are shown for r = -0.5 and r = 0.5, showing the cut-off for a *strong* correlation coefficient. Abbreviations: PO1, average power output on a 1 minute all-out time trial; PO10, average power output on a 10 minute all-out time trial; GE, gross efficiency; FatOx, Fat Oxidation at 65% peak power output; CarbOx, Carbohydrate oxidation at 65% peak power output; sRPE, session rating of perceived exertion; KJ, total work done in kilojoules; TSS, training stress score; PI, polarisation index

The relationships between the changes in test performance from PRE to POST training period and changes in physiological values (GE, FatOx, and CarbOx) for both the ‘fresh’ and ‘fatigued’ states are shown in the supplementary figures. Significant correlations were found between change in $PO1_{fresh}$ and change in $PO10_{fresh}$ (r = 0.71) and $GE_{fatigued}$ (r = 0.74) and between change in $PO10_{fatigued}$ and change in $FatOx_{fatigued}$ (r = 0.82) and $CarbOx_{fatigued}$ (r = 0.67).

Correlations between the change in test performance measures with the training load measures are shown in Figure 5.3. Significant correlations were found between $PO1_{fatigued}$ and sRPE (r = 0.74), between GE_{fresh} and total training time (r = 0.72), and between $FatOx_{fresh}$ and total training time (r = -0.71), kJ (r = -0.73) and LuTrimp (r = -0.72).

Discussion

The current study aimed to investigate the potential dose-response relationship between training load and performance outcomes over an 8-week training period. Performance was assessed using a standardised testing protocol with measures both in a ‘fresh’ state as well as in a ‘fatigued’ state to create possible new insights into durability. Key findings indicate no clear evidence that higher (or lower) training loads lead to better performance on PO1 and PO10, both in ‘fresh’ and ‘fatigued’ state, and there was a large variation between the assessed training load measures. Additionally, especially for substrate oxidation (FatOx and CarbOx), the relationship between training load and change in substrate oxidation indicators between tests was different for ‘fresh’ compared to ‘fatigued’ state, suggesting that the same training load can have different effects on ‘fresh’ compared to ‘fatigued’ substrate oxidation.

In the current study, performance assessed in both ‘fresh’ state as well as in a ‘fatigued’ state is presented before and after an 8-week training period. For both ‘fresh’ and ‘fatigued’ states the performance improvement in PO10 (6.4 - 7.3%) was larger compared to the performance improvement in PO1 (2.5 - 3.6%). This confirms with the literature that aerobic performance has a higher trainability compared to anaerobic performance [120]. It was also shown that the improvements in PO1 and PO10 in a ‘fatigued’ state were only *moderately* related to each other (POST PO1 – PRE PO1 vs

POST PO10 – POST PO1), supporting the hypothesis [115] that durability cannot be generalised across efforts of varying lengths and has not yet been defined as a unidimensional measure.

When assessing the relationship between changes in performance and training, *small* to *moderate* dose-response relationships were observed between nearly all training load measures and performance on the 1-min TT and 10-min TT. This finding contrasts with the study of Sanders et al. [112], which used a similar study design (8-week training period with competitive cyclists). Although not all used performance parameters and training load measures aligned precisely between the studies, comparable trends in the relation of training load with the improvement in PO10 (current study) were expected compared to the 8-min PO (PO8) in the study of Sanders et al. [112]. However, in the current study, only a *trivial* relationship was found between 10-min PO improvement and sRPE (r = -0.06) and TSS (r = -0.01), which contrasts with the *moderate* to *strong* relationships of 8-min PO with sRPE (r = 0.51) and TSS (r = 0.41) in the study of Sanders et al. [112]. Several factors may have contributed to these different study outcomes. Although the level of the participants was reported to be reasonably similar (LT2 339 vs 347 W), the average training load per week for TSS (957 vs 729 AU) and RPE (4562 vs 4086 AU) was higher in the current study. Also, the improvement in PO10 was greater (6.4%) compared to the improvement of PO8 (1.0%) in the study of Sanders et al. [112]. In addition, the PO8 was executed in the field with a mobile power meter while the PO10 was performed in a laboratory setting, which cannot be used interchangeably.[121] Given that the primary aim of training load measures is to be relatable to the outcome of a training plan (performance, fitness, and/or fatigue) [112, 113], the outcomes of the current study strengthen the hypothesis that the currently used training load measures don't match this objective [122]. This could be caused by two sides of the dose-response relationship: 1) the load of training cannot (yet) be captured by a single load measure which is the 'gold standard' [122], also strengthened, and as shown before [95], by the large variation in relationships for the various training load measures used in the current study; 2) the performance in a performance test may not provide a perfect reflection of an individual's current physical level, due to day-to-day variations in performance [123], as well as the influence of mental and motivational factors on the performance outcome [124]. Important to mention is that a major part of the participants had the same coach and therefore more or less the same training strategy (i.e. philosophy), however, still large differences in the outcome variables were found between participants, showing the difficulties in finding an ‘optimal’ individualised training plan for every athlete.

The novelty of the current study is that it presents the relationship between training load and performance not only in a ‘fresh’ state but also after accumulated load in a ‘fatigued’ state. In the previous study of this group [115] it was concluded that substrate oxidation plays an important role in the maintenance of performance in a ‘fatigued’ state. From the results of the current study, the individual responses in substrate oxidation change from PRE to POST training period could be highlighted, revealing both increases and decreases for individual participants for both FatOx and CarbOx following the 8-week training period. First of all, this could show the difficulties regarding the standardisation of these measurements and the general noise in the data, but could also indicate different adaptations to the training period for different participants. However, within our dataset, no clear cause for these different adaptations were found. However, it could be suggested that the adaptations were influenced by the intensity and duration of the training related to other factors related of nutrition, such as substrate availability during the training, where interindividual differences can be significant [125, 126]. Although the relationship with training was shown, this was an observational study and the training intensity and duration were not manipulated, which could therefore have influenced the adaptations in substrate oxidation. The same could be argued for the substrate availability, as the diet was not controlled or manipulated during the study.

Also, particularly when looking at substrate oxidation, the relationship of changes in substrate oxidation indicators with training load measures is shown to be different when the performance was obtained in the ‘fatigued’ rather than the ‘fresh’ state. The various training load measures have a positive relationship with CarbOx in the ‘fresh’ state (higher training loads resulted in a larger reliance on carbohydrates and a significantly smaller reliance on fat), but no or a negative relationship with CarbOx in the ‘fatigued’ state. In addition, the percentage of training time spent under LT1 had a positive relationship with CarbOx in the ‘fatigued’ state, while the percentage of training time spent between LT1 and LT2 had a negative relationship with CarbOx in the ‘fatigued state. So, relatively higher training loads (high volume) improve the ability to burn more carbohydrates in a ‘fresh’ state, but not in a ´fatigued state´. Moreover, it is noteworthy to mention the fact that training in a zone where carbohydrate oxidation is greater in the ‘fresh’ state, such as between LT1 and LT2, has a negative effect on the same substrate oxidation in the ´fatigued’ state. Because both high training loads and greater time spent in a highly demanding metabolic zone (between LT1 and LT2) can induce a high internal load that can not always be well tolerated by the athlete, this could lead to dysfunctional adaptations (and potential chronic fatigue). In this sense, the management of fatigue throughout the training period (and the corresponding context) could be an interesting approach to understand why both volume and intensity doses should be properly understood and planned to improve endurance durability during exercise. Therefore, high-volume loads with a polarised model could be suggested as an effective way to control fatigue while improving endurance durability, as this has been shown to improve carbohydrate oxidation in both ‘fresh’ and ‘fatigued’ states (which have been shown to have beneficial effects on durability performance [115]), although interindividual differences exist. In any case, it should be noted that this is a suggestion and the current study did not show that training in the abovementioned way had direct effects on performance (PO1 and PO10) after accumulated load.

It has been previously suggested that the maintenance of gross efficiency after accumulated load is related to the maintenance of performance after accumulated load [74-76]. However, the previous study of this group on the same dataset could not confirm this finding as the decrease in gross efficiency was not related to the decrease in performance [115]. The current study adds to this that the improvement in gross efficiency in ‘fatigued’ state from PRE to POST training period was not related to the improvement in 1-min TT and 10-min TT performance in a ‘fatigued’ state. It could be suggested that the fatiguing protocol, which only consisted of endurance intensity, was not fatiguing enough, as previous research showed that not only the accumulated load but also the intensity of this load has an impact on the decrease in performance [102, 103]. However, it is noteworthy to mention that the improvement in gross efficiency from PRE to POST training period showed a *moderate* to *very strong* relationship with the improvement in 1-min TT performance in the ‘fresh’ state. In addition, relatively higher training volumes during the training period had a *strong* to *very strong* correlation with improvement in GE in ‘fresh’ and ‘fatigued’ state, supporting the hypothesis that GE improves with training [127], also when measured in a ‘fatigued’ state.

The current study and its findings have several limitations. Ideally, a greater number of participants would provide a more robust foundation for investigating the dose-response relationship between training and performance. However, conducting these studies with participants at a highly competitive level presents practical challenges. As the participants compete in races throughout almost the entire year, minimising interference with their training programs and races becomes challenging. Additionally, unforeseen factors such as illnesses and injuries further limited the inclusion of some participants who could not complete both performance tests. Furthermore, although the manufacturer of the 4iiii power meter claims that the power output can be accurately measured (±1%), no independent scientific study, to our knowledge, has confirmed this claim. Therefore, no big claims can be made based on this study, but the current study can, in an exploratory way, show some valuable insights into highly competitive cyclists, which can have implications on the highest level of professional cycling and contribute to the understanding of the complexities involved in optimising training strategies.

Practical applications

The findings of this study enhance our understanding of durability in professional road cycling, particularly highlighting that identical training can lead to different adaptations when comparing ‘fresh’ to ‘fatigued’ performance. This can give coaches different insights into how to design their training programs toward specific goals. The current study also shows that single training load measures are not completely able to predict performance improvements after a training period of 8 weeks, which should be taken into account when monitoring the training of professional road cyclists.

Conclusion

This observational study illustrates the relationship between training load and performance change after an 8-week training period within semi-professional cyclists. It can be concluded that there was no clear trend indicating that higher or lower training loads resulted in more or less performance improvement during a 1-min TT and 10-min TT, with significant variation between the assessed training load measures. However, indirect indicators of durability performance, such as carbohydrate oxidation showed a *strong* correlation with training volume in the ‘fresh’ state and with time spent below LT1 intensity in the ‘fatigued’ state. It could also be highlighted that the relationship between training load and performance change from PRE to POST training period was different for performance parameters obtained in a ‘fresh’ compared to a ‘fatigued’ state, suggesting that the same training can have different effects on ‘fresh’ versus ‘fatigued’ performance.

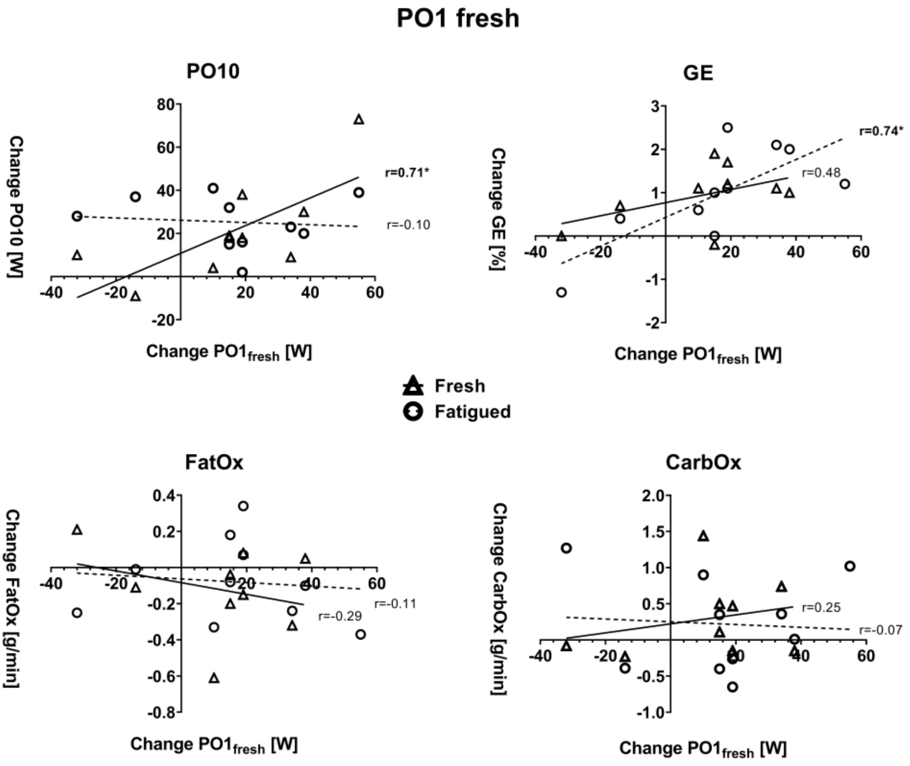

Figure S5.1: Relationships of the change in $PO1_{fresh}$ from PRE to POST training period with the Δchange in PO10 and physiological variables (GE, FatOx and CarbOx) in both ‘fresh’ and ‘fatigued’ state. *Significant Pearson’s correlation ($p < 0.05$).

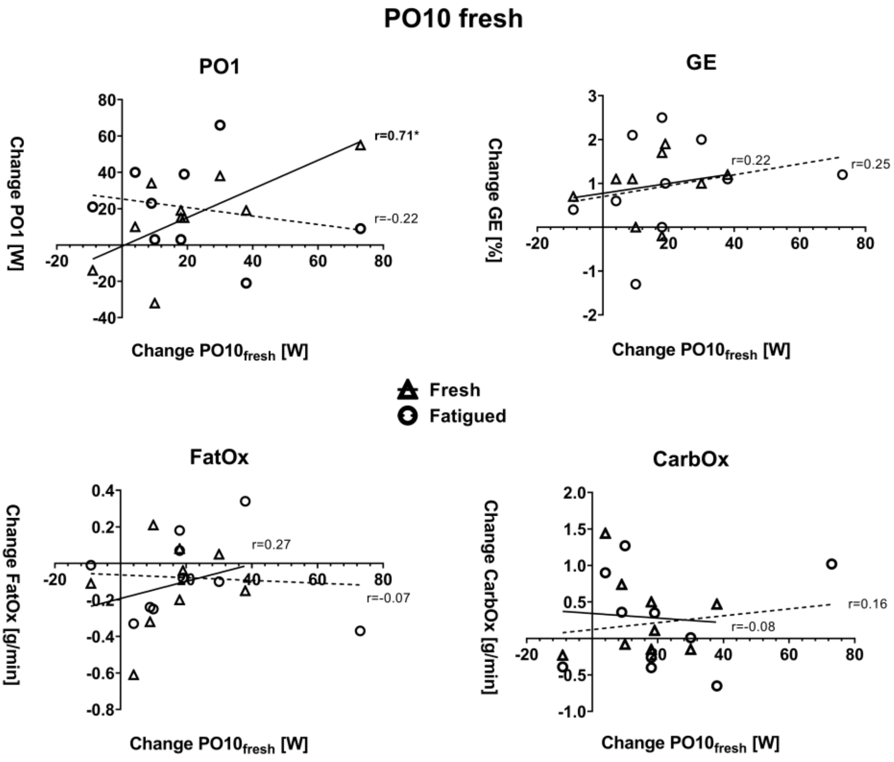

Figure S5.2: Relationships of the change in $PO10_{fresh}$ from PRE to POST training period with the change in PO1 and physiological variables (GE, FatOx and CarbOx) in both ‘fresh’ and ‘fatigued’ state. *Significant Pearson’s correlation ($p < 0.05$).

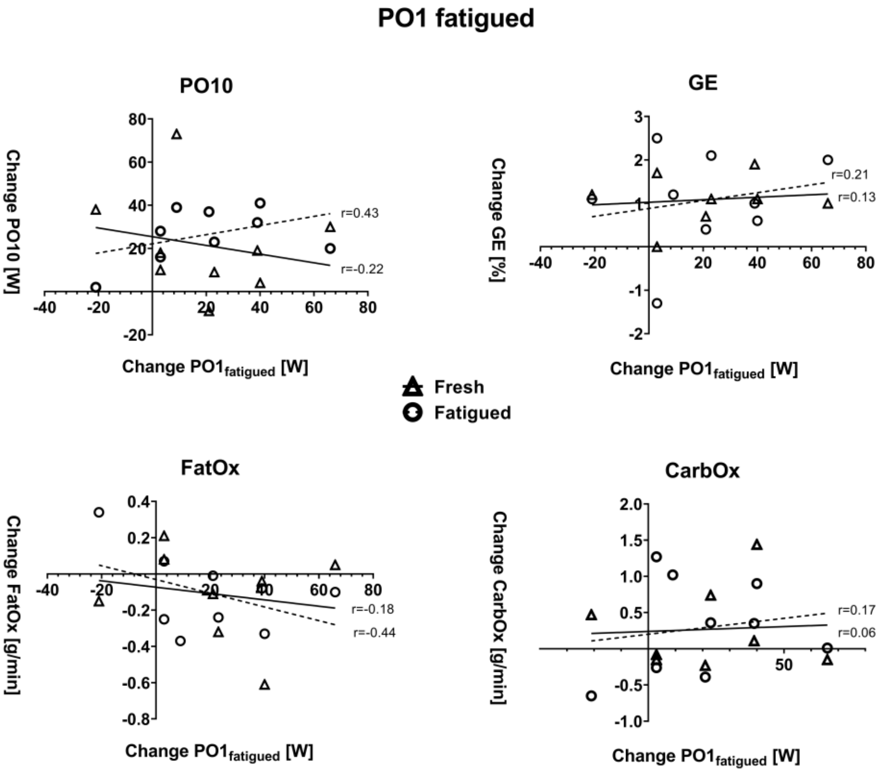

Figure S5.3: Relationships of the change in $PO1_{fatigued}$ from PRE to POST training period with the change in PO10 and physiological variables (GE, FatOx and CarbOx) in both ‘fresh’ and ‘fatigued’ state. *Significant Pearson’s correlation ($p < 0.05$).

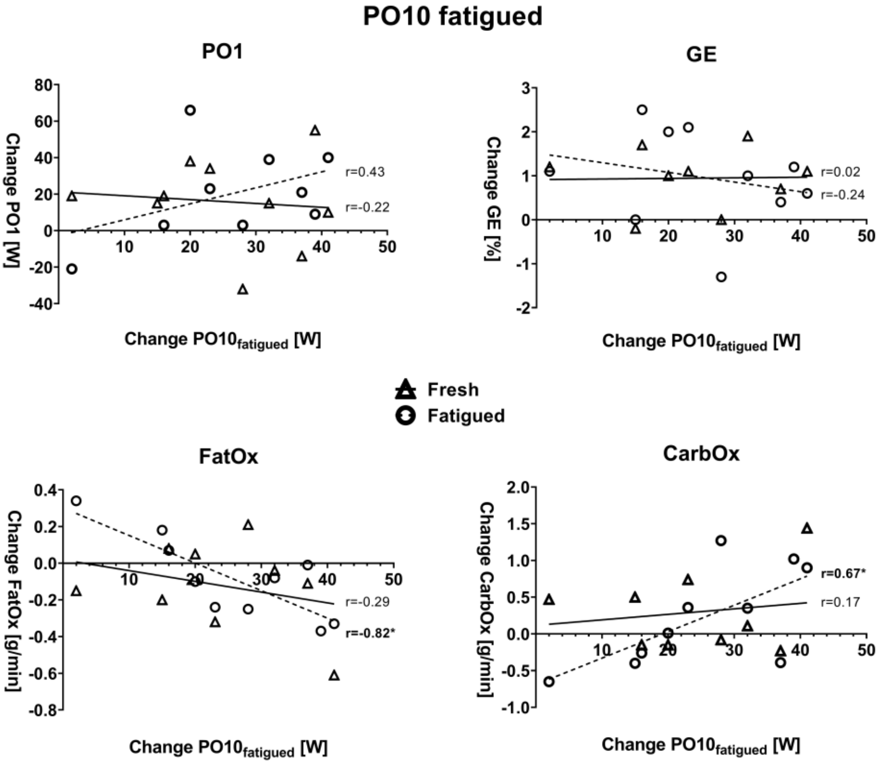

Figure S5.4: Relationships of the change in PO10$_{fatigued}$ from PRE to POST training period with the change in PO1 and physiological variables (GE, FatOx and CarbOx) in both 'fresh' and 'fatigued' state. *Significant Pearson's correlation ($p < 0.05$).

CHAPTER 6

Differences in execution and perception of training sessions as experienced by (semi-) professional cyclists and their coach

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Abstract

This study aimed to investigate whether (semi-)professional cyclists' execution of a training program differs from the coach's designed training program. Also, the study sought to ascertain, in instances where the training sessions were indeed executed as designed by the coach, whether the perception of the cyclists differed from the intention of the coach. This study highlights the differences between the coach and the individual cyclist. In total 747 training sessions were collected from 11 (semi-)professional cyclists. Rating of Perceived Exertion (RPE) and session Rating of Perceived Exertion (sRPE) were compared with intended RPE (iRPE) and intended sRPE (isRPE), planned by the coach. Pearson's correlation, regression coefficients and Typical Error of Estimate (TEE) were used to identify differences between the executed and planned training sessions. Moderate to large TEEs were noted between executed and intended sRPE, which indicates that cyclists do not always execute the training program planned by the coach. Furthermore, when the training was executed as planned by the coach, very large correlations but moderate to very large TEEs were noted between cyclists' (s)RPE and the coach's i(s)RPE, with unique individual regression coefficients. This indicates that the relationship between RPE and iRPE is unique to each cyclist. Both the different execution and perception of the training program by the individual cyclists could cause an impaired training adaptation. Therefore, the coach must pay attention to the perception of training sessions by the individual cyclist. Improved individual management of training load could result in the optimization of the proposed training program.

Introduction

Athletes are systematically exposed to stimuli during training. The goal of this process is to induce adaptations in the performance determining factors [128]. Coaches can change the outcome/stimuli of the training by manipulating, among others, the intensity and/or duration of the training session [129]. Changing the intensity and/or duration will influence the training load of the session and, potentially, the training outcome.

An easy, inexpensive, and non-invasive tool to measure the intensity of a training session is the Rating of Perceived Exertion (RPE) which can be measured using the 0 - 10 [130] or 6 - 20 Borg scale [116]. A training session can be defined as: low- (<3 or <11), intermediate- (3 - 5 or 11 - 14), or high- (>5 or >14) intensity for the 0 - 10 and 6 - 20 scale, respectively [131, 132]. Foster *et al*. [133] transformed the RPE intensity measure into an internal training load measure by multiplying the RPE score with the duration of the training session. This is called the session RPE (sRPE) which is used widely amongst sport disciplines [134, 135]. Training load can be measured as either external or internal. The external training load is an objective measure and independent of an athlete’s internal characteristics [136]. Internal training load is considered to be more important as it represents the biological stress imposed by the training [129] thus, ultimately, determining the outcome (i.e. positive or negative adaptation) of the training stimulus. Therefore, monitoring intensity and duration, and consequently training load, is of considerable importance in competitive sports, including professional cycling.

A coach often pre-plans intensity, duration and training load to create a training program which is designed to balance overload and recovery [128]. It is known that a too high training load can result in non-functional overreaching and, ultimately, overtraining syndrome [106]. Besides fatigue, high training loads have also been associated with an increased likelihood of developing overuse injuries [137]. In contrast, a too low training load results in de-training and ultimately poorer training and performance status [112]. In addition to this misbalance between training load and recovery, an unvaryingly hard (e.g. monotonous) training program could also heighten the risk of overtraining as well as injuries and illness [138]. Despite the fact that most experienced coaches plan their training program upfront and carefully monitor the intensity and training load of their athletes, incidences of overtraining syndrome [106] and overuse injuries [137] still persist.

This phenomenon could be ascribed to the discrepancy between duration and intensity intended by the coach, and the perceived intensity and training load (as experienced by the athlete). There are various factors which could lead to a mismatch between intended and perceived intensity and training load. Foster *et al*. [131] investigated the misbalance between a designed training plan and athletes' executed training. They observed significant differences between the designed and executed training plan that could result in maladaptation to training in competitive runners [131]. In addition, multiple studies have shown that a mismatch exists between the coach's intended Rating of Perceived Exertion (iRPE) and the athlete's RPE of the same training session [131, 139-142]. For example, Brink *et al*. [140] observed that young elite soccer players perceived low-intensity training sessions as more intense than envisioned by the coach and high-intensity training sessions as less intense than envisioned by the coach. This mismatch in training sessions' iRPE and RPE results in an increasingly monotonous training program and subsequent mismatch in the coach's intended training load (i.e. isRPE) and athletes' perceived training load (i.e. sRPE) [131, 140, 143]. The i(s)RPE and (s)RPE mismatch could be caused by multiple external factors including: school exams [138], sleep deprivation [144], environmental circumstances [145], nutritional status [146], age [147] and experience [147]. All these factors impact upon the athlete and, as such, influence the RPE of the training. Therefore, a specific athlete can experience the same external training load differently every day and different athletes may each experience the same external training load in a unique and person-specific manner. Coaches thus experience significant challenges to match their intended intensity and training load with the perceived intensity and training load of the individual athlete on a daily basis seeing that RPE is unique to every athlete and fluctuates on a daily basis.

Multiple studies investigated the relationship between the executed and intended (s)RPE in different sports. However, this relationship is not yet investigated within (semi-)professional cyclists, although this could have an impact on their training process. Furthermore, to the best of the author's knowledge, no study has investigated how these relations differ between the individual athlete (i.e. cyclists) and their coach. Therefore, the aim of this study was two-fold: firstly, to investigate whether the coach's designed training program differed from the cyclist's execution of the training program and, secondly, to determine whether the perceived intensity and training load differed from the intended intensity and training load even when the training program is executed as designed by the coach. As RPE is an internal measure and thus unique to every cyclist, this study focuses on the relationship between the cyclist's individual perception of the training and the coach's intended training.

Methods

Subjects

In total, 9 male (mean ± SD age: 21 ± 3 years, bodyweight: 69.1 ± 4.4 kg, 20 min Maximal Mean Power: 380 ± 22 W) and 2 female (mean ± SD age: 19 ± 0 years, Bodyweight: 60.8 ± 1.1 kg, 20 min Maximal Mean Power: 274 ± 4 W) (semi-)professional cyclists participated in this study. All cyclists belonged to the same (semi-)professional cycling team with 8 male cyclists being members of the U23 team and the 2 females and 1 other male cyclist competing at the highest level in cycling, as part of the World Tour team. All cyclists were trained by the same coach who designed the training programs. The coach had 5 years' experience in coaching cyclists at UCI Continental level, or higher. Data were collected as part of the normal coaching process. All participants provided written informed consent and the study was conducted in adherence with guidelines set out in the Declaration of Helsinki (2013).

Research design

Data were collected during an in-season period, from May till November. Individual training programs were designed two weeks in advance, but adapted later if needed, and communicated with riders via an online logbook. Training programs contained training plans for each day as well as detailed descriptions as to duration, intensity and specific interval types to be executed by the rider. All cyclists trained power based and therefore training sessions were mostly planned based on a certain duration and power output for the total session and for the specific intervals. In addition, the coach estimated the iRPE-score (i.e. 6 - 20 scale) and duration of each training session. The iRPE was blinded for the cyclists. The cyclists were instructed to complete their RPE-score for each training session (6 - 20 scale) in the same online logbook, within 30 minutes post training. Due to the nature of this study, it was impossible to control this aspect. Notwithstanding, RPE is remarkably robust relative to the timing between the training session and the collection of the RPE [135, 148]. isRPE was quantified by multiplying the intended duration with the iRPE of the training session, while sRPE was quantified as the experienced RPE by the cyclists multiplied by the actual duration of the training session [133].

Execution of training program

To investigate whether the training program was executed as intended by the coach, all training sessions that contained both iRPE and RPE scores were included for analysis, except those which deviated from the training program as a result of an injury, crash, or illness.

Perception of training program

To investigate the relationship between the i(s)RPE and (s)RPE, all training sessions who differed more than 30 minutes from the prescribed session or were executed with different intervals were excluded from further analysis for this research question. This approach was adopted as cyclists who did not execute the intended training plan could not yield meaningful values relative to the intended and perceived intensity as well as training load, and therefore would skew the outcomes. The inclusion of only the well-executed training sessions, allowed us to compare the i(s)RPE of the coach with the perceived (s)RPE of the cyclists. Similar to Foster *et al.* [131], but transformed from the 0 - 10 scale to the 6 - 20 scale [132], training sessions were divided into three intensity zones, low (<11), moderate (11 - 14), and high (>14), based on the iRPE score of the coach [131, 132].

Statistical analyses

All data were imported into MATLAB (2018b, The Mathworks, Inc., Natick, Massachusetts, USA) and the analysis, as described above, was performed. Data are reported as mean (± SD). An independent samples t-test grouped by variables was performed to determine differences between the planned training program (duration, iRPE and isRPE) and the executed training program (duration, RPE and sRPE). Furthermore, the relationship and the level of agreement between the planned (duration, iRPE and sRPE) and executed training program (duration, RPE and sRPE) was analysed with Pearson’s correlation coefficients (r) and (standardised) Typical Error of Estimate

(TEE) using the spreadsheet developed by Hopkins [149]. In addition, Bland-Altman 95% limits of agreement (95% LA) were calculated. Based on the iRPE of the coach, training session intensities and load were divided into easy (iRPE <11), moderate (iRPE 11 – 14), and high (iRPE >14). An independent samples t-test grouped by variables was used to compare the coach's and athletes' perceptions at each intensity level (easy, moderate and high). All statistical analyses were performed with the use of STATISTICA version 12 (Statsoft Inc, Tulsa, Oklahoma, USA). Figures were created with GraphPad Prism (version 8.01, GraphPad Software, La Jolla California, USA). The level of statistical significance was set at 0.05. The magnitude of correlation (r) between the measures was considered as: <0.1 trivial, 0.1 - 0.3 small, 0.3 - 0.5 moderate, 0.5 - 0.7 large, 0.7 - 0.9 very large, and 0.9 - 1.0 almost perfect [67]. The TEE was analysed using half the thresholds of the modified Cohen scale, based on the spreadsheet developed by Hopkins [149]: <0.1 trivial, 0.1 - 0.3 small, 0.3 - 0.6 moderate, 0.6 - 1.0 large, 1.0 - 2.0 very large, >2.0 extremely large.

Results

Execution of training program

In total, 747 training sessions were collected with both iRPE and RPE scores with the average data set of an individual cyclist containing 68 ± 17 training sessions. The average executed duration (167 ± 92 min) and sRPE (2011 ± 1358 AU) for all cyclists combined did not differ from the planned duration (164 ± 80 min) and isRPE (2005 ± 1207 AU). There was, however, a tendency for sRPE vs isRPE to differ ($p = 0.09$). On an individual level, lower duration (Participant 2) and a tendency for lower duration (Participant 6) and sRPE (Participant 8) were reported when compared to the intended duration and isRPE of the coach (Table 6.1). Large individual correlations, but differences in regression coefficients (i.e. slope and intercept) were found between planned and executed duration and sRPE (Table 6.1). Standardised TEE was considered as moderate to large on an individual level for duration and sRPE, while Bland-Altman 95% LA varied from 44.4 to 106.0 for planned vs executed duration and from 702 to 2025 for isRPE vs sRPE (see also Table 6.1).

Table 6.1: Mean difference (± SD), Pearson correlations (slope and intercept and typical error of the estimate (TEE)) as well as Bland and Altman's 95% limits of agreement (95% LA) between the planned and executed duration and sRPE in 11 (semi-)professional cyclists.

Cyclist	Training sessions	Difference cyclist - coach	Pearson correlations					Bland-Altman
Duration			**r**	**Intercept**	**Slope**	**TEE**	**Standardised TEE**	**95% LA**
1	49	2.0 ± 22.7	0.95	-8.39	1.07	22.41	0.33 (M)	44.4
2	92	23.8 ± 35.1*	0.87	24.95	0.99	35.26	0.56 (M)	68.8
3	65	- 8.3 ± 50.8	0.82	23.83	0.82	48.93	0.69 (L)	99.6
4	46	- 2.7 ± 30.3	0.95	-11.65	1.05	30.33	0.31 (M)	59.4
5	77	- 1.8 ± 49.3	0.87	-9.69	1.05	49.47	0.57 (M)	96.6
6	79	25.7 ± 51.9$^{\#}$	0.85	16.42	1.06	52.03	0.62 (L)	101.8
7	47	- 1.4 ± 54.1	0.82	17.70	0.90	53.93	0.71 (L)	106.0
8	96	- 13.4 ± 31.0	0.93	-14.96	1.01	31.19	0.38 (M)	60.8
9	62	3.1 ± 34.5	0.93	-7.79	1.07	34.35	0.39 (M)	67.5
10	76	3.3 ± 53.5	0.86	-6.21	1.06	53.64	0.59 (M)	104.8
11	58	- 0.7 ± 54.1	0.81	-0.86	1.00	54.49	0.72 (L)	105.9
sRPE			**r**	**Intercept**	**Slope**	**TEE**	**Standardised TEE**	**95% LA**
1	49	130 ± 359	0.95	-79.85	1.12	344	0.32 (M)	702
2	92	149 ± 514	0.90	-2.91	1.09	509	0.49 (M)	1007
3	65	-136 ± 836	0.78	364.60	0.77	790	0.80 (L)	1638
4	46	-133 ± 577	0.93	-237.49	1.04	581	0.40 (M)	1131
5	77	-90 ± 672	0.86	88.76	0.91	668	0.59 (M)	1317
6	79	-41 ± 597	0.88	205.40	0.87	578	0.55 (M)	1170
7	47	13 ± 983	0.76	352.78	0.85	974	0.86 (L)	1926
8	96	-317 ± 445$^{\#}$	0.93	-169.83	0.92	437	0.39 (M)	872
9	62	75 ± 497	0.93	49.88	1.01	500	0.41 (M)	973
10	76	179 ± 758	0.88	39.07	1.07	758	0.55 (M)	1485
11	58	362 ± 1033	0.77	115.50	1.10	1036	0.83 (L)	2025

Abbreviations: sRPE, session Rating of Perceived Exertion; TEE, Typical Error of the Estimate; 95% L.A, 95% limits of agreement.

*Sig. (<0.05), $^{\#}$(<0.10) with Independent samples t-test grouped by variables. Standardised TEEs were considered as M(oderate): 0.3 - 0.6 and L(arge): 0.6 - 1.0 [25]

Perception of training program

In total, only 22 of the 747 training sessions were excluded from further analyses due to not meeting the inclusion criteria for this research question. When the training sessions of all cyclists were combined, no differences were noted between RPE (11.3 ± 2.6 AU) vs iRPE (11.5 ± 2.1 AU) and sRPE (2012 ± 1352 AU) vs isRPE (1988 ± 1211 AU). RPE, however, had a tendency ($p = 0.06$) to differ from iRPE. In addition, very large relationships were found to exist between the overall (i.e. all cyclists combined) RPE vs iRPE ($r = 0.73$, TEE = 1.78), as per Figure 6.1A, and sRPE vs isRPE ($r = 0.87$, TEE = 664), as per Figure 6.1B.

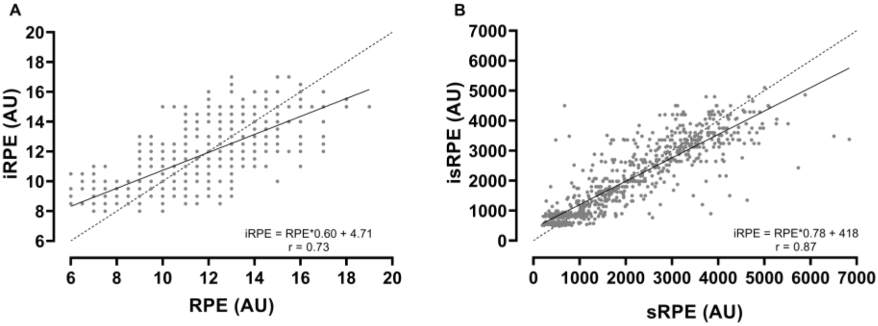

Figure 6.1. The perception of training sessions expressed in RPE (A) and sRPE (B) for 11 (semi-) professional cyclists in relation to the iRPE (A) and isRPE (B) planned by the coach with the predicted regression lines (solid line) and lines of identity (dashed line). Abbreviations: RPE, Rating of Perceived Exertion; iRPE, intended Rating of Perceived Exertion; sRPE, session Rating of Perceived Exertion; isRPE, intended session Rating of Perceived Exertion.

Despite this, on an individual level, significantly lower (2 participants) or higher (2 participants) RPE were reported when compared to the iRPE of the coach, while 1 participant tended to have a lower sRPE when compared with the isRPE of the coach. Large individual correlations were found for both RPE vs iRPE and sRPE vs isRPE, although the TEE was considered as moderate to very large (RPE vs iRPE) and moderate to large (sRPE vs isRPE) and Bland-Altman 95% LA ranged from 2.49 to 3.63 for RPE vs iRPE and 666 to 1960 for sRPE vs iSRPE. Further individual differences were noted for regression coefficients (i.e. slope and intercept) between RPE vs iRPE and sRPE vs isRPE, as per Table 6.2.

When combining the training sessions of all 11 participants, training sessions at low-intensity (p = 0.004) and high-intensity (p < 0.001) were found easier by the cyclist for RPE vs iRPE (Figure 6.2A), while no differences were found for medium-intensity training sessions. Furthermore, no differences were noted between sRPE and isRPE for low-, medium- and high-intensity training sessions (Figure 6.2B).

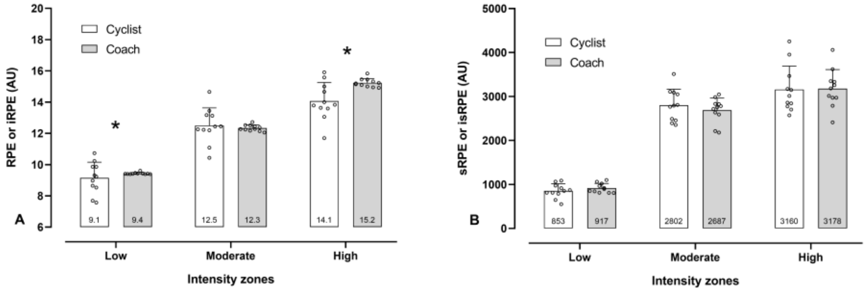

Figure 6.2. The perception of training sessions expressed in RPE (A) and sRPE (B) for 11 (semi-) professional cyclists and planned by the coach in iRPE (A) and isRPE (B). Training sessions are divided into three intensity zones (<11, 11 - 14, >14), based on the iRPE score. *Significant (p <0.05) different.

Table 6.2: Mean difference (± SD),), Pearson correlations (slope and intercept and typical error of the estimate (TEE)) as well as Bland and Altman's 95% limits of agreement (95% LA) between the intended and perceived RPE and sRPE in 11 (semi-)professional cyclists.

Cyclist	Training sessions	Difference cyclist - coach	Pearson correlations					Bland-Altman
	RPE		r	Intercept	Slope	TEE	Standardised TEE	95% LA
1	49	0.51 ± 1.27	0.89	2.73	0.74	1.27	0.50 (M)	2.49
2	92	-0.40 ± 1.60	0.82	4.41	0.63	1.61	0.71 (L)	3.14
3	65	-0.12 ± 1.64	0.74	3.98	0.65	1.62	0.90 (L)	3.21
4	46	-1.05 ± 1.77	0.81	5.10	0.64	1.79	0.73 (L)	3.47
5	77	-0.20 ± 1.69	0.65	3.59	0.70	1.48	1.17 (VL)	3.30
6	79	-1.39 ± 1.52*	0.72	1.20	1.02	1.08	0.97 (L)	2.99
7	47	-0.43 ± 1.94	0.75	4.80	0.63	1.94	0.88 (L)	3.30
8	96	-1.35 ± 1.38*	0.85	4.52	0.67	1.38	0.61 (L)	2.71
9	62	0.23 ± 1.29	0.74	2.34	0.78	1.18	0.92 (L)	2.53
10	76	0.98 ± 1.42*	0.77	1.61	0.79	1.32	0.83 (L)	2.77
11	58	1.45 ± 1.85*	0.74	5.18	0.51	1.87	0.92 (L)	3.63
	sRPE		r	Intercept	Slope	TEE	Standardised TEE	95% LA
1	49	147 ± 340	0.96	188	0.83	329	0.31 (M)	666
2	92	149 ± 514	0.90	317	0.74	509	0.49 (M)	1008
3	65	-55 ± 791	0.81	454	0.81	758	0.73 (L)	1550
4	46	-133 ± 577#	0.93	532	0.83	581	0.40 (M)	1131
5	77	-68 ± 649	0.87	403	0.83	644	0.56 (M)	1273
6	79	-41 ± 597	0.88	242	0.89	578	0.55 (M)	1170
7	47	27 ± 986	0.75	676	0.69	965	0.88 (L)	1933
8	96	-288 ± 432	0.94	373	0.94	425	0.37 (M)	846
9	62	75 ± 496	0.93	244	0.85	500	0.41 (M)	973
10	76	214 ± 638	0.91	313	0.77	632	0.44 (M)	1250
11	58	356 ± 1000	0.78	857	0.56	1002	0.79 (L)	1960

Abbreviations: RPE, Rating of Perceived Exertion; sRPE, session Rating of Perceived Exertion; TEE, Typical Error of the Estimate; 95% L.A, 95% limits of agreement. *Sig. (<0.05), #(<0.10) with Independent samples t-test grouped by variables. Standardised TEEs were considered as M(oderate): 0.3 - 0.6, L(arge): 0.6 - 1.0 and V(ery) L(arge): 1.0 - 2.0 [25]

Discussion

To our knowledge, this is the first study which investigated the individual execution and perception of a training program within (semi-)professional cyclists. Most studies which focused on this topic investigated the overall differences as apparent in all their athletes. This study, however, investigated the relationship between the individual cyclist and his/her coach. This study found moderate to large TEE between the planned (duration and isRPE) and executed (duration and sRPE) training program. Furthermore, when training sessions were executed as planned, substantial differences were noted in the individual relationships between the perception of the cyclist and the intention of the coach, measured in RPE vs iRPE and sRPE vs isRPE. In addition, when the training sessions of all participants were combined, this study found that training sessions at low- and high-intensity yielded a lower RPE for the cyclist compared with the iRPE of the coach, while these differences were absent between sRPE and isRPE.

Execution of training program

Firstly, this study investigated whether the execution of a training program by (semi-)professional cyclists differed from the training program designed by the coach. Comparing the planned duration and isRPE with the executed duration and sRPE, limited differences were found. However, moderate to large TEEs were found for all individual participants indicating the significant importance of assessing the execution of the training program individually and for each training session. TEE for the duration was, on average, 42 minutes which indicates the difference between planned and executed training as possibly ~25%. A difference of ~25% could seriously impair the training program as more training load could lead to an increased risk of overtraining [106] or injuries [137], and a lower training load could result in reduced training progress [112], both of which would be likely to impair performance. In contrast to this study, although they only studied the combined overall duration for all participants, Foster *et al*. [131] did not note any differences between planned and executed duration within running. This could be attributed to the nature of Foster *et al*.'s [131] study where the coach was more often present at the training session and could thus control duration. In professional cycling, however, coaching is mostly done remotely, which could be a reason for less agreement between intended and perceived training load.

Perception of training program

This study found no overall differences and very large relationships between RPE vs iRPE and sRPE vs isRPE, when all participants were combined, for training sessions in which major elements of the training were executed as described by the coach. The magnitude of these relationships was similar to the relationships found in studies investigating individual sports [131, 147, 150], but contrasts to the weak and moderate relationships found in studies investigating team sports [140, 151]. These differences can likely be ascribed to the inherent differences between team and individual sports. In a team sport, the coach assigns one iRPE or isRPE score to the whole team and thus not to an individual, as done in this study. Although on an overall level (i.e. all participants combined) this study found very large relationships and no differences for RPE vs iRPE and sRPE vs isRPE, interestingly on an individual level significant differences and moderate to very large TEEs were noted (RPE vs iRPE and sRPE vs isRPE), indicating large differences between the intended and perceived training stimulus. The reason for this mismatch between coach and cyclist could be varied. The perception of the athletes RPE-score is influenced by multiple factors including: school exams [138], sleep deprivation [144], environmental circumstances [145], nutritional status [146] as well as training load (resulting in fatigue) in the days before the training session [152]. However, the coach created the training program some weeks in advance and these factors could thus not be considered. Furthermore, one coach created training programs for multiple cyclists, but all cyclists had a different perception of the same training. This is clearly visible in the different slopes and intercepts between the individual cyclist and the coach, as per Table 6.2. For illustration, based on the slopes and intercepts, an iRPE score of 8 results on average in an RPE score of 5.1 and 6.6 (for Participants 7 and 6, respectively), while an iRPE score of 16 results in an RPE score of 17.8 and 14.5 (for Participants 7 and 6, respectively). The same intended intensity thus results in different perceptions of this intensity in two cyclists. In general, the relationship between the cyclist and coach has an intercept above zero and a slope smaller than 1, which means that the cyclist and coach interpret the same training differently. Thus, an iRPE score of 1 point higher on the intensity scale does not automatically mean that the cyclist will also rate this training 1 RPE score higher. Because the current study only investigated cyclists all trained by the same coach, it is not possible to make universal statements, however the above mentioned reasons highlight the difficulties a coach experiences when planning intensity (RPE) and thus training load (sRPE) for a training session. Coaches should be well aware of the factors that influence the perceived training load because a mismatch could, as mentioned before, increase the risk of overtraining [106], injuries [137] or de-training [112].

The differences between cyclists' and the coach's interpretation of a training session resulted, when training sessions of all participants were combined, in a lower RPE for the cyclist compared with the iRPE of the coach for low- and high-intensity training sessions. In several sports, similar differences were found for training sessions at high intensity [131, 140, 143]. It is suggested that the coach might mentally overprepare athletes for high-intensity training sessions because the coach wants this session to be extremely intense, but said training session may turn out to be easier than envisioned [143]. In addition, it is possible that although a training session has high-intensity intervals, the total RPE score of the training is rated lower, because the remaining training time is executed at a low intensity with RPE, by definition, being a measure for the entire training session. This effect should be further investigated.

For training sessions performed at low intensity, the RPE scores for the cyclists were lower when compared to the iRPE scores of the coach. This conflicts with findings in literature where other sports yielded higher RPE scores for low-intensity training sessions when compared to the iRPE score of the coach [131, 140, 143, 150]. This could be explained by the use of the polarized training model by the coach, which is based on an approximate 80-to-20 ratio of low-intensity to high-intensity training [153]. The significant amount of low-intensity training sessions could have resulted in the cyclists perceiving these sessions as easier with another possible explanation being the interpretation of the RPE scale. The coach's lowest iRPE score was an 8, while cyclists rated 92 (of 725 in total) training sessions with an RPE of 7.5, or lower. Six training sessions were even rated with an RPE score of 6, which should be total rest. This misinterpretation could have resulted in lower RPE scores being recorded when compared to the coach's iRPE scores. Nevertheless, the differences in intensity (RPE vs iRPE) did not lead to differences in training load (sRPE vs isRPE) for all intensities, which conflicts with results yielded by other sports [131, 140, 143]. This could be ascribed to the duration of the training sessions in the other studies, which was on average ~60 min, whereas the average duration for the training sessions in this study was almost three times longer.

Practical applications

The results of this study contribute to a better understanding of the execution and perception of a training program in (semi-)professional cyclists. Although it is not possible to make universal statements, it could provide valuable insights for coaches into understanding why cyclists do not always execute the training program as designed as this could influence the outcome of the training. Coaches should further note that various cyclists can perceive the same training session differently and this could lead to different adaptations compared to the intended training program. The relationship between the intended intensity and the perceived intensity by the cyclist should be examined in an effort to prevent this problem. In addition, it could be suggested to give the cyclists an iRPE score as an instruction for the training session to create a better match between the iRPE of the coach and the RPE of the cyclist. Improved management of intended and perceived intensity, together with training load, could result in the optimization of the proposed training program and thus to better performances.

Conclusion

To conclude, this study found *moderate* to *large* TEEs between the planned (duration and isRPE) and executed training (duration and sRPE), which indicates that (semi-)professional cyclists train differently than planned by the coach, despite the fact that on average (mostly) no differences were found. Further, it seems as if the relationship between RPE and iRPE is unique to each cyclist, an important tenet to keep in mind when a coach trains multiple cyclists. In general, the relationship between cyclist and coach has an intercept above zero and a slope smaller than 1, which means that cyclists and coach interpret the same training differently. This relationship between RPE and iRPE results in an easier perception of low- and high- intensity training sessions by the cyclists compared to the intention of the coach.

CHAPTER 7

General discussion

Key findings

The aim of the present thesis was to expand the knowledge about talent identification and talent development in professional road cycling. This thesis specifically focused on development teams of professional cycling structures in the under-23 (U23) category, using the framework in Figure 7.1. The first step in talent development is the identification of riders for a development trajectory, which in the context of this thesis usually occurs between the ages of 18 to 20 years old. The goal of talent identification is to select the cyclists with the greatest potential for future performance at professional/elite level, where that future performance is not yet known. Within this selection process, there may be some selection biases, as we investigated in **Chapter 2** and **Chapter 3**. The investigated selection biases were caused by the relative age (RAE; **Chapter 2**) and anthropometric characteristics (**Chapter 3**) of the cyclists. Awareness of these selection biases can help improve the effectiveness of those responsible for talent identification and avoid unnecessary selection or deselection. Once the cyclists are selected for the development team, the goal is to develop them as good as possible to fulfil their dream of becoming a professional cyclist. This includes several factors, such as mental, physical, and tactical factors (Figure 7.1). A substantial part of this thesis focuses on the physical development of cyclists, with a particular emphasis on durability. Durability can be defined as the ability to maintain performance after significant accumulated workloads, most often at the end of a cycling race [22]. This concept is mostly presented on the basis of mean maximal power outputs (MMP) in cycling races [19, 70-72], which has the disadvantage of uncertainty regarding whether it truly represents a maximal effort. We therefore investigated this concept using a standardised test protocol by studying the changes in durability within a cycling season and suggested underlying factors: gross efficiency (GE), energy expenditure (EE), fat oxidation (FatOx) and carbohydrate oxidation (CarbOx) (**Chapter 4**). In addition, to improve the understanding of how training contributes to (durability) performance, we presented the so-called dose-response relationship between changes in test performance (using the same test data as in **Chapter 4**) after an 8-week training period and the executed training load (**Chapter 5**). As durability has been shown to be an important success factor in professional road cycling, a better understanding of it can indicate how far along a cyclist is in his physical development. In addition, a better understanding of how durability can be developed could help talented cyclists to become professional riders and succeed on this level. To gain even a further understanding of the training and development process, we also focused on the coaching process of the U23 development teams through the lens of individual coaches. In **Chapter 6** we investigated the relationship between the intended training program of the coach and the executed and perceived training program by the cyclist. This provides insights into training execution and shows the importance of communication between cyclist and coach within the development process. All in all, a better understanding of the talent identification and development process can help development teams to use their resources efficiently and can assist coaches to guide the development of young cyclists to help them to achieve their dream of becoming a professional cyclist. The purpose of this chapter is to discuss the findings of this thesis and to provide guidance to practitioners working in the field of talent identification and development in professional road cycling.

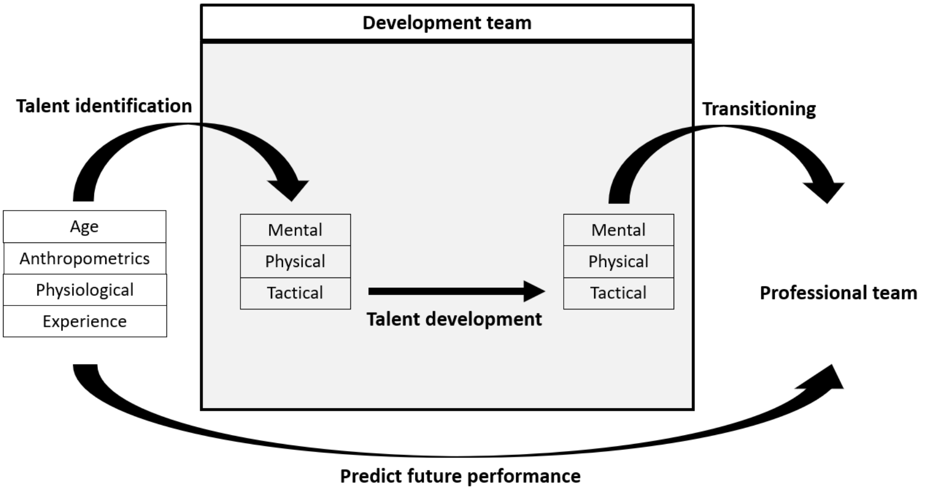

Figure 7.1. Schematic representation of a model to be used for talent identification and talent development practices relevant for development teams of professional road cycling teams.

Talent identification

In **Chapters 2** and **3,** we described some of the potential selection biases present in professional road cycling. First, as shown in **Chapter 2**, the relative age effect (RAE) seems to be present in the development path to professional road cycling. This was shown by a relatively higher presence of riders born in the first quarter of the year (January, February, March; Q1) compared to the last quarter of the year (October, November, December; Q4) when analysing all riders that have been part of a team at Continental (CT) level. More specifically, this RAE was seen in the riders who did not make it to professional level, and even more specifically, in the riders who started at CT level as 1st or 2nd year U23 (18 or 19 years old). However, no RAE was found when only looking at the riders who made it to professional level. This implies that riders born in Q4 have less chance of being selected for a CT development team, especially at the age of 18 and 19. As a result, there is a risk that highly talented riders born in Q4 lack in their development or even drop out early due to not being selected, potentially leading to a loss of motivation [45], missing the right facilities (i.e. coaches/materials) to develop [44] and missing the opportunity to compete against higher-level athletes at a younger age [44]. When becoming older (20, 21 years) the RAE disappears as the differences in maturation status become smaller with age and therefore also no RAE was found at professional level. This shows that the RAE especially plays an important role in the talent identification process. In addition to the RAE, in **Chapter 3** we presented another selection bias in professional road cycling based on the weight and height of the rider. Firstly, we found that riders from mostly flat countries (i.e. the Netherlands, Belgium, and Germany) are relatively more specialised in flat sprint races, whereas riders from more mountainous countries (i.e. Colombia, Spain, and Portugal) are relatively more specialised in climbing races. In addition, our results show that being tall and heavy can give a young cyclist a relatively better chance of being selected in a mostly flat home country, while being short and light can give you a relatively better chance in a home country with more mountainous terrain. This is likely caused by the fact that young cyclists mostly compete in races in their own or neighbouring countries. This automatically means that when the terrain of their country is primarily hilly, they will mostly take part in hilly races, and vice versa for a country with a mostly flat terrain. If the selection process in the youth categories is primarily based on race results, this can lead to the selection bias, as mentioned above. The findings of **Chapter 2** and **Chapter 3** can have important implications for the ones responsible for talent identification in U23 development teams. For both the RAE and the selection bias based on weight and height could be suggested to be caused by the way talent selection for CT development teams is structured. When cyclists get selected for these CT development teams they are mostly 18 or 19 years old. If the selection process is mostly focused on current performance (whether this is race performance and/or power output (PO) data), these selection biases have a greater influence. The presented selection biases show that the riders are not always selected based on the largest future potential, which should be the aim of talent identification (Figure 7.1). If a rider is relatively older and more mature, it is reasonable that he will perform better at 18 years old, but that does not necessarily mean he has more capacity to develop into a professional cyclist. The same can be said of a very short and light rider who only races in his own, flat country. He probably will not do very well in these races because his anthropometrics are not favourable to this type of race [65], but, that does not mean that he cannot develop into a professional cyclist later who can do very well in races on more mountainous terrain. Both selection biases are even more important to be aware of as there is a recent tendency for more and more riders that skip the U23 level and sign a professional contract directly, which is illustrated by the increasing number of riders who are part of a World Tour team under the age of 20 (2010: 3. 2015: 0, 2020: 4, 2024: 11) [48]. In addition, there is a rise in the number of U19 teams that are part of or linked to the structure of professional teams, which ensures that selection takes place at a younger age, increasing the possibility of the selection biases mentioned above. This even increases the financial investment in riders who may not even be able to develop into a worthy professional cyclist and misses out on riders who may have huge potential for the future.

Talent development – Durability

The development of athletic talent includes multiple factors that play a role such as training, teaching/coaching, parental support, enjoyment, recovery, age, psychological skills and attributes, and innate abilities [23]. This could be simplified into three categories: mental, physical and tactical factors (Figure 7.1). Part of this thesis focused on the physical side of talent development and how to assess and improve this, with specific attention towards durability, which is the ability to maintain performance after accumulated load (usually towards the end of a cycling race) [22]. Previous studies have shown the importance of durability in professional road cycling, which appears to discriminate between different age categories and performance levels [17, 19, 20]. In **Chapter 4** we investigated durability in semi-professional cyclists three times during a cycling season. Time trial (TT) performance was assessed before ('fresh') and after accumulated load ('fatigued'), as well as GE, EE, FatOx and CarbOx. It was shown that POs on shorter TTs (1 min) were affected by accumulated load whereas POs on longer TTs (10 min) were not. Additionally, over the season, the 10-min PO improved more than the 1 min PO. In addition, while EE did not change significantly, FatOx increased and CarbOx decreased from a 'fresh' to a 'fatigued' state. This effect diminished as the cycling season progressed, showing a similar trend as the 1 min PO, which improved more in the 'fatigued' compared to the 'fresh' state. In **Chapter 5** we did a follow-up on this study, investigating the dose-response relationship between training and performance over an 8-week pre-season training period (Dec-Jan). The performance was, similar to **Chapter 4**, assessed both in a 'fresh' state as well as after accumulated load ('fatigued' state). Within this study, we found no clear relationships between dose (training loads) and response (1-min and 10-min TT performance, GE, EE, FatOx, and CarbOx) for both 'fresh' and 'fatigued' performance. It should explicitly be mentioned that there was a large variation between the used training load measures (training volume, sRPE, KJ spent, LuTRIMP, Training Stress Score, polarisation index, and time spent in 3 PO zones) and between individual participants. Only a clear relationship was observed for the change in CarbOx in the 'fresh' state and training volume, and CarbOx in the 'fatigued' state and time spent below the 1st lactate threshold. Although there were no clear relationships, there were clearly different trends observed when comparing performance parameters in the 'fresh' and 'fatigued' states, showing that similar training can have different effects on the 'fresh' and 'fatigued' performance.

The findings of the studies in **Chapter 4** and **Chapter 5** have multiple implications for the physical aspect of talent development in professional road cycling. It highlights the difficulties of measuring development purely from physical/physiological data. The concept of durability originates from MMPs derived from training and race data, and the studies in **Chapter 4** and **Chapter 5** are some of the first investigating durability in cyclists of this level in a standardised way. There was a highly variable response when comparing participants, with some riders even showing improvements in 10-min TT PO from the 'fresh' to the 'fatigued' state, as shown in Figure 4.3. The variation in the results could be caused by multiple factors, such as day-to-day variations in performance [123], but also by the influence of mental and motivational factors on the performance outcomes [124]. As the test protocol that was used in the studies of **Chapter**

4 and **Chapter 5** already included multiple measures during one day, it was chosen to design the fatiguing protocol with an endurance intensity (3.2 $W \cdot kg^{-1}$) to obtain a similar accumulated load as compared to races. Although previous research has shown that not only the magnitude of the accumulated load but also the intensity of that load plays an important role in durability [102, 103], the current protocol was chosen to mitigate potential mental fatigue and motivational issues during a long day of testing. It could also be suggested that the test protocol should be carried out more ecological valid during training on the road rather than in a laboratory. However, the current protocol was chosen to find a balance between scientific standardisation and practical relevance. In addition, it should be noted that the sample sizes in **Chapter 4** and **Chapter 5** are relatively small, limiting statistical power. However, we defined the level of our participants as Tier 3 (Highly Trained/National level) or Tier 4 (Elite/International level) [83]. At this level, it is more challenging to recruit participants that want to participate in scientific studies that may interfere with their training program. Nevertheless, even with smaller sample sizes, these studies can still provide valuable insights that translate directly into daily practice [83, 154]. This aligns with a key goal of this thesis: to directly improve decision-making in professional road cycling. Despite the mentioned limitations, some statements can be made if we are willing to use durability as an indicator for physical talent development in cycling. It seems, above all, to be necessary to test not only the 'fresh' but also the 'fatigued' POs, as the results of our studies show that there is more improvement in the 'fatigued' POs during a cycling season. This, combined with results from other studies showing the importance of durability for cycling performance [17, 19, 20, 70], suggests an important role for testing durability to track physical talent development. Based on our results, we can conclude that it may be more necessary to test and retest PO of shorter TTs (1 min) rather than longer TTs (10 min) when assessing durability. In the context of durability and the decline in performance after accumulated load, it was previously concluded that this could be caused by a decrease in GE and CarbOx and a increase in FatOx [74, 76]. However, within our studies, we did not find a significant decrease in GE after accumulated load, and also on an individual basis no relationship was found between a decrease in GE and a decrease in TT (1 and 10 min) performance. Therefore, we cannot confirm this hypothesis on the base of our results, which could be due to the use of our chosen fatiguing protocol, as discussed earlier, and the high level of the participants. However, we did observe a decrease in CarbOx and an increase in FatOx from a 'fresh' to a 'fatigued' state, as shown in **Chapter 5**. While progressing during the season, the decrease in CarbOx and increase in FatOx was diminished, while durability improved, showing an important role for CarbOx in the maintenance of performance after accumulated load [76, 88], possibly (although not directly measured) caused by increased sparing of glycogen. This suggests two things: 1) 'training the gut' could be a beneficial strategy to be able to absorb a higher amount of carbohydrates [155] and therefore improve durability; 2) improved training status could lead to an improved mitochondrial function which results in a better maintenance of glycolytic capacity, and therefore high-intensity performance, during exercise [97, 98].

From the studies in **Chapter 4** and **Chapter 5,** we can also take away some valuable points concerning training and its relationship to physical development. There seems to be a larger training effect on longer (10-min) compared to shorter (1-min) efforts, which is in line with the literature concluding that aerobic performance has a higher trainability compared to anaerobic performance [120]. This trend can also be seen when looking at durability performance, which has a larger training effect compared to 'fresh' performance parameters. Out of both these statements it can be concluded that aerobic capacity suits better to track physical development compared to anaerobic capacity. In contrast, anaerobic capacity is more suitable for talent identification, as there is less development possible. Moreover, we found in **Chapter 5** that the relationships between TT performance (1 and 10 min) and training load measures were different when performance was obtained in the 'fatigued' state compared to the 'fresh' state, which suggests that one type of training may be optimal for 'fresh' performance, but not for 'fatigued' performance. Relatively higher training loads could for example result in an improved CarbOx in the 'fresh' state, but a reduced CarbOx in the 'fatigued' state. To add to this, the percentage of time spent below the 1st lactate threshold showed a positive relationship with CarbOx in the 'fatigued' state. This has implications for the planning of a training program in practice, as it suggests that a combination of both a high training volume and a large percentage of this training volume on an intensity below the 1st lactate threshold can be beneficial. A polarised training strategy would contain both of these and would therefore be preferred, which is probably also one of the reasons why this strategy is widely used (with success) by riders at the highest level of professional cycling [104]. Summarising the results found in **Chapter 5**, coaches should be very careful when planning the training and monitoring the progress of their cyclists, as training that is beneficial for ‘fresh’ POs does not necessarily mean that the ‘fatigued’ POs will also improve, which are decisive for race performance [19, 70-72]. In addition to this, coaches should be cautious when monitoring the training by the use of training load measures, as these measures are not directly related to performance improvements. As shown in **Chapter 5**, the relationships of the used training load measures (training volume, session rating of perceived exertion [sRPE], KJ spent, Lucia’s training impulse [LuTRIMP], training stress score [TSS], and % of time spent in 3 zones) with performance improvement on a 1-min and 10-min TT were only *small* to *moderate* for most of the measures. This implies that the currently used training load measures are not directly relatable to the outcome of a training plan, as previously also stated [122]. As there are so many factors that play a role in the ‘real’ load on the body of a cyclist, it seems to be difficult to capture all of this in a single load measure. Similarly, there are a lot of factors that play a role in the variability of the performance outcome in a laboratory test [123, 124], which makes it even more difficult to obtain valid dose-response relationships. However, in my opinion, this does not mean that training load measures should not be used at all by coaches to monitor the training load, as they can give certain benchmarks for the volume and intensity that a cyclist can handle in training in order to achieve optimal performance. In addition, previously it was also shown (as opposed to our findings) that some training load measures can have some predictive capacity for performance improvements [112, 156]. However, these training load measures should be used with caution, and the training should not be purely planned and monitored by the use of these training load measures. Also, all other factors playing a role in the adaptation to training should be taken into account, such as nutrition, environmental circumstances, and psychological status [129].

Talent development - Coaching

An important part of the talent development process is having the opportunity to work together with a highly skilled coach [23], as the coach-athlete relationship is perceived as really important for the ability to improve [27]. The results of **Chapter 6** show how important it is that the cyclist and coach understand each other well, as this chapter shows the mismatch between the intention of the coach and the perception of the cyclist of the same training session. Training sessions were divided into low-, moderate- and high-intensity sessions, and the perception of the training was scored with the rating of perceived exertion (RPE) on a scale from 6 to 20 [116] by both the coach and the cyclist. For the low- and high-intensity sessions, the cyclists had an easier perception of the training compared to their coach. Also, an average difference of 42 minutes was found between planned and executed training time, which could lead to huge differences when summed up. These results were in contrast to those found in running [131], but this also highlights an important characteristic of coaching cyclists. In cycling, coaching is mostly done remotely, which makes it even more difficult for the coach to have a good understanding of how the cyclist is feeling. Even more, as the results of **Chapter 6** show that different cyclists can have a completely different perception of the same training session, which makes the coach-athlete relationship even more important to ensure an optimal training adaptation. The mismatch found in **Chapter 6** could also partly explain the results found around training adaptation in **Chapter 5**. The results of **Chapter 5**, in line with the study by Spragg et al. [25] suggest that a polarised training approach is the most optimal for improving durability. However, if the cyclist executes the training differently than intended (as shown in **Chapter 6**) this could alter the training approach as designed by the coach, ultimately resulting in a deviation from a polarised approach. The coach creates the training plan with a specific volume and intensity in mind, to achieve positive physical adaptations. If the training plan is executed or perceived differently by the cyclist, this could result in less improvement after a training period. However, it also shows that with the current measures, it is difficult for the coach to estimate the ‘real’ internal load on the body of the cyclist. This makes the training process challenging and requires good communication between the coach, who has the overview and the knowledge of the training process, and the cyclist, who can give feedback on how the training is perceived.

Practical implications

This thesis has a mostly practical focus and could therefore have some important implications for day-to-day practices in talent identification and development within professional road cycling. This sector discusses these practical implications, together with the author’s research-based opinion on improving talent identification and development practices in professional road cycling, focusing on the framework for U23 development teams (Figure 7.1). As in line with this thesis, these practical implications are divided into 2 sections: talent identification and talent development.

Talent identification

A few suggestions could be made on how to improve talent identification within U23 development teams in professional cycling in the future and to decrease the chance of selection biases. As discussed, the goal of talent identification is to select young athletes in a talent program that have the highest potential for future performance at professional level. Therefore, talent selection should be focused on future performance rather than current performance. Although this sounds simple, it is quite complicated as there are currently, to my knowledge, no models that are able to do this with high accuracy. The first starting point is to create awareness among practitioners responsible for talent identification. However, it has been shown that awareness of the RAE alone is insufficient, as the issue still persists across other sports [157]. Therefore, placing the current performance of a cyclist in relation to the background of that performance, such as relative to the biological age, training background, and/or previous professionality and support, could provide valuable insights. The performance between two riders could, for instance, be compared using a correction factor for the relative age effect, as previously shown in alpine skiing [158]. This would create more understanding of where the performance is coming from and what space there is left for improvement towards the future. Also for the selection bias based on weight and height, the background has an important role, as this selection bias is probably caused by too much focus on race results solely. Including multiple factors (physical capacities, training background, etc.) in the argumentation for rider selection would give a fairer view. In addition, placing the performance of the cyclists into certain benchmarks, as was done in speed skating [159], can assist in having a better view of where the cyclist is standing relative to other cyclists with a similar biological age and/or training background. By developing these benchmarks, it can also be visualised how the cyclist is progressing throughout the years, with an example of this given in Figure 7.2.

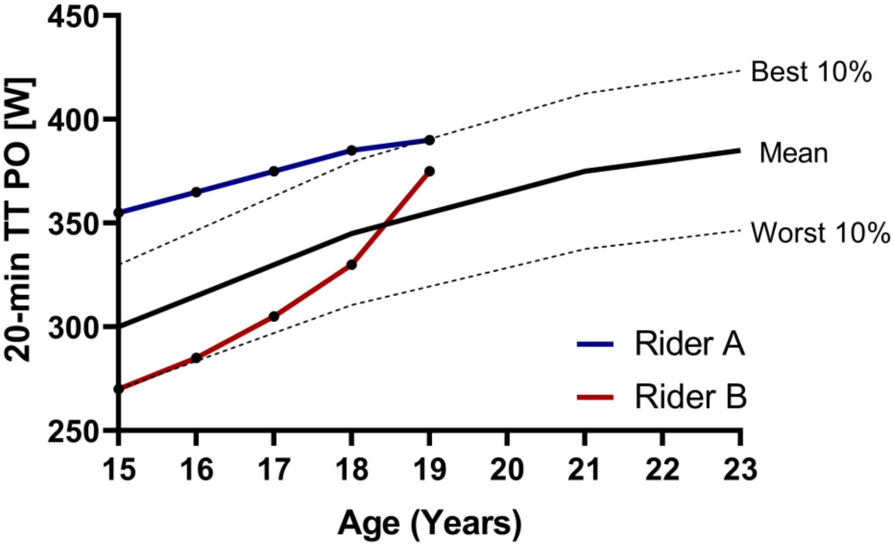

Figure 7.2: Simulated data of performance progression in the average power output (PO) during a 20-minute time trial.

Focusing solely on current performance at ages 18 and 19, rider A would be the best choice. However, in this figure, it can be clearly seen that rider B had a better performance development in the previous years and will probably be a better-performing cyclist in the future if he keeps progressing like this. Of course, this does not 100% guarantee that rider B will be a better choice, but as performance progression can be seen as an important determinant for future success [160], this could improve the process of talent identification.

Concentrating solely on physical factors and their impact on talent identification, it was shown in **Chapter 4** that there is a larger training effect for longer duration efforts (10 min) compared to shorter duration efforts (1 min). This is in line with the studies comparing U19, U23 and professional races showing similar maximal POs from 1 to 60 seconds, but higher POs at professional level for efforts longer than 5 minutes[15, 17]. This implies for talent identification that the POs up to 1 minute are to a lesser extent trainable and already give an indication at a young age of how the rider will be able to perform at the professional level. However, for longer duration efforts, there should be a better look at the expected improvement and trainability of the rider, to see if he would be able to reach professional level. Next to physical and maturation factors, it has also been shown within elite athletes that self-regulation of learning has high predictivity for potential performance development [161]. Self-regulation of learning includes the ability to set realistic goals, to reflect on training and performance, and to be motivated to make efforts to improve. Athletes with high self-regulation are taking responsibility for the progress they make. As this has high predictivity for potential development, it could make sense to include this in the talent selection processes in professional cycling. Other psychological requisites could also be thought of, such as self-motivation, being coachable, independence, competitiveness, mental toughness, and concentration [28]. Ideally, a combination of all of the above-named factors would be used to make the best possible prediction for talent identification.

In addition to the teams that execute the talent selection, there could also be a role for the International Cycling Federation; UCI, and the national federations. Suggested solutions for the RAE are, amongst others, rotating the cut-off dates of youth categories or determining the age categories based on biological rather than chronological age [157]. This could lead to a more ‘fair’ competition and consequently also to a fairer selection of talent. However, more research should investigate the effects of this as it will complicate the age structure in cycling substantially. Furthermore, in my opinion, the national federations play an important role in stimulating young cyclists to enjoy and continue enjoying cycling races, even if they are not the top performers at a given time. These cyclists may simply be later developers but could still reach a high potential in the future when they receive continued support. This includes facilitating the possibility for every cyclist to be competitive at their own level. The same could be stated for giving riders the opportunity to ride on different terrains so they can showcase their capacities. As this is not always possible for every young cyclist financially, there could be an important role for national federations in making this possible. Lastly, although it sounds simple, if there is no selection, there can be no selection biases. An increased focus on U19 (and even younger) teams and the increased presence of rider agents at younger ages will not help to prevent these biases. Therefore, in my opinion, the national federations should not focus on the early selection of young cyclists, but keep their focus on facilitating possibilities for riders of all levels.

Talent development

Once riders are selected for a development team, the goal of both the team and the rider is to develop them as much as possible so that they are able to make it to a professional career as cyclist. Based on this thesis, some recommendations can also be made focusing on talent development. Both **Chapter 4** and **Chapter 5** show that there is a larger training effect for longer efforts (10 min) compared to shorter (1 min) efforts and that there is a larger training effect for 'fatigued' compared to 'fresh' efforts. As the duration of races also increase from U19 to professional level from an average of 2.4 to 3.9 hours [15], this requires an improved endurance capacity and durability. Therefore, the endurance capacity of a young 18-year-old rider needs a lot of focus to improve, in order to be able to perform under the demands of the professional level later on. This requires an increase in training volume, as previously was shown that an increase in training volume was related with improvement in aerobic potential [24]. In order to reach this increased training volume, an increased session duration would be needed, which could also improve durability even more, as it has been suggested that regular exposure to a stimulus wherein durability is challenged is important in developing durability [22]. In order to avoid a too large increase in training load, with the risk of overtraining [106], the increase in training volume should be carefully managed. A suggestion for increasing the training volume without increasing the training load on the body too much could be to train with a polarised training philosophy [162]. By performing the low-intensity part of the training at a really low intensity, the rider will be able to handle a higher training volume without getting too fatigued because of a training load that is too high. Keeping some high-intensity training in the program would still be important to keep the anaerobic stimulus as most races are decided by a short effort [16], but the main focus should be on developing the endurance capacity. This might not always give the best results in the short-term in races, and therefore it is important that coaches and teams keep their riders involved and informed about the long-term goals and give them the time to develop physically. This training philosophy is also in line with the findings of **Chapter 4** and **Chapter 5**, showing the importance of low-intensity endurance training to be able to improve fat oxidation and therefore to save carbohydrates for the high intensity efforts at the end of a cycling race. However, this has implications for a rider's race program within a development team. As races have been shown to have a higher load compared to training [107], a balance must be found between being able to improve the endurance capacity in the long-term, and, at the same time, getting the tactical and mental experience of racing to improve this ability.

Obviously, the physical aspect of talent development is not the only factor that should be focused on, as multiple factors will play a role in the development of a cyclist towards professional level. Next to the above-named tactical and physical factors, mental factors can also play an important role in the development of a cyclist. For example, post-competition evaluation, imagery, relaxation, and self-talk are used to stimulate the mental aspect of development [23], but also the ability to pace an effort well seems an important skill in developing as an athlete [163]. Also, the possibility to get a variety of experiences, which can be different race experiences, but also meeting people from different cultures or travelling to new places, can help the athlete to get out of their comfort zone and give them more confidence and skills to handle new situations [23]. Within this process of physical and mental development, a coach has an important role to assist the rider in finding the optimal way to develop. Previously, it has been shown that the coach-athlete relationship is an important factor in a high training response [27]. In **Chapter 6** we showed that it is not straightforward that the coach and the athlete have the same intention and perception of the intensity of a training session. This highlights that it is very important that the coach and cyclist have a good relationship and spend a lot of time together to really understand each other. Even more as cycling is a sport where coaching is most of the time done remotely, which makes it harder to have a good connection. Therefore, a coach who is present at many training camps and races and takes the time to talk with and get to know the rider is an important prerequisite for the development of talent in professional road cycling.

Future Research

This thesis explored the framework for talent identification and development in U23 development teams in professional road cycling (Figure 7.1). Although the executed studies add some new information and understanding to this framework, there is still a lot unknown about talent identification and development in professional road cycling. First of all, it would be interesting to be able to distinguish between factors that can predict future performance (genetic prerequisites) and factors that can still develop. Related to this, it would be interesting to see if and what the important requisites are for the development of these factors and how the possible room for improvement (trainability) can be predicted. This requires a longitudinal research design that includes the collection of many variables that are suggested to play a role in talent development, such as physical, mental, and tactical capacities. The first step would be to collect this data and retrospectively analyse it, and the next step could be to apply changes to the talent identification and development process to investigate the consequences. Regarding the physical side of talent development, this thesis explored some interesting findings around durability in **Chapter 4** and **Chapter 5**, investigating durability in a standardised testing protocol. However, the concept of durability could still be explored further, especially on how to improve it. In **Chapter 5**, we retrospectively investigated the effect of training on durability, but most of the cyclists trained based on a similar training philosophy. It would be interesting to investigate durability in a training study, investigating groups with different training approaches. In addition, it would also be interesting to investigate other additional factors that contribute to durability, as for example mental fatigue/resistance and or rider type (sprinter vs climber). Also, with the data from our current studies, we were not able to fully predict durability based on 'fresh' performance parameters. This would of course be beneficial as it could prevent the need to execute a long testing protocol.

This thesis focused mostly on the physical side of talent development, but as mentioned before, many more factors can play a role. For example, tactical factors are not yet widely investigated, but play an important role in the outcome of a cycling race. Some studies investigated the tactics of sprinting [164, 165], but to my knowledge, there are no studies investigating the tactical skills in other situations in professional road cycling and whether this is a skill that can be developed or not. In addition, there could also be an interest in conducting further research on the environment of the cyclist. In **Chapter 6** we showed that the intention and perception of the training is not always the same by the cyclist and his coach, but it could be interesting to investigate if this also leads to a better or worse training effect. As autonomy has also been shown as an important requisite for talent development by stimulating intrinsic motivation [166], it could also be that sometimes not listening 100% to your coach but making your own decisions about the training can move you forward. This would provide insights into whether a strong coach-athlete relationship is truly necessary for performance improvement. Another role for further research could be focused on talent transfer from other sports to road cycling. Some recent examples, such as the Slovenian rider Primoz Roglic show that it is possible to transfer to a successful road cycling career at a relatively old age (24 years old). As cycling is technically not very demanding, this can open doors for talent transfer, as this is mostly easier from a high-skilled demand sport to lower skilled demand ones [167]. If the necessary requisites to switch to road cycling are detected, this could open doors for possible talent identification practices. Lastly, the current thesis only focused on talent identification and development in men's cycling, but it would also be interesting to explore this field in women's cycling. Especially as women's cycling has a slightly different structure, it could be interesting to investigate the differences between men's and women's cycling and the effect of this on talent development.

Conclusions

This thesis aimed to increase the knowledge about talent identification and development in professional road cycling focused on U23 development teams. Based on the findings in this thesis, it can be concluded that some selection biases occur in professional road cycling, based on the relative age and the weight and height of the cyclist. This shows that there is space to improve talent identification with the aim of selecting riders for a development team with the highest potential for future performances. In addition, we presented durability as an important factor for the measurement of physical talent development. Durability has a larger effect on efforts of shorter (1 min) compared to longer (10 min) duration and seems to change differently within the season compared to fresh POs. Also, there seems to be an important role for the maintenance of carbohydrate oxidation after accumulated load to maintain performance. Furthermore, similar training can have varying effects on fresh POs compared to fatigued POs, suggesting a polarised training approach for optimal physical development. Lastly, we showed the differences in the intention of the coach and the perception of the cyclist of the same training program, highlighting the importance of a good coach-athlete relationship for optimal talent development.

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English summary

Most of the teams in professional male road cycling consist not only of their professional team but also have an U23 development team. These development teams act on a semi-professional level and aim to detect (talent identification) and develop (talent development) young talents from the U23 category into professional cyclists. Both talent identification and development are based on multiple factors, including physical, tactical, and mental capabilities. This thesis aims to extend the knowledge about talent identification and development in professional male road cycling. Hereby focusing on U23 development teams acting at semi-professional level.

In **Chapter 2**, we investigated the presence of the relative age effect in (semi-) professional road cycling, especially focusing on the talent selection process for continental (CT) development teams. To do this, we analysed a database with 2854 riders that were part of a CT team between 2005 and 2016 out of the top 25 countries on the Procyclingstats (PCS) ranking. The included cyclists were distributed into four birth quarters (Q1, Q2, Q3, and Q4), their starting year at CT level ($U23_{year1}$, $U23_{year2}$, $U23_{year3,}$ and $U23_{year4}$), and it was noted whether the cyclist reached professional level or not (assessed in 2021). The distribution of the birth quarters was compared with an expected distribution based on the date of birth of the general population of representative countries. The results showed that a relative age effect was found for the total dataset, with an overrepresentation of riders in Q1 and an underrepresentation of riders in Q4. This was caused by the riders that did not reach professional level and even more specific, by the riders that started at CT level as $U23_{year1}$ and $U23_{year2}$. This effect was not seen for riders who were able to reach professional level. This all means that there is a selection bias when selecting riders for CT teams at the age of 19 and 20, favouring riders that are born in Q1 (January, February, March), at the expense of relatively younger riders out of Q4 (October, November, December). As this effect diminishes at professional level, it shows that this is mostly a selection error in development teams, which can give a relatively younger cyclist (Q4) fewer chances in his path to becoming a professional cyclist and therefore it is likely that talents born in Q4 are missed out within talent identification in professional road cycling.

Continuing the investigation of selection biases, we investigated in **Chapter 3** the influence of anthropometrics (weight and height) of cyclists in relation to the speciality (one day, climb, sprint, time trial (TT) and general classification (GC)) of the rider and the landscape of their home country. We collected body weight, body height, and PCS points from 1810 professional cyclists out of 15 countries, as well as the elevation span of those countries. To make an equal comparison, we normalised the body height based on the average body height of the countries' population and used the BMI to correct for body weight. The races the riders participated in were divided into 5 specialisations: one day, climb, sprint, TT, and GC races. We showed that the average anthropometric measures (body weight and body height) of professional cyclists in a country are correlated with the relative number of PCS points scored in GC, sprint, and climb races (but not with TT and one day races). This indicates that countries perform better in certain specialisations linked to the anthropometric characteristics of their riders. We also showed that countries with relatively larger and taller cyclists have a less mountainous (elevation span) landscape compared to countries with relatively lighter and smaller cyclists, also taking the above-named normalisations into account. This suggests a selection bias towards smaller/lighter or taller/heavier cyclists in various countries based on the terrain of the country. This would, for example, give a sprinter type who is heavier and taller a greater chance of reaching professional cycling in a mostly flat country compared to a light climber type. This can lead to reduced chances for some talented cyclists in the selection process for professional road cycling.

In **Chapter 4**, we focused on the physical aspect of talent development, especially investigating the role of durability in cycling performance. We investigated 16 semi-professional cyclists who were part of a CT team, who executed a performance test three times during a cycling season: PRE (December), START (February), and IN (July). This performance test included the measurement of TT performance (1 min and 10 min), both in a 'fresh' state and in a 'fatigued' state (also called durability) after burning 38.1±4.9 $kJ \cdot kg^{-1}$. Before the TTs (both in the 'fresh' and 'fatigued' state), the cyclists performed a standardised submaximal warm-up during which gross efficiency (GE), energy expenditure (EE), fat oxidation (FatOx) and carbohydrate oxidation (CarbOx) were measured. For the 1-min TT, the average power output (PO) significantly decreased from the 'fresh' to 'fatigued' state, while there was no change in the PO in the 10 min TT. During the season (from PRE to IN), the mean PO in the 10 min TT improved both in the ‘fresh’ (from 355±29 to 390±31 watt) and the ‘fatigued’ (from 346±27 to 387±33 watt) state. In the 1-min TT, there was a smaller decrease from the ‘fresh’ to ‘fatigued’ state over the course of the season (from PRE to IN) as the ‘fresh’ PO remained approximately the same (671±68 vs 667±72 watt) while the ‘fatigued’ PO improved (601±67 vs 629±73 watt). No change was found for GE and EE from the ‘fresh’ to the ‘fatigued’ state, while FatOx increased and CarbOx decreased at PRE and START. However, this effect diminished during the season showing no longer any significant change for FatOx and CarbOx at IN. Based on the outcomes, it can be concluded that TTs of 1 min are more affected by accumulated load compared to TTs of 10 min and that durability (‘fatigued’ TT of 1 min) and longer TTs (10 min) improve more during the season compared to ‘fresh’ performance and shorter TTs (1 min). This shows a similar pattern as the changes in substrate oxidation, which is therefore probably playing an important role in this. These outcomes are important for talent identification, as shorter efforts are less trainable compared to longer efforts and therefore a better predictor for future performances. In addition, it shows which parameters (longer efforts/durability in relation to substrate oxidation) are important to still develop for talented young cyclists.

As a follow-up to this study, we investigated in **Chapter 5** the relationship between training and TT performance, as assessed in the ‘fresh’ and ‘fatigued’ state, once again including the measurements of GE, FatOx, and CarbOx. To study this, we included 10 semi-professional cyclists who underwent a similar performance test as described in Chapter 4, before and after an 8-week training period. Training load during the 8-week training period was defined using multiple metrics: sRPE, kJ spent, LuTRIMP, Training Stress Score, Polarisation Index, and time spent in 3 zones based on the 1st and 2nd lactate threshold. No clear relationship was found between higher or lower training load and performance in the 1-min and 10-min TT. However, CarbOx in the ‘fresh’ state showed a *strong* correlation with training volume and CarbOx in the ‘fatigued’ state showed a *strong* correlation with time spent at a PO below LT1 intensity, which could suggest a polarised training strategy. Different trends were clearly observed in the relationship between training load and the change in performance between tests for ‘fresh’ and ‘fatigued’ performance. This suggests that similar training can have different effects on ‘fresh’ compared to ‘fatigued’ performance. Also, a lot of variation was shown between participants, showing that a single training load metric cannot predict performance improvements after an 8-week training period as probably many more factors play an important role in this. This has important implications for talent development, showing a potentially beneficial training strategy (polarised) for the development of durability. It also highlights the difficulties of managing the training load by solely using training load measures and therefore shows the importance of good communication between the cyclist and the coach.

Another possible explanation for the poor relationships between training load and performance change as found in **Chapter 5** was explored in **Chapter 6**, where we studied the coach-athlete relationship. To do this, we analysed 747 training sessions from 11 (semi-)professional male and female cyclists, all supervised by the same coach. The planned training intensity (iRPE) and training load (isRPE) set by the coach, was compared with the executed and perceived training intensity (RPE) and training load (sRPE) of the cyclists, using correlation , regression, and the typical error of estimate (TEE) analysis. The results showed *moderate* to *very large* TEEs between the executed and intended sRPE, which indicates that the training program was executed differently from the coach's plan. In addition, even when the training was executed in the duration as planned, *moderate* to *very large* TEEs were shown between the i(s)RPE of the coach and the (s)RPE of the cyclist, which shows that also the perception of the training session was different compared to the intention of the coach. The individual regression coefficients were different between participants, indicating that the perception of the same intended training session can differ between individual cyclists. It was also shown that, when dividing the sessions into three intensity zones, during the low- and high-intensity (but not moderate) sessions the cyclists' perceived intensity (RPE) was lower compared to the iRPE of the coach. This chapter highlights the importance of a good relationship between the cyclist and his coach to obtain optimal adaptations and shows the difficulties of pre-planning an ideal training program.

Based on the findings of this thesis, some suggestions for improving the talent identification and development process in professional road cycling are made in **Chapter 7**. It seems to be hard to make perfect predictions for the future, but shifting the focus to the individual progression of the cyclist rather than current performances is suggested to provide more valuable insights and could result in a higher predictivity for future performances. The investigated selection biases based on the relative age and the weight and height of the cyclist should be included in this as well as a correction factor. In addition, durability appears to be important in talent development and can, therefore, play an essential role in the selection of talent and tracking the physical development of the cyclist. In addition, it should be noted that talent development is an individual process with different individual learning curves. It therefore requires an individual approach to achieve maximal performances in the future.

Nederlandse samenvatting

De meeste professionele ploegen in het wegwielrennen voor mannen bestaan niet alleen uit een professioneel team, maar hebben ook een opleidingsploeg voor renners onder de 23 jaar. Deze opleidingsploegen opereren op semi-professioneel niveau en hebben als doel om jonge talenten vanaf de onder-23 categorie te scouten (talentidentificatie) en te ontwikkelen tot professionele wielrenners (talentontwikkeling). Binnen zowel talentidentificatie als talentontwikkeling zijn meerdere factoren belangrijk, waaronder fysieke, tactische en mentale capaciteiten. Dit proefschrift is gericht op het uitbreiden van de kennis over talentidentificatie en talentontwikkeling in het professionele wegwielrennen, waarbij de focus ligt op het mannen wielrennen. Hierbij werd er gefocust op de opleidingsploegen voor renners onder-23 jaar op semi-professioneel niveau.

In **Hoofdstuk 2** onderzochten we de aanwezigheid van het relatieve leeftijdseffect in het (semi-)professionele wegwielrennen. Het relatieve leeftijdseffect houdt in dat wielrenners die in Q1 (januari, februari, maart) zijn geboren ~10 maanden ouder kunnen zijn dan renners uit dezelfde leeftijdscategorie geboren in Q4 (oktober, november, december). Dit verschil in leeftijd kan een mogelijke voorsprong geven+

. Bij het onderzoeken hiervan richtten we ons met name op het talentselectieproces voor continentale (CT) opleidingsploegen voor renners in de onder-23 categorie. Hiervoor verzamelden we een database met 2854 renners uit de top 25 landen op de Procyclingstats (PCS) ranglijst die tussen 2005 en 2016 deel uitmaakten van een CT team. De geïncludeerde renners werden verdeeld in vier geboortekwartalen (Q1, Q2, Q3 en Q4), hun startjaar op CT niveau ($U23_{jaar1}$, $U23_{jaar2}$, $U23_{jaar3}$ en $U23_{jaar4}$) en er werd genoteerd of de renner was doorgestroomd naar professioneel niveau of niet (beoordeeld in 2021). De verdeling over de geboortekwartalen werd vergeleken met een verwachte verdeling op basis van de geboortedatum van de algemene bevolking van de representatieve landen. De resultaten lieten zien dat er een relatief leeftijdseffect werd gevonden voor de totale dataset, met een oververtegenwoordiging van renners in Q1 en een ondervertegenwoordiging van renners in Q4. Dit werd veroorzaakt door de renners die het professionele niveau niet bereikten en nog specifieker, door de renners die begonnen op CT niveau als $U23_{jaar1}$ en $U23_{jaar2}$ (19 & 20 jaar oud). Dit relatieve leeftijdseffect werd niet gezien bij renners die wel professioneel niveau hadden bereikt. Dit alles betekent dat er een selectievooroordeel is bij het selecteren van renners voor CT teams op 19- en 20-jarige leeftijd, waarbij renners die geboren zijn in Q1 (januari, februari, maart) bevoordeeld worden ten koste van relatief jongere renners uit Q4 (oktober, november, december). Aangezien dit effect afneemt op professioneel niveau, laat het zien dat dit vooral een selectiefout is binnen opleidingsploegen, waardoor een relatief jongere renner (Q4) minder kansen krijgt om professioneel wielrenner te worden.

Voortbordurend op het onderzoek naar selectievooroordelen, onderzochten we in **Hoofdstuk 3** de invloed van de lengte en het gewicht van wielrenners in relatie tot de specialiteit (eendagskoers, klim, sprint, tijdrit (TT) en algemeen klassement (GC)) van de renner en het hoogteverschil van hun thuisland. We verzamelden hiervoor de lengte, het gewicht en PCS-punten van 1810 professionele wielrenners uit 15 landen, evenals het hoogteverschil (hoogste punt min laagste punt) van die landen. Om een eerlijke vergelijking te kunnen maken, hebben we de lengte van de renners genormaliseerd op basis van de gemiddelde lengte van de bevolking van de desbetreffende landen en werd de body mass index (BMI) gebruikt om te corrigeren voor het lichaamsgewicht. We toonden aan dat de gemiddelde lengte en -gewicht van professionele wielrenners in een land gerelateerd zijn aan het relatief aantal PCS-punten die werden gescoord in klim, sprint, en GC-wedstrijden (maar niet met PCS-punten in eendagskoersen en TT's). Dit geeft aan dat landen beter presteren in bepaalde specialisaties op basis van de antropometrische kenmerken van hun renners. We toonden ook aan dat landen met relatief grotere en zwaardere renners een minder bergachtig landschap hebben in vergelijking met landen met relatief kleinere en lichtere renners, ook wanneer er rekening werd gehouden met de eerder genoemde normalisaties. Dit suggereert een selectievoordeel voor kleinere/lichtere of grotere/zwaardere wielrenners in verschillende landen op basis van het landschap van het desbetreffende land. Twee renners met vergelijkbare fysieke potentie kunnen dus verschillende kansen krijgen, afhankelijk van het land waarin ze zijn opgegroeid. Dit zou bijvoorbeeld een zwaardere en langere sprinter grotere kans geven om professioneel wielrenner te worden wanneer hij geboren is in een overwegend vlak land, ten opzichte van als hij geboren zou zijn in een bergachtig land. Dit kan leiden tot verminderde kansen in het selectieproces voor sommige getalenteerde wielrenners.

In **Hoofdstuk 4** richtten we ons op het fysieke aspect van talentontwikkeling, waarbij we de rol van presteren onder vermoeidheid in het wielrennen (durability) bestudeerden. We onderzochten 16 semi-professionele wielrenners die deel uitmaakten van een CT team, die drie keer tijdens één wielerseizoen een prestatietest uitvoerden: PRE (december), START (februari) en IN (juli). Deze prestatietest omvatte het meten van tijdritprestaties (1 en 10 minuten), zowel in een 'uitgeruste' als 'vermoeide' toestand (ook wel 'durability'). De 'vermoeide' toestand werd bereikt door het uitvoeren van een vermoeidheidsprotocol dat zorgde voor het verbranden van 38.1 ± 4.9 $kJ \cdot kg^{-1}$ aan energie. Voorafgaand aan de tijdritten (zowel in 'uitgeruste' als 'vermoeide' toestand) werd er ook een gestandaardiseerde submaximale warming-up uitgevoerd waarbij de efficiëntie (GE), het energieverbruik (EE), de vetverbranding (FatOx) en de koolhydraatverbranding (CarbOx) werden bepaald. Voor de tijdrit van 1 minuut nam het gemiddelde vermogen (PO) significant af van 'uitgeruste naar 'vermoeide' staat, terwijl er geen significante verandering was in de PO in de tijdrit van 10 minuten. Gedurende het seizoen (van PRE naar IN) was er meer verbetering in de tijdrit van 10 minuten in vergelijking met de tijdrit van 1 minuut, wat werd geobserveerd in zowel de 'uitgeruste' (van 355±29 naar 390±31 watt) als de 'vermoeide' (van 346±27 naar 387±33 watt) staat. In de tijdrit van 1 minuut was er in de loop van het seizoen (van PRE naar IN) een kleinere afname van de 'uitgeruste' naar de 'vermoeide' staat omdat de 'uitgeruste' PO ongeveer gelijk bleef (671±68 naar 667±72 watt), terwijl de 'vermoeide' PO verbeterde (601±67 naar 629±73 watt). Voor de fysiologische parameters EE en GE werd er geen verandering gevonden van de 'uitgeruste' naar de 'vermoeide' staat, terwijl de FatOx toenam en de CarbOx afnam tijdens PRE en START. Dit effect nam echter af gedurende het seizoen, waarbij er uiteindelijk geen significante verandering meer werd gevonden voor FatOx en CarbOx tijdens IN. Op basis van de uitkomsten kan worden geconcludeerd dat tijdritten van 1 minuut meer worden beïnvloed door opgebouwde belasting/vermoeidheid vergeleken met tijdritten van 10 minuten. Gedurende het seizoen verbeterde de 'durability' ('vermoeide' tijdrit van 1 minuut) en de langere tijdrit (10 minuten) meer in vergelijking tot de 'uitgeruste' prestaties en de kortere tijdrit (1 minuut). Dit liet hetzelfde patroon zien als substraatverbranding, dat dus waarschijnlijk een belangrijke rol speelt in de afname van prestaties met vermoeidheid.

Als vervolg op deze studie onderzochten we in **Hoofdstuk 5** de relatie tussen training en tijdritprestaties, zowel in 'uitgeruste' en 'vermoeide' staat, met opnieuw de metingen van GE, FatOx en CarbOx inbegrepen. Om dit te onderzoeken includeerden we 10 semi-professionele wielrenners die een prestatietest ondergingen zoals beschreven in Hoofdstuk 4, zowel voor als na een trainingsperiode van 8 weken. De trainingsbelasting tijdens deze trainingsperiode werd gedefinieerd aan de hand van meerdere maten voor trainingsbelasting: session Rating of Perceived Exertion (sRPE), totale energie (kJ), Lucia's training impulse score (LuTrimp), Training Stress Score, Polarisatie Index en de tijd gespendeerd in 3 zones gebaseerd op de 1^e en 2^e lactaatdrempel. Er werd geen duidelijk verband gevonden tussen een hogere of lagere trainingsbelasting en prestaties op de 1 en 10 minuten tijdrit. Echter, CarbOx in de 'uitgeruste' staat vertoonde een *sterke* correlatie met het trainingsvolume en CarbOx in de 'vermoeide' staat liet een sterke correlatie zien met de gespendeerde tijd op een intensiteit onder de 1^e lactaatdrempel. Dit zou een gepolariseerde trainingsstrategie kunnen suggereren, wat inhoudt dat een groot deel (~80 %) van de trainingen op lage intensiteit wordt uitgevoerd in combinatie met een klein deel (~20%) op hoge intensiteit, en vrijwel geen trainingen op gemiddelde intensiteit. Er werden duidelijk verschillende trends waargenomen voor prestaties in 'uitgeruste' en 'vermoeide' staat in relatie tot de trainingsbelasting. Dit suggereert dat dezelfde training verschillende effecten kan hebben op 'uitgeruste' en 'vermoeide' prestaties. Ook was er veel variatie te zien tussen de deelnemers, waaruit blijkt dat er niet één enkele maat voor trainingsbelasting in staat is om prestatieveranderingen na een trainingsperiode van 8 weken te voorspellen, omdat er waarschijnlijk veel meer factoren zijn die hier een rol in spelen.

Een andere mogelijke verklaring voor de beperkte relaties tussen trainingsbelasting en prestatieverbetering in **Hoofdstuk 5** werd onderzocht in **Hoofdstuk 6**, waar we de relatie tussen coach en atleet bestudeerden. Hiervoor analyseerden we 747 trainingen van 11 (semi-)professionele mannelijke en vrouwelijke wielrenners, allemaal getraind door dezelfde coach. De geplande trainingsintensiteit (iRPE) en -belasting (isRPE) van de coach, zoals gemeten met de RPE-score, werd vergeleken met de uitgevoerde en ervaren trainingsintensiteit (RPE) en -belasting (sRPE) door de wielrenners. Hiervoor werden correlaties, regressies en de 'typical error of the estimate' (TEE) gebruikt. De resultaten toonden *middelgrote* tot *zeer grote* TEE's tussen de uitgevoerde en de beoogde sRPE, wat aangeeft dat het trainingsprogramma anders werd uitgevoerd dan de planning van de coach. Bovendien werden er, zelfs als de training volgens plan werd uitgevoerd, *middelgrote* tot *zeer grote* TEE's gevonden tussen de iRPE en isRPE van de coach en de RPE en sRPE van de wielrenner, wat laat zien dat de perceptie van de training ook verschillend was in vergelijking met de beoogde intensiteit. Ook de individuele regressiecoëfficiënten verschilden tussen de proefpersonen, wat aangeeft dat de perceptie van dezelfde geplande training kan verschillen tussen verschillende wielrenners. Ook werd er aangetoond dat bij het verdelen van de trainingen in 3 intensiteitszones, de ervaren intensiteit (RPE) lager was voor de wielrenner in vergelijking met de iRPE van de coach voor de trainingen met lage en hoge (maar niet gemiddelde) intensiteit. Dit hoofdstuk benadrukt het belang van een goede relatie tussen de wielrenner en zijn coach om de prestaties van de wielrenner te optimaliseren en laat zien hoe ingewikkeld het is om vooraf een ideaal trainingsprogramma te plannen.

Op basis van de bevindingen van dit proefschrift worden in **Hoofdstuk 7** enkele suggesties gedaan om talentidentificatie en -ontwikkeling in het professionele wegwielrennen te verbeteren. Het blijkt lastig om perfect te voorspellen welke wielrenners in de toekomst goed zullen presteren, maar het verleggen van de focus van huidige prestaties naar de individuele progressie van de wielrenner wordt gesuggereerd om meer waardevolle inzichten te verschaffen. Hierbij zouden ook het onderzochte relatieve leeftijdseffect en het effect van lengte en gewicht als correctiefactor binnen talentidentificatie mee genomen moeten worden. Daarnaast blijkt ‘durability’ belangrijk te zijn voor het meten van wielerprestaties en kan daarom een belangrijke rol spelen in de selectie van talent en het volgen van de fysieke ontwikkeling van de wielrenner. Er moet ten slotte worden opgemerkt dat talentontwikkeling een individueel proces is met verschillende leercurves. Daarom is een individuele aanpak binnen talentontwikkeling vereist om in de toekomst optimaal te kunnen presteren.

List of publications

Voet, J.G., Lamberts, R.P., de Koning, J.J. & van Erp, T. (2022). The role of the relative age effect on talent identification in professional road cycling. *Journal of Sports Sciences, 40*(19), 2159-2165. DOI: 10.1080/02640414.2022.2144877

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