Case study: A Finnish junior's eight-year road to cycling's World Tour

Jamie Given

Bachelor's Thesis
Degree Programme in Sports and Leisure Management
2019

Abstract

Date

Author(s) Jamie Given	
Degree programme in Sports and Leisure Management	
Report/thesis title Case study: A Finnish junior's eight-year road to cycling's World Tour	**Number of pages and appendix pages** **47 + 11**

The most elite level in road cycling is the World Tour. The World Tour is only reachable to a small number of exceptionally talented riders. Getting a contract with a World Tour team mostly rest on the performance and results made between the ages of 19-23. To get to this point most young riders will start from childhood with participation in athletics and dedicate many years to training, competition and improvement.

The purpose of this study was to investigate how the participant's training characteristics developed over an eight-year period, that saw the athlete develop from a 14-year-old junior mountain biker to a 22-year-old professional road cyclist, riding in the World Tour. This study attempts to provide a longitudinal description of the athlete's maturation to elite status.

The research questions asked how the athlete's training had evolved between the years of 2012 – 2019 in terms of a) training volume, b) competition volume c) training intensity distribution and d) performance in competition. This study looks retrospectively at the athlete's training to answer the question how did the athlete developed from a junior to World Tour professional?

The study is based a retrospective analysis of a) self-reported training that the athlete made between the years of 2012 – 2019, b) publicly available race data that was collected from the web, and c) an interview with the athlete. In following sections is outlined how the data for each of the parts mentioned above were collected and how they relate to the aim and the research questions.

Training volume and competition volume progressively increased over the eight years of the study. The athlete selected a pyramidal training intensity distribution based on time in heart rate training intensity zones. Annual top 10 finishes were compared with annual race days. Top 10 finishes were unlikely both in years where the athlete was the youngest rider and in between 2018 and 2019 when he was racing in top amateur level and World Tour. Yet the athlete was able to make several top 10 finishes in DN1 and one top 10 finish at the World Tour level.

This study had it's limitations but it was also a useful discription of how a young athlete progressed from junior to World Tour professional. This progression was shown across all the areas set out in the research questions

Keywords
Fincycling, Endurance, Development, Training Intensity Distribution, World Tour, Cycling

Table of contents

1 Introduction

The road to professional sports is long and for young talent there is no map showing them the best route there. In fact, research on talent development tells that every future professional must find their own roads to the professional level (Elferink-Gemser 2011, 683). It may seem obvious that this process starts early between 6 – 7 years of age, through childhood participation in athletics. If these children continue year after year to make progress and improve at around 25 – 29 years of age they will finally reach their peak performance age (Haugen et al. 2018, 1122; Menting et al. 2019, 2). This gives an idea of the vast dedication and determination needed to reach the premier level of professional sports.

The premier elite level in road cycling is the World Tour (WT). It is only reachable to an exclusive number of exceptionally talented cyclists and getting a contract with a WT team mostly depends on performance and results made between the ages of 19 – 23. This is a short and critical period and to make the most of it, riders must be able to perform at a high level already by 19 years of age (Svendsen et al. 2018, 1287-1288). Unfortunately, there is a lack of information to guide us on how we can prescribe training to 16 – 18-year-old junior cyclists to give them the best chance to succeed as an U23 rider and ultimately reach the World Tour. Svendsen's group also reported that the junior athletes in their study that went on to become World Tour professionals were riding between 600-800 hours per year by age 18. It was also noted that 70 – 120 hours of their annual volume was competition (Svendsen et al. 2018, 1291). The annual training volumes of World Tour professionals have been reported to be between 900 – 1000 hours per year driving some 30,000 – 35,000 annually with 70 – 100 competition days each year (Lucia et al. 2001; 326; Van Erp et al. 2019, 7). The Tour de France is raced over 21 days and covers 3,500 km, the fastest riders will use between 80 and 100 hours to complete the race. Ultimately, this is the progression young riders must make and more information how this progression happens is needed (Lucia et al. 2001, 326).

The purpose of this thesis is to investigate how the training characteristics of the participant evolved over an eight-year period (2012-2019) which took this athlete from a talented junior focused on mountain bike events to a World Tour professional. This thesis is a longitudinal description of the participants maturation to elite status. It is the opinion of the author that this thesis could be a valuable example to future generations of cyclist on the road to elite performance since it addresses some key issues related to talent development and the training characteristics of elite endurance athletes.

The idea for this thesis starts already back in the spring of 2018. I had just started working with Fincycling as part of an educational work practice. Since the spring of 2014 Fincycling has been providing junior cyclist (16–18 years of age) from Finland an international race calendar that takes these young riders to number of the most prestigious international junior races on the UCI calendar. Typically, Fincycling will travel to about 10 international races per year between April – September which equals about 25 race days per season at the highest level of junior cycling. In 2015 an agreement between Fincycling and the national cycling federation (Suomen Pyöräily) was reached that saw Fincycling take responsibility for all junior national team activities. Fincycling works in co-operation with Finnish Cycling to develop the country's young talent.

My work with Fincycling and being around junior athletes has got me interested in how junior road cyclists should organize their training and competition to best facilitate a progression to the next level of cycling. In the autumn of 2018, it was announced that the participant of this study had signed a contract to ride with a World Tour Team in 2019. The participant was a member of the Fincycling team, racing for them during the 2014 – 2015 seasons. He is now the first rider to come through the development team and go on to race in the World Tour. It was through Fincycling the opportunity for this study came up as they contacted the athlete and put us in contact to discuss what could be possible. The first time I spoke with the athlete was in the summer of 2019, he was in Finland recovering from injuries he had sustained during a race when a motorcycle working for the organizer collided with him. He was just starting to train again with long sessions of easy riding to build up his endurance and do what he could do. Before long he was back racing in Europe with a full schedule of racing until mid-October. In the beginning of November 2019, I was able to connect with the athlete for an interview and his training and racing data were made available to me. This study reports seven-years' worth of training data which equals almost 5000 hours of training and close to 30,000 km of competition across 300 races.

The first part of this thesis lays the foundation for everything that follows by introducing the physiological factors involved in endurance performance. The traditional performance model introduced by (Joyner & Coyle 2008, 37) shows how multiple physiological factors such as VO2max, the lactate threshold and efficiency interact to determine performance velocity or power output and why this is important to endurance performance.

The next section opens current scientific perspectives on the endurance training process. The training in all endurance sports largely aimed at improving the athletes' aerobic capacity. The simple reason for this is about 95% of the energy used to power continuous activity lasting longer than 30 minutes is derived from aerobic energy conversion Åstrand et al. (2003, in Tønnessen 2010, 4). It appears that positive changes in aerobic capacity are determined by the intensity of the exercise; the frequency of the sessions; the durations of each session; the length of the training programme; and the initial fitness level of the subjects (Wenger & Bell 1986, 347). This thesis looks at how elite endurance athletes typically organize their training to reach higher levels of performance.

Then we review case studies that have shared how world-class athletes put the science of training into practice and what training process seems to produce the most champions. It is impossible to compare athletes from one sport to athletes from another when looking at training characteristics. Training volume is a great example of this because the muscular loading characteristics of running make it impossible to run 700-800 km per week but of course this is quite normal for cyclist in the general preparation phase. (Seiler & Tønnessen 2009, 43-44.) Thus, this section breaks up the sports into running, XC skiing and cycling and will show what is normal for the top athletes in those sports.

The final section of this thesis is a case study or descriptive study of a young cyclist's seven-year road to cycling's world tour. Here is presented his training and competition data from 15 – 22 years of age. In 2012 when the study begins, he is dreaming about becoming a professional mountain biker and he is competing in XCO and marathon events. In 2015 he sees more opportunities for him in road cycling and make the switch to road racing. By the end of the study he has completed his first season as professional road cyclist in the World Tour. The discussion aims to describe how the participant organized his training and competition from 15 to 22 years of age and show his progression from junior to World Tour Professional. The author also wants to highlight the years of investment and effort that the participant has put towards becoming one of the best in the sport. Even though the participant might say "he was just having fun."

2 The Physiology of Endurance Performance

2.1 Determinants of Endurance Performance

Athletes are constantly redefining the boundaries of human performance as the rest of us watch with amazement. Most recently a boundary that most people thought of as the ultimate limit of human performance was broken when Eliud Kipchoge crossed the finish line of the INEOS 1:59 Challenge in Vienna, becoming the first human to cover the distance of a marathon in under two hours. Consider for a moment that in order to run the 42.195 km in the time of 1:59:40, Kipchoge would have to maintain a running speed of 21.2 kilometres per hour for almost 2 hours. This is a pace of 2 minutes and 50 seconds per kilometre or to be more exact 5.88 meters per second. A speed that most people could only run for a few seconds.

Almost 30 years before Kipchoge would run a marathon in under two hours a scientist by the name of Michael Joyner was using computer modelling to explore the limits of endurance running which he thought could be quantified with three physiological parameters: the aerobic capacity, also referred to as maximal oxygen consumption or VO2max, which one could visualize as the size of the athlete's "engine". The so-called lactate threshold which is the aerobic to anaerobic transition point that dictates how much power the engine will be able to sustain over long periods of time and then there is efficiency which we still don't know a lot about but is thought of as the engines fuel economy. (Joyner 1991, 683; Hutchinson 2018, 2-3.) When researchers started to measure these values in elite marathon runners, they observed very good values in all three parameters and exceptional values in one or two. (Joyner1991, 685.) Joyner used this information to model a runner that had exceptional values in all three parameters (the "ideal runner") and his model predicted that this runner would be capable of running a marathon time of 1:57:58 (Joyner 1991, 685).

Some years later Joyner and Coyle teamed up to expand on each other's work and together they published a review that was centred around performance VO2. Which is based off what Hill referred to as performance velocity. They explained that there is an interaction between an individual's VO2max, and their lactate threshold and that point is what was termed performance VO2 and defined as the highest level of oxygen consumption that can be maintained for several hours. (Joyner & Coyle 2008, 38.) In this same paper they also presented a conceptual framework shown in (Figure 1.) This explained how several physiological factors interacted with their performance parameters and formed performance VO2.

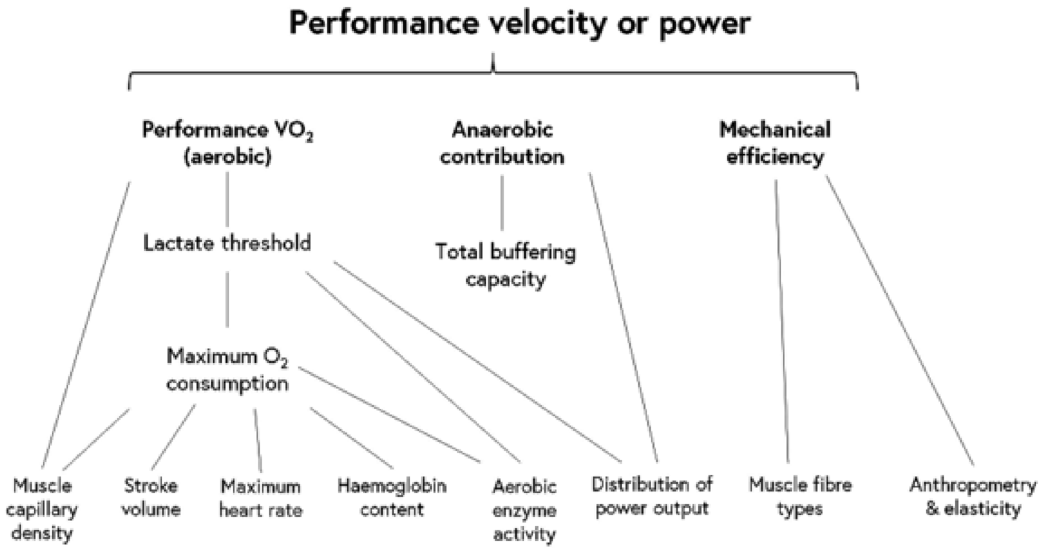


Figure 1. Joyner and Coyle's Performance Model: An over-all schematic of the interaction of multiple physiological factors that determinants performance velocity or power output Michael J. Joyner1 and Edward F. Coyle

It should be said that the information discussion in this thesis mainly focuses on the physiological capacities of elite endurance athletes unless otherwise mentioned. It is important to remember that elite endurance athletes as a group most likely represent the upper limits of human performance, for comparison it is well known that VO2 max values in elite endurance athletes are around 50–100% greater than those seen in normal active healthy young individuals of similar age and sex (Jones 2006, 103; Joyner and Coyle 2008, 37.) Sebastian Weber gives a great example of this in an analysis of Kipchoge's 1:59:40 performance in Vienna. Weber estimated that to run at a speed of 5.88 metres per second would require an oxygen demand of 75.4 ml min^{-1} kg^{-1}. Most recreational runners have VO2 values below 75 ml min^{-1} kg^{-1}. This means that Kipchoge was able to maintain a speed for almost two hours that most people could not even tolerate for a few seconds. (Weber, 2019.)

2.2 Maximal Oxygen Consumption

In the 1920s a scientist by the name of A.V. Hill recorded the first reliable measurements of maximal oxygen consumption better known as VO2max. These first experiments to measure an individual's maximal endurance capacity involved participants running around an 85-metre grass track in Hill's garden. To measure oxygen consumption, they used large airbags that could be worn on the participant's back, from the airbag ran a breathing tube and mask which was worn by the participants. As the participants ran around the track at increasing intensities, they would consume more and more oxygen from the bag. (Hutchinson 2018, 22-24.) The big observation was, there is a linear relationship between exercise intensity and oxygen consumption until a certain point. At that point the runners could still increase their running speed, but oxygen consumption appeared to plateau. Hill called this plateau maximal O2 intake which is a direct translation of what he observed in his research. Hill wrote that *"oxygen intake reaches a maximum beyond which no effort can drive it."* This is VO2max which Hutchinson describes as (Bassett 2002, 1573; Hutchinson, 2018, 22-24).

"A pure objective measure of endurance capacity that is, in theory, independent of motivation, weather, phase of the moon, or any other possible excuse". (Alex Hutchinson 2018, 23-24)

Through his work Hill had concluded that VO2max was ultimately limited by the heart and circulatory system and that some athletes were just blessed with "bigger engines". As the science has evolved so has our understanding. Figure 1. shows that VO2max is influenced by cardiac stroke volume, increased blood volume and haemoglobin content, increased capillary density, mitochondrial density and aerobic enzyme activity in the trained muscles (Costill et al. 1976, 105; Joyner & Coyle 2008, 37; Sjödin & Svedenhag 1985, 84). From these factors, the most important one is stroke volume (Coyle et al. 1984, 1857; Martin et al. 1986, 988). The development of these components above increase an individual's ability to deliver key nutrients, remove by products of the metabolisms and aids in thermoregulation. (Joyner & Coyle 2008, 39.) There is of course a genetic component to the VO2max, but long-term endurance training can have a significant positive effect on VO2max and thus endurance performance.

While it is true that VO2max is associated with endurance performance this can only be said for groups of mixed performers where a wide range of VO2max values are seen. In these groups the individuals with the highest values will have a clear advantage over the individuals with the lowest values. In groups of elite athletes where almost all individuals have similar values, VO2max is not a great predictor of performance and factors such as performance VO2 and efficiency become better determinates of endurance performance.

This means that a high VO2max is necessary, but it is not enough to explain success at the elite level. (Haugen, Paulsen, Seiler and Sandbakk 2018.)

It has been reported that at the elite level maximum oxygen consumption (VO2max) values can range between 70-85 ml kg^{-1} min^{-1} in male distance runners, cross country skiers and cyclists. The highest values reported have been between 90-96 ml kg^{-1} $min^{-1.}$ (Jones 2006, 107-108; Haugen et al. 2018). VO_2 max values in women are typically around 10-15% lower on average than men and this is mainly due to lower haemoglobin concentrations, smaller body size and higher levels of body fat (Joyner & Coyle 2008; Jones, 2006). The highest VO2max values reported in women have come from world cup medal winners in cross-country skiing and are between 70-80 ml kg^{-1} min^{-1}. According to Haugen et al. (2008,) VO2 max values of 70 ml kg^{-1} min^{-1} in women appear to be necessary to be competitive internationally at the elite level in both cycling and long distance running and orienteering.

In his sweat science column author Alex Hutchinson (2019) writes about Oskar Svendsen's recording the highest-ever VO2max. At 18-years-old, the Norwegian cyclist recorded a VO2max of 96.7ml kg^{-1} min^{-1}. One month after the test he would win a gold medal in the junior men's individual time trial at the World Championships. Svendsen's got his first bicycle when he was 15 years old. His routine was 2-3 bike weekly bike sessions during the summer to help him maintain condition for his real passion alpine (downhill) skiing.

Through his school Svendsen took his first VO2max test and for an untrained teenage the results were exceptional 74,6ml kg^{-1} min-1. This result got him invited to the national development programme. From here Svendsen would get serious about his training and after six months he recorded an 83.4ml kg^{-1} min^{-1}, A year after that his VO2max increased to 86.8ml kg^{-1} min^{-1}. At age 18 he recorded a 96.7ml kg^{-1} min^{-1}. They tested him one more time that year well into his off season and his value was 92.8ml kg^{-1} min^{-1} During this test he was already enjoying the off season and was 2.2kg heavier than the last time he tested.

Svendsen went on to ride for a Norwegian under 23 team which has sent several riders to the World Tour. During the two years he raced for that team he showed signs of real promise, but also had his share of disappointment. At 20 years old he decided to walk away from cycling and focus on school. Svendsen was tested one more time after a 15-month break with no structured training. His VO2max value had almost returned to baseline. In that last test he recorded a 77ml kg^{-1} min^{-1} quite close to the first values he recorded as 16-year-old.

In Svendsen's case he started with a naturally big VO2max, with training he improved a lot. Svendsen's major weakness according to Hutchinson (2019) was his efficiency on the bike, while he had the ability to produce huge amounts of energy, he lacked efficiency and the ability to produce big power numbers over the longer durations seen in professional competitions. Svendsen is a good example that a high VO2max may be necessary but does not guarantee success at the elite level.

2.3 Lactate Threshold and Performance VO2

When scientist started to notice that elite endurance athletes have high VO2max values and that athletes with the highest values are not always the most successful. They started to question whether VO2max was the key predictor of success in endurance activities that they had originally thought. Scientist started looking at other factors that could explain endurance performance. Hill had suggested that there was a sub-maximal performance velocity or "fractional utilization" of the VO2max that an athlete could sustain for a long time. (Joyner & Coyle 2008, 36-37.) Joyner, a leading expert in human performance became very interested in the predictive power of the lactate threshold during his time as an undergraduate student. His studies as a student and researcher proved to him that in principle an improvement in aerobic capacity can be achieved through either a higher maximum oxygen uptake (VO2max), or through better utilization of VO2max. The latter being an incredibly accurate predictor of marathon finish time. (Hutchinson 2018, 32-33)

Performance VO2 is simply the highest oxygen consumption that can be sustained for an extended time. Joyner (2008) explains that an individual's VO2max sets the upper limit of their aerobic metabolism while the blood lactate threshold defined as the intensity at which lactate starts to rapidly accumulate in the blood, exceeding the muscle's ability to clear it. The next piece of the puzzle is how efficiency appears to interact with the VO2 max and the lactate threshold to determine the performance velocity or power at lactate threshold. In distance running "*this speed is generally a speed similar to (or slightly slower than) that sustained by individual runners in the marathon:"* (Joyner 1991, 683.) The higher this aerobic to anaerobic transition intensity is (as a percentage of VO2max) the faster the athlete can go for an extended period. (Joyner and Coyle, 2008, 35-44.)

The lactate threshold is highly correlated to endurance performance in heterogenous groups, (similar performance levels) even more so than maximum oxygen consumption or VO2 max (Coyle 1999, 182). It makes sense that in groups of elite level performers where all competitors have large aerobic capacities, the individuals with the ability to use and maintain the highest percentage of their VO2max over the longest time certainly possess an advantage. A good example of what elite athletes are capable of is found in a study by Coyle (1999, 183) where he reports that in events lasting approximately two to three hours such as the marathon, elite marathon runners typically run at a slightly higher than average intensity (~75% of VO2max) than their lactate threshold (~70% of VO2max). (Coyle 1999, 183.) In another study published by Coyle he reports that in an event such as cycling's hour record, trained elite cyclists typically maintain an intensity between 85-95% of VO2max. This is well above their lactate threshold which is estimated to be reached around 73 – 84% of VO2max. (Coyle et al. 1999, 184-185.)

The physiological determinants of the lactate threshold are complex, and a full explanation is not within the scope of this thesis. However, the main component of the lactate threshold seems to be the oxidative capacity of the skeletal muscles. This increase in oxidative capacity as a result of long-term endurance training has been linked to the high lactate threshold values seen in elite endurance athletes. The reason behind this increase in oxidative capacity is the idea that long term endurance training has been reported to increase both the number of mitochondria and their effectiveness. Mitochondrial aerobic enzyme activity is a major determinant of Lactate Threshold VO2. (Hopker and Jobson, 2012, 7-13.)

A clear example of the trainability of the lactate threshold and performance VO2 is made when comparing the capacities of untrained individuals to elite athletes. In untrained athletes the lactate threshold can be reached already at 50% of VO2max but in highly trained elite endurance athletes the lactate threshold might be as high as 80-90% of VO2max. Most likely the individual who can hold the highest percentage of VO2max (performance VO2) for an extended amount of time will also have the better performance. Holloszy and Coyle write that training this capacity at the correct intensity for 20-120 min can over time more than double the lactate capacity in individuals. (Holloszy et al. 1977, 442; Holloszy & Coyle 1984, 831-832.) Many other studies have shown that exercising at or slightly above the lactate threshold can improve both aerobic capacity and the lactate threshold (Ghosh, 2004, 24-36). Performance VO2 and the lactate threshold are highly trainable, and athletes and coaches stand to gain a good amount of performance by dedicating some time to developing this capacity during the training year.

2.4 Efficiency

The final component of Joyner and Coyle's performance model has been termed "economy or efficiency". Efficiency makes a significant contribution to endurance exercise performance. Joyner and Coyle define efficiency as how much speed or power can be generated for any given level of oxygen consumption (Joyner & Coyle 2008, 40). In the book Performance Cycling (2012, 16-18). Coleman explains efficiency with the example of two athletes working at the same level of physical stress. The athlete that can produce a higher speed or power output for the exact same energy cost is more likely to have the better performance. Efficiency can also be looked at as the energy cost in individuals for a given speed or power output. The story of Oskar Svendsen showed that he had a huge aerobic capacity that allowed him to produce a lot of energy, but his efficiency was poor, this means his energy cost for riding at a given intensity was greater than many of the people who had smaller VO2max values than him. This is one explanation for why this rider never reached his full potential. An interesting question is would he be able to improve his economy if he had kept going a few more years? In a study, Coyle and his team made a group of trained endurance cyclists' cycle at 300W and found that efficiency in individuals varied from 18,5 to 23,5%. The study concluded that more than half of the variability was related to the percentage of slow twitch muscle fibres of the vastus lateralis muscle. (Coyle et al. 1992, 782-783.) While others have researched gross mechanical efficiency in distance runners and found that at given speeds efficiency can vary about 30-40% between runners (Farrell et al. 1979, 340-342; Conley and Greenbul 1980,360).

Several studies researched the relationship between efficiency and cadence in cyclists. These studies found that type 1 (slow twitch) fibres displayed greater mechanical efficiency at cadences of 60-120 revolutions per minute (rpm). While another study showed that elite endurance cyclists tend to have more type 1 muscle fibres. Then there was a study that researched self-selected pedal cadence of champion cyclists which reported that most of them prefer or self-select a cadence of around 90 rpm. This cadence may increase whole body oxygen consumption, slightly raising the cyclists VO2 max output. This didn't appear to be present at lower cadences of 50–60 rpm. These studies support other research that found that champion endurance cyclist is more efficient than their peers. (Joyner & Coyle 2008, 40.) A good illustration of just how much efficiency can help the performance of an athlete is presented by Coleman he writes that typical efficiency vales from 16-24% are observed in cyclists. If we take two riders at each end of these extremes and fix their oxygen cost at 3l per min and fuel use of approximately 94 per cent carbohydrate and 6 percent fat. Rider 1 who is 16% efficient would produce 168W and rider 2 who is 24% efficient would produce 252W. In this example that for each percentage point in efficiency the cyclist can gain about 10W. (Hopker & Jobson 2012, 17-18.)

Researches have made many different investigations on the topic of efficiency, studying it from both the physiological and mechanical components, the degree to which efficiency can be improved with training is currently unknown. It has been generally believed until several years ago that efficiency did not improve with training (Moseley et al. 2004, 377). Paavolainen's and his colleagues along with Millet's team showed that slight improvements to efficiency could be seen after months of explosive type strength training. (Paavolainen et al. 1999, 1530-1532; Millet et al. 2002, 1356.) Other researchers believe that the key factor is the athlete's body size. Simply said that larger riders typically must move more body mass than smaller riders and that comes at an energy cost (Hopker & Jobson 2012, 17-18). There is still a lot that is not understood about the efficiency, but it is know that it plays a significant role in the determinants of performance.

2.5 Pacing Behaviour and Self-Regulation

In a recently published research Menting et al studied the role of pacing and self-regulation in the development of elite level athletes. Their research found that although there are many different roads to reaching the elite level in adulthood. Elite athletes must first invest many years in their development acquiring and refining skills through training and competition. It has been hypothesized that failure to acquire or refine certain skills could be a reason why some junior champions fail to succeed as adults. (Menting et al. 2019, 1-2.) One way to measure an athlete's commitment is the time they spend on training and improvement. A research by Haugen and colleagues reports that elite athletes may being participation in sports from as early as the age of six or seven years old, and typically won't reach peak performance until an age of 24,5 to 29 (Haugen et al. 2018).

A factor of great interest is how elite athlete makes decisions regarding their regulation of effort over time, this has been termed pacing behaviour (Haugen et al. 2018). While Smits defines pacing behaviour as the process of decision-making regarding how and when to expend energy (Smits, Pepping & Hettinga 2014, 763). Pacing has also been defined as the goal-directed distribution of energy over a pre-determined exercise task (Edwards and Polman 2013, 1057). It's clear that the regulation of effort is important for optimal performance during a single race. An athlete who starts too fast will not be able to maintain that speed until the end of the race and risk premature fatigue. But an athlete who holds back too long may miss the winning move and not perform to their full potential. Many distance running events now offer groups that are designed to help pace people to a desired finishing time. The ultimate example of this was the recent INEOS 159 challenge where Eliud Kipchoge broke the two-hour marathon barrier covering the 42 km distance in 1:59:40. To help Kipchoge pace himself to an under 2 hour marathon the event organizers used a pacing car with lasers that guided the lead runners at the exact pace they needed to run. Kipchoge was also helped by 41 rotating pacemakers running in a V formation to help Kipchoge save energy and keep the optimal pace to break two hours. This is of course an extreme example, but it also shows how important pacing is during an event.

The idea of pacing behaviour can also be extended over longer periods. It is believed, to reach the elite level, athletes need to learn how to manage their effort over a single session, multiple days, season, four-year Olympic training cycles, as well as current and future events. Inadequate regulation of effort at any point in the athlete’s journey could put them at a higher risk of injuries, overtraining and dropout (Menting et al. 2019, 1). Clearly pacing behaviour impacts performance throughout the athlete’s career and is an important factor in the development of athletes. Yet not much is known about how young athletes learn and develop the abilities associated with optimal pacing behaviour. An athlete’s ability to distribute their effort over the long term has been linked to the motivation and drive of the athlete. (Schiphof-Godart & Hettinga 2017, 4.) Furthermore, pacing behaviour is influenced by the specific nature of the task (Hettinga, De Koning & Foster. 2009, 234). The longer the event or task the more important it becomes to evenly distribute energy resources over the duration of the event. (Menting et al 2019, 2.)

Most of the research made on pacing behaviour to date has focused on adults and the current knowledge on the process of how young athletes acquire the skill of pacing and develop optimal pacing behaviour is limited. According to Mickelwright et al. (2012, 367-368) the skill of pacing is not fully innate but develops throughout maturity. Pacing behaviour is also believed to develop as young athletes gains experience with specific exercise task (Foster et al. 2009, 767-768).

In one study on the pacing behaviour of children, five to eight-year olds were given a four min running task. It was observed that the children’s speed decreased throughout the task, which implies a lack of pacing skill. The children were not able to set an initial pace they could manage throughout the exercise or anticipate the demands of the task. (Mickelwright et al. 2012, 365-366.) In ten-year-old children it was noticed that some start to develop the ability to keep some energy in reserve to complete the exercise task. (Micklewright et al. 2012, 367.) It’s not until adolescents when we start to see both physical and cognitive maturation as well adolescents is a time where young athletes have more opportunities to participate in sport and as result increase their experience in specific task. (Menting et al. 2009, 2.) Several studies have shown that by adolescents, elite athletes are able to develop more from the same number of training hours and show more consistent improvements in their performance. They are also known to take responsibility for their progress, are more aware of their own strengths and weaknesses, tend to set goals that are more realistic and clear, and are more willing to put the effort into training and competition (Elferink-Gemser et al. 2011, 683).

3 Perspectives on Optimal Endurance Training Organization

3.1 Introduction to Endurance Training

In the last two decades there has been a growing interest among the scientific community to investigate whether there is an optimal way to organize training for endurance sports. A common method used by scientist is a retrospective analysis that studies the training dairies of top-level endurance athletes. Through these diaries it's been observed that endurance athletes favour high training volumes and variety in training sessions (not training at the same intensity or duration every day) Therefore volume, frequency and intensity are manipulated day to day with the implied goals to maximize physiological capacity over time while staying healthy. (Seiler & Tønnessen 2009, 36.) Through long term training it may be that elite athletes have developed their training to a point where it is or very close to optimal. If this is the case, a comprehensive description of their training may provide more knowledge about what is required to develop endurance athletes from a young talent to a world-class performer. It may also reveal larger principles about the training process that can help guide the next generation of athletes.

Like the analysis of an athlete's training characteristics, there is also a great deal to learn from the national programmes of successful nations such as Norway and the coaches working in these programmes. In recent years the Norwegian Olympic Committee (Olympiatoppen) along with some of their best coaches and scientist have shared a lot of the information that brought them so much success internationally.

> *"My experience as a coach tells me that to become world champion in endurance disciplines, you have to train smart, and you have to train a lot. One without the other is insufficient." Dag Kaas.*
> *(Seiler & Tønnessen, 2009, 33)*

Ultimately, expert knowledge of exercise physiology is not required to prescribe smart training, but one must be aware of how the organization of training impacts the health, daily training tolerance, and performance of the athlete Coaches and athletes must also have the ability to recognize when the training is not working and make necessary adjustments. (Seiler & Tønnessen, 2009, 38.) The three main factors of any endurance focused training programme are volume, frequency and intensity (Hawley and Stepto 2001, 512). With a strong consensus in the literature that the intensity and duration of the training are the two most important factors for aerobic performance development in endurance sports

(Seiler 2010, 285). The goal behind the day to day organization of these factors and along with training frequency is to maximise performance, minimise risk of negative training outcomes, and time peak fitness and performance to be achieved when it matters most (Seiler 2010, 276). It is only through the experience gained by consistent training over a period of many years that a successful athletes and coaches learn how to distribute the training sessions in a way that maximizes the training benefits and minimises the risk of negative training outcomes such as illness, injury, stagnation and overtraining (Seiler & Tønnessen 2009, 38).

Norway's Olympiatoppen have developed some of the world's greatest endurance athletes. The Norwegian approach to endurance training has been described by Espen Tønnessen as holistic where in every training session there is a focus on the physical, technical, mental aspects of training. In terms of training intensity distribution (TID) most training sessions (80-90%) are performed at low intensities between 55-75% (zone 1) and 75-85% (zone 2) of heart rate max (HR max). Tønnessen sees low intensity training (LIT) as the time where athletes are "training the trainability", accumulating repetitions and working on good technique to improve work economy, along with the physiological adaptations that come from long slow distance training. The next aspect is moderate (MIT) and high intensity training (HIT) between 5-15% of the training are usually performed at 85-90% HR max. Tønnessen puts an emphasis on spending many hours at a training intensity of 85-90% of HR max as the basis for developing the capacity to perform at higher intensity levels 90-95% and 95-100% HR max. The last aspect he describes as training of the preconditions, this can make up from 5-20% of the athletes training and is where they focus on injury prevention, build tolerance for more training, and develop optimal technique.

In endurance activities where large muscle groups are activated for longer than 30 minutes such as running, cross-country skiing, at least 95% of energy will be produced by the aerobic metabolism, this is according to Åstrand et al. (2003, in Tønnessen 2010, 4). The longer the activity last the greater the proportion of aerobic energy conversion will be. Therefore, the aerobic capacity is the most important factor in maintaining a high average speed throughout long competitions. Training should be largely focused on improving the maximal aerobic capacity as well as the performance VO2 and athlete's ability to work more efficiently. (Tønnessen 2010, 1-15.)

3.2 Training Volume and Frequency

The best endurance athletes in the world train a lot, throughout the literature high training volume has been observed to be a major commonality in successful endurance training. For those athletes competing at the top level of their sport, training volumes are most likely near or at the maximum limit of human durability. It has been reported that distance runners run between 180 and 232 km per week or about 500 hours per year (Billat et al. 2001, 2093; Tønnessen et al. 2014, 1). Another study on gold medal winning XC skiers reported annual training volumes up to 800 hours per year spread across 500 training sessions (Tønnessen et al. 2014, 5). Two recent case studies investigated the training characteristics of cyclists and observed that the training volumes of professional male cyclists were between 900-1000 hours per year (Svendsen et al. 2018, 4; van Erp et al. 2019, 12). manuscripts of these two studies were available from www.researchgate.net. Page numbers refer to the manuscript.

It is difficult to compare training volumes across sports, an explanation for this variation seen in annual training volumes may be the difference in the loading characteristics and stress related to the different activities (Tønnessen et al. 2014, 5). As an example a runner cannot train as much as a cyclist because it would be physically impossible in terms of muscular loading to run 700 -1000 km per week without getting injured. But because the loading characteristics of cycling are different this is normal for professional cyclists.

Training the best way, often implies training the most!
- Espen Tønnessen, The Norwegian Training Model 2010, 8

It is well established that the most elite endurance athletes in the world have large training volumes in comparison to the constraints of their sport. In order for the athletes to be able to handle these high training volumes there must be long term training progression, it has been observed that training volume in elite performers increases with age (Seiler & Tønnessen 2009, 43). A case study of the most successful XC skier ever showed how training hours increase over a decade of training. The athletes training evolved from about 10 – 18 training hours per week, an increase of about 30 ± 53 h per year. In their chapter on longitudinal training strategies Menaspa and Abbiss recommended that young athletes between 12 – 18 years of age, training volume be limited to less hours per week than the age of the child (Nimmerichter 2018, 91).

In sports such as running and XC skiing the increase in training volume is a result of an increase in training frequency. Elite endurance athletes typically train more than one time per day, and between 5 – 7 days per week. This becomes particularly evident when comparing young endurance athletes who often perform 5 – 8 sessions per week while senior athletes have been reported to train between 10-13 sessions per week. Increasing the number of weekly training sessions is responsible for most of the increase in yearly training hours. An exception to this would be cycling, where tradition dictates single daily sessions of durations between 4 – 6 hours among professionals. (Seiler & Tønnessen 2009, 36.) It is possible to find some cyclist doing two sessions per day at certain times of the year but mostly cyclists stick to a single session and work to extend the duration of the session. Svendsen et al., reported that national level junior cyclist (16-18 years old) train about five days per week and accumulate anywhere from 10 to 15 hours per week (Svendsen et al. 2018, 12). It has also been reported that professional cyclists average about 1000 km per week which is roughly about 25-30 hours per week spent on the bike and that is equivalent to around 30-35 000 kilometres per year or upwards of 1000 hours per year. (Lucia et al. 2001,326; Seiler & Tønnessen 2009, 43; Svendsen et al. 2018, 4.)

Measuring training volume is not complicated. Athletes record the duration of their sessions in terms of distance (annual training kilometres) or time (annual training hours). It appears the reason to choose one measurement system over another is more pragmatic or traditional than scientific. According to Seiler and Tønnessen (2009, 43) runners and cyclists traditionally measure training volume in kilometres, while swimmers measure thousands of meters and cross-country skiers tend to count training hours. Seiler and Tønnessen (2009, 43) also suggest that the body is “*sensitive to stress duration*” thus, measuring training volume in training hours is an appropriate measurement.

3.3 Training Intensity distribution

With training volumes of elite endurance athletes at or near the maximum. It’s important to consider how the day-to-day training intensity ought to be is distributed over time (Esteve-Lanao et al. 2007, 943). The athletes training intensity distribution (TID) is then an essential component of prescribing the training stimulus (Stöggl & Sperlich 2015, 2; Treff et al. 2019,1). Training intensity is typically broken into “intensity zones” which are often based on easily accessible parameters such as heart rate (i.e. 55-75% of HR max), blood lactate levels, gas exchange, power output or velocity, and/or perceived exertion (Esteve-Lanao et al. 2007, 943; Stöggl & Sperlich 2015, 2).

Four main evidence-based intensity distribution patterns have emerged from the literature. The most commonly used TID pattern selected by elite performers is termed “polarized training” which is characterised by about 80% of training sessions or 90% of all endurance training time being performed as low intensity training (LIT). (Seiler & Kjerland 2006, 49-50; Seiler and Tønnessen, 2009, 42-43; Seiler 2010, 282-283; Treff, et al. 2019, 2-3.) LIT is performed below the first lactate turn point (LT1) or below the aerobic threshold it is also known as zone 1 training (Tønnessen et al. 2014, 1-2; Stöggl & Sperlich 2015, 1-2, 6). While the remaining 20% of sessions or 10–25% of training time is comprised of high intensity training (HIT) performed above the first lactate turn point (Tønnessen et al. 2014, 1-2). The distribution of 80:20 could be divided into 75 – 80% low intensity training, 5% at the threshold intensity, and 15 – 20% performed as high intensity training (Seiler & Tønnessen 2009, 42). Another intensity distribution pattern observed mainly in untrained or well-trained amateur athletes is the “threshold” TID, which emerged from several studies reporting significant improvements in untrained subjects training at or around their lactate threshold (LT2) intensity (Seiler & Kjerland 2006, 49). For further information see (Kindermann et al. 1979; Denis et al. 1984; Londeree 1997; Gaskill et al. 2001). In the threshold training model, training at intensities at or very close to lactate threshold are emphasized (Seiler & Kjerland 2006, 49). Athletes using a threshold TID will often perform very long intervals, a typical session is 2 or 3 X 20 min. at intensities between the first lactate turn point (LT1) and the second lactate threshold (LT2) or by continuous exercise accompanied by bouts of moderate intensities with no distinct recovery periods (Stöggl and Sperlich 2015, 2). As an example, athletes who select a threshold TID would typically spend 40% of their training time performing LIT, below LT1. 50% of their time at threshold intensity between LT1 and LT2 or moderate intensity training (MIT) and 10% of their training time performing HIT above their lactate threshold. Like threshold TID there is the high intensity TID where training is predominately made as high intensity training (HIT). The typical break down of this TID is 10% of activities performed as LIT, 20% as MIT and 70% as HIT. Finally, they identified a pyramidal TID which is described as most of the training time performed as LIT and a decreasing amount of time distributed as MIT and HIT. Appendix 1. Illustrates the TID characteristics of each of the models presented above.

This demonstrates that there are several different ways to organize the training process and distribute intensity over time. It has been reported that international women marathon runners as well as professional female cyclists tend to select a high-intensity low volume TID (Jones 2006, 112; van Erp et al. 2019, 10-11). While the best female XC skiers tend to use a polarized TID (Solli, Tønnessen & Sandbakk 2017,5). Most male endurance athletes seem to select a high-volume low-intensity approach and research has described their TID as polarized or 80:20 training.

3.4 Intensity and Interval Training

3.4.1 Measuring training intensity

Training intensity is commonly organized into specific intensity zones. These zones are typically defined in terms of heart rate, power, or blood lactate levels (Esteve-Lanao et al. 2007, 943; Stöggl & Sperlich 2015, 2). There is clearly a practical need for breaking training intensity up into easy to understand zones. For example, Foster et al. (2001, 6) reported the tendency for club level runners to train harder than prescribed by the coach on easy days and at a lower intensity than prescribed on hard days. However, if training zones are to be meaningful in any way, they should be fixed to identifiable physiological markers (Esteve-Lanao et al. 2007, 493). A popular intensity zone scale among physiologist is the three training intensity zones scale. Using the first and second lactate turn points or ventilatory turn points to divide the intensity zones can be a meaningful way to detect differences in sympathetic stress load, motor unit involvement, and duration to fatigue. (Seiler & Kjerland 2006, 49-50.) In this type of intensity scale zone 1 represents any exercise intensity under the first lactate turn point, zone 2 is an exercise intensity between lactate turn point 1 and 2 and zone 3 is anything above lactate turn point 2. See appendix 2. For an illustration of training intensity distributions associated with (a) the threshold training model and (b) the polarized training model and how each of the distributions are anchored to the physiological turn points (Seiler & Kjerland 2006, 50).

While coaches, national and international governing bodies typically endorse a five differ aerobic intensity zone model (Seiler & Kjerland 2006, 49). It is important to note that while five training zones are commonly used around the world, they are somewhat arbitrary and convey a degree of physiological specificity that is not there (Esteve-Lanao et al. 2007, 943). Another criticism often heard of the five-zone training intensity scale is that it does not account for individual physiological differences (Seiler 2010, 277). The standard 5 zone intensity scale is most often based on a percentage of heart rate max or blood lactate concentrations at certain percentages of heart rate and/or power output. Zone 1 is often described as 55–75% of HR max, zone 2 is 75–85%, and these make up the LIT zones. Then zone 3 is an intensity between 85–90% of HR max, zone 4 is 90–95% and zone 5 is 95–100% of HR max. (Seiler & Tønnessen 2009, 36.)

Successful endurance training involves manipulating key characteristics such as intensity, duration, and frequency over an extended period. This is accomplished by understanding the roles played by low intensity training, lactate threshold training and high intensity training, common terms for exercising within different regions of the intensity continuum.

3.4.2 High Intensity Interval Training

In a polarized TID high intensity training makes up about 20% of the yearly training sessions. For athletes who perform 500 training sessions per year that puts them at about 100 high intensity sessions per year. Cyclists have been reported to perform up to 370 sessions per year (Pinot & Grappe 2014, 3). In this senerio 70-75 sessions would make up the proportion of high intensity training. These sessions would likely be performed as interval sessions at an intensity above the first lactate turn point (Tønnessen et al. 2014, 1-2). A high intensity interval training session is characterised by repeated bouts of high intensity exercise interspersed with low intensity exercise or complete rest (Laursen and Buchheit, 2019, 3-5). The strategy behind interval training is to accumulate an increased volume of work at intensities higher than what would be sustainable during a single continuous session of training. The purpose of HIIT is to stress specific physiological systems used in sport to an equal or greater amount than that required during competition so that new levels of performance can be reached. (Buchheit and Laursen, 2019, 5.)

In recent years HIIT training has seen an increase in popularity and marketability. This trend seems to be driven by "fitness experts" and scientists who believe that HIIT training is the only type of training required to increase performance and optimize health. The promise that makes HIIT so appealing is the maximum amount of benefits in the minimum amount of time. However, HIIT is not a new concept, already in the early 1900s athletes were experimenting with repeated bouts of intensity. There are reports from as early as 1912 of Finnish distance runner Hannes Kolehmainen performing 5 to 10 repetitions at his 10km race pace of 3:05 min per kilometre in preparation for the Olympic Games. (Laursen and Buchheit, 2019, pg. 5–6.)

The most common types of interval training used in preparing endurance athletes with long events such as cycling are long intervals, short intervals and sprint interval training. L In a long interval training session, the work durations range between 1 and 6 minutes at an intensity of 85 – 95% of HR max or 85 – 100% of maximum aerobic power (MAP) with rest rations of 1:0,5 and 1:2. The goal of long interval sessions are to accumulate between 20 and 40 minutes of high intensity work in zone 3 (Laursen & Buchheit, 2019, pg. 302 – 303). By manipulating the work and rest ratio, these intervals can target greater use of the aerobic or anaerobic metabolism. To put more emphasis on the aerobic metabolism, durations greater than three minutes could be used with rest periods reduced to less than 3 minutes. (Laursen & Buchheit, 2019 pg. 303.)

Short Intervals are another common type of interval used in endurance sports. Short intervals are 20 to 60 second work duration performed at 100 – 140% of MAP. In the three-intensity zone scale this work is performed above zone 3 intensity or rather at an intensity greater than VO2max. Rest intervals are usually half or equal to the duration of the work interval, athlete should look to perform a total of 10 – 20 minutes of work split between 3 to 10 sets. (Laursen & Buchheit, 2019 pg. 303.) Another type of short interval is sprint interval training, in cycling this kind of training would be used by pure sprinter type riders that are looking win in a mass sprint at the end of a race. These are maximal efforts of between 10 and 30 seconds with recovery periods of 2 – 10 minutes. The session goal for this type of interval is to hit maximum power or to perform every interval at the maximum effort so the number of sprints should be low between 1 to 5 per session with lots of recovery time between sprints, up to 30 min. (Laursen & Buchheit, 2019 pg. 303.) It is important to note that the short interval types are performed above zone three intensity, targeting the anaerobic and neuromuscular systems.

4 Case Studies: Training Characteristics of Endurance Athletes

4.1 Introduction

This chapter is a review of three case studies from three different endurance sports. The sports covered in this chapter are distance running, XC skiing, and cycling. These sports were chosen because there are some excellent descriptive studies available for distance running and XC skiing. Regarding cycling only, a small number of quality studies exist but this thesis is mainly focused on cycling, therefore I try to make use of what research is available.

Case studies are the weakest form of evidence (Seiler & Tønnessen 2009, 47.) Descriptive case studies such as the ones reviewed in this chapter help us understand how elite athletes from various sports train and help to grow our knowledge about what is needed to progress to the elite level of endurance sports. For a coach each athlete they work with is a case study (Seiler & Tønnessen 2009, 47.) The case studies reviewed in this thesis give a comprehensive description of the training characteristics elite athletes. Each study has its own unique lens from which to study the athletes and this review will try to express that but will also try to express the training characteristics of the athletes specifically through training load determined by training volume, training frequency and training intensity distribution.

4.2 Running

4.2.1 A Nine Time New York Marathon Winner

Tjelta, Tønnessen and Enoksen (2014, 139-156) published a case study on the career of Grete Waitz. GW was a world class long distance runners in the 1970-1980s running her fastest time over the marathon distance in 1983 in London when she ran 2 hours 25 minutes 29 seconds. GW started athletics at 12 years of age and partcipated in sprint, jumping and throwing events until she was 14 years old. At 15 she began racing distances over 200 metres. When she was 16 years old she ran her first 800 m event, she was training 5 times a week at 16 years of age. Her training consisted of interval training and continious runs covering 8 - 10 km. The authors reported that GW trained regularly with boys and she performed a lot of HIT already at 17-18 years of age. By 19 years old she could easily run a pace of 4:00 min per km on a 10 km run.

From 20-23 years of age, her training volume started to increase gradually and the number of HIT sessions were reduced to between 2-3 times per week. Frequency of training sessions increased to 2 sessions per day. A typical training session was a continious run of about 12 -13 km. In the morning she would run at a pace of 4 minutes per km and her afternoon session was run at a pace between 3:20 - 3:45 min per km. Grete used a lot of MIT in the form of continious running near or at her lactate threshold, compared to other female distance runners her training volume was low to moderate. Coming into her best seasons she was running between 119 and 132 km per week depending on which phase of training she was in. The authors report that other female runners such as Ingrid Kristiansen had a weekly training volume of between 155-160 km.
While, Sonia O'Sullivan is reported to have had regular weekly training volumes of 160 km per week. With the biggest weekly volume coming during her preparation phase and equalling 180km. During the competition phase of her season she would run 115-120 km per week.

One difference to other runners that the authors reported about GW was her preference for short sprint interval sessions over longer aerobic interval sessions. GW training resembled more the training of Paula Radcliffe who also used long continious runs at a realitively high intensity over long slow runs or long intervals that targeted VO2max. In there study the authors reported two different approaches to training used in women's distance running. The first is the high volume – low intensity (HVLI) training and the second is a high intensity – low volume (HILV) approach. Grete Waitz used a more HILV approach in her training.

4.3 Two Case Studies of an Olympic Runner

From Jones (1998, 39-43; 2006. 101-116) we get two case studies that follow the career of Paula Radcliffe, a former world record holder in women's marathon with a time of 2 hours, 15 minutes, and 25 seconds. In the first study Jones investigates how five years of endurance training changed Radcliffe's physiology in terms of VO2max, lactate threshold and efficiency and what role that had on her 3000m performance.

Jones reports that over the five years PR training volume progressively increased from 48,3 – 64,4 km a week as a junior to 112.6 – 145 km a week as senior international elite athlete. Typical training for PR was in the form of a long continuous runs near or at lactate threshold intensity. This study reported that while her performance in 3000m improved her VO2max decreased from 72.8 to 66.0 ml/kg/min. However a 20% improvement was observed in her lactate threshold and 11% improvement in running effciency. As an example her blood lactate concentration running at 16 km/h decreased from 3.7 mmol to 1.4 mmol over the five year period.

In the second study Jones (2006) now has 15 years of physiological testing data on PR and he reports that PR's VO2 max remained relatively stable between 1992 – 2003 at approximately 70 mL/kg/min .This time takes her from 18 – 29 years old and jones notes that this is an extremely high value for any female endurance athletes. Jones also reports big improvements in running effiency and her running speed at VO2 max intensity. Her running speed at LT1 increases from 14 – 15 km/h in 1992–1994 to 17.5 – 18.5 km/h in 2000–2003; similarly, her LT2 increased in from 16 km/h in 1992 to 20 km/h in 2003.

PR training is reported to stay very much the same throughout her career with continuous running sessions where she runs at or near her lactate threshold (LT2) making up the largest fraction of her total weekly mileage, these sessions are typically performed at a pace of 3:20–3:40 min:sec per km. During a typical week of training she would also perform 1–2 higher-intensity interval sessions at about 95–100% VO2 max as well as two strength training sessions with weights. Another interesting finding was that much of her training was made at altitude. The final thing to say about her training is that part of her philosphy was never comprimising training quality for quanity and if she felt too tired to perform a session at an appropriate intensity then she would always choose complete rest over performing the session sub-optimally.

4.3.1 The Three Norwegian Brothers

A study from Tjelta (2019, 1-7) tells about the performance, development and training characteristics of three Norwegian brothers, who are all European champions in 1500m event. At the 2018 European Athletic Championships in Berlin one of the brothers won both the 1500m and 5000m events at just 17 years of age. This young Norwegian has two older brothers that are also European Champions (EC)and have multiple championships and podium places in EC for track and cross country.

The oldest brother started playing football at age 10 and continued with this for four years. At age 13 he also took up competitive XC skiing during the winter and long distance running in the summer, this was his routine until age 17. Then he started to focus more to running and weekly training volume increased from 100–110 km per week to between150 – 160 km per week at 21 years of age. A very similar pattern with the middle brother who seemed to follow in his big brother's footsteps starting in football, XC skiing and track and field, then shifted focus to distance running at age 17. An increase in weekly training volume was observed from an average of 70 – 80 km per week at age 17 to 120 – 130 km per week at 20 years old. The largest weeks of training leading up to the 2018-2019 season was between 150-160 km per week.

The youngest brother started in the same track and field club where his older brothers were members at 7 years of age. He also competed in XC skiing at reginoal level up until 12 years old. From 12 years old he trained one session per day seven days a week. From this point year by year he gradually increased his weekly training volume and the number of training sessions per week. Between 17–18, while preparing for the 2018 season, he ran an average of 130 –140 km per week over 13–14 weekly training sessions. During preparation for the 2019 season he was running the same training volume as his older brothers at 150-160 km per week.

The author found that the brothers had taken different paths to the elite level of distance running but what they did have in common is participation in sports from a young age and very active lifestyle through childhood. They all ran about 150-160km per week spread across 13-14 training sessions and a large part of their training (23–25%) was made as interval training above the LT1 and most was performed around the LT2 velocity. Their father coaches all three of them and tightly monitors their heart rate and blood lactate values during their interval sessions.

4.4 Cross Country Skiing

4.4.1 The Importance of Low Intensity Training (LIT)

A case study published by Solli, Tønnessen and Sandbakk (2017, 1-13) examined the training characteristics of a female XC skier who has won six gold medals at the Olympic Games, 18 gold medals at the World Championship, and has 110 World Cup victories making her the most successful female skier of all time. They studied her best seasons but also tried to characterize her long-term training patterns over the 17 years she competed.

In total, the group analysed 8,105 training sessions from the period of 2000 - 2017. These sessions consisted of 7,642 training sessions and 463 XC skiing competitions. It was observed that the participant’s annual training volume increased from the age of 20–35 (2000–2015) by 80% (from 522 to 940 h) This shows a yearly progression of 30 ± 53 h the biggest reason for this was an increase in weekly training hours from about 10 hours to 18 weekly training hours.

The training sessions were divided into three intensity zones LIT/MIT/HIT and analysed to see how the training intensity was distributed. For the first seven years of her senior career (20– 27 years old) the training was polarized with about 88% of her training being LIT, MIT making up 2% and 10% being HIT while the latter half of her career (28–35 years old) became even more polarized with LIT making up 92% of the total training, MIT at 3% and HIT at 5%. Low intensity training volume grew from about 430 hours at 20 years old to almost 800 hours at 35 years old. The amount of MIT + HIT remained pretty much the same through her entire 17-year career at around 60 hours. From age 23-28 the participant experimented with her training and during this 5-year period the amount of HIT increases to about 80 hours annually with the addition of extensive HIT blocks during the general preparation phase.

The accumulated LIT time during the general preparation phase was also very high, around 76 hours per month and reduced in the competition phase to 55 hours per month. While the frequency of LIT sessions remained stable across each of the phases at about 32 sessions per month, this change was due the athlete reducing the number of sessions greater than 90 minutes from 25 sessions per month in the general preparation phase to 14 sessions per month in the competition phase. Another distinct change they observed was during the general preparation phase the athlete had no LIT sessions lasting less than 50 min in duration. But this increased to about 14 sessions per month during the competition phase. This shows that the duration and frequency of LIT sessions are distributed differently throughout the year. We also see that 21% of the participants annual LIT training volume which totalled 167 hours consisted of the warmup and cool downs in MIT/HIT and resistance training sessions.

Even though up to 90% of the total training volume of elite endurance athletes is performed as LIT. The effects of how LIT is organized in terms of frequency and duration has yet to be studied.

4.4.2 Training and Peaking Characteristics

A case study by Tønnessen et al. (2014, 1-12) looked at the day to day training data from 11 XC skiers (4 males, 7 females) in the year leading up to the most successful race of their careers. All these athletes had won either an Olympic gold medal or World Championship gold medal. They also attempted to examine the relationships between annual training and peaking characteristics in these athletes.

The athlete's annual training characteristics looked like this; The total training volume was between 622 hours and 942 hours. This was distributed across 375 to 585 annual training sessions. Aerobic endurance training accounted for 94±3% of all training time while 5±2% comprised of strength training and 1±1% ski sprint training. Breaking that down even further they saw that the athletes spent 91±1% of all endurance training time was performed as LIT in zone 1 and 2. The other 9±1% was shown as HIT in zone 3–5. The total annual HIT duration which included competitions was between 46–85 hours through the year across 85–147 sessions. Altogether, the distribution across every intensity zone was as follows: zone 1: 86.0±3.4%, zone 2: 5.3±3.0%, zone 3: 3.3±0.9%, zone 4: 3.3±1% and zone 5: 2.1±1.0%. Most of the athlete's training (64±3%) was sport specific training (ski or roller ski) while the other 36±3% was composed of non-specific activities like running, cycling and swimming. In the general preparation phase 48±6% of the training was sport-specific training, this increased throughout the season and in the competition phase 92±4% of the training was sport-specific activity forms.

In terms of peaking for their primary competition the most significant period was the reduction in training from the general preparation phase when the training volume was at it's highest to the peaking phase which the authors define as the last 14 days prior to the athletes' most successful competition. The decrease in training volume was almost entirely due to the reduction in non-sport-specific training. There was also a small 9±15% weekly training volume reduction in LIT endurance training (easy sessions got shorter) and there was also a noticeable reduction in strength training as well, while sprint training time stayed quite similar across pre-peaking and peaking phase. There were no significant changes in weekly training session frequency (8-10 sessions per week) between the peaking phase and any of the other phases.

In this study there was a lot variability between athletes' peaking strategies and the authors were unable to say if one strategy worked better than another. But their study was able to demonstrate that athletes in elite sport have started to use competitions as part of their peaking process. They also saw that most of the athletes performed regular HIT sessions throughout the final 14 days (about 5 sessions in total per athlete) They also report that 10 out of 11 athletes performed a HIT session (>LT2) within 48 hours of their competition. Finally, rest days were 3 times more likely to be taken between days 6-12 of the taper and only 3 out of the 11 athletes in the study took a complete rest day in the last 5 days prior to their competition.

4.5 Cycling

4.5.1 Training Volume Improves Power Outputs

The first study by Pinot and Grappe, (2015, 907-914) is a six-year case study that follows how progression in training load over several years affects the performance of a top 10 Grand Tour finisher. The study analysed; 2208 training sessions recorded by the athlete over a six-year period. These sessions were then divided into training sessions which totalled 1727 or competitions which consisted of 481 competition days of which 68 were counted as time trials.

In 2018, when the study started the rider was 18 years old competing as junior in the U19 category, his training volume totalled 526 hours. In 2013 when the rider was 23 years old and already part of the World Tour his annual training volume had increased to 943 hours per year. This study also observed a substantial increase in training volume between the ages of 18 and 20 years old when the rider turned professional, a plus 60% increase in training from U19 to U23 and a 62% increase from U23 to his first year as a professional in the World Tour.

Then the studied compared how the increase in training volume affected the athletes performance over multiple years measured by the athlete's Record Power Output which is a measurement of the athletes best power outputs over several durations (1 sec., 5 sec., 30 sec., 1 min., 5 min.,10 min., 20 min.. 30min., 45min., 60min., 120min., 180min., 240 min.) The study found that increases in training load measured by an increase in training volume significantly correlated with improvements in the athlete's aerobic potential shown by an increase in the record POs in all durations but with the most increases being seen the durations between 5 min and 4 hours.

4.5.2 Nature or Nature

(Svendsen et al. 2018, 1287-1292) investigated whether training, performance or an athlete's physiology at 18 years old could predict an athlete's future potential to become a World Tour professional. In their study they retrospectively analysed the training dairies of athletes who were 18 years old in 2005 and active in cycling through 2011. They were then grouped by the performance level they had achieved at the age of 23.

This study found that athletes who had reached the World Tour level at age 23 had significantly more race hours (91.5 ± 19.1 hours) when they were 18 years old compared to 62.8 ± 21.8 hours for the riders who ended up racing at the club level at 23 years old. Going further into the data they found that this was in part due to the longer duration of each competition as well as the tendency to take part in a larger number of races. Athletes who reached the World Tour at 23 years of age probably had opportunities at 18 years old to compete in more prestigious races which tend to be longer and harder than club races (1.9 ± 0.4 hrs) While the 23 year old club level athletes races were a little shorter in duration and they didn't typically race as many times (1.5 ± 0.2) at 18 years of age. The study also reported that those athletes who made it to the World Tour placed significantly higher in the U19 National Road Championships than the other groups who didn't make it to the World Tour. There was no significant difference in any of the other physiological measurements.

Race performance at the junior level was found to be a strong predictor of later success as a senior elite cyclist. However, this could be due to the fact that better junior riders are for example on invited to the national team where they get more support and more racing opportunities at 18 years old which leads to them getting more attention from teams looking for talent juniors to develop at the next level.

The authors reported that typical training volumes for elite cyclists are between 900-1000 hrs per year which has them performing 700-800 km of cycling per week during pre-competition and competition phases of the annual training plan. At age 18 all the rider in this study who made it to the World Tour were riding between 600-800 hours per year, with 70-120 hrs of that being racing. The authors note that that the lower end of this range may just represent the minimum threshold of training and competition required to reach the super-elite level of the World Tour.

The authors were unable to determine whether the athletes who made it to the World Tour level became better riders because they raced more, or if they were already better than their peers as juniors and thus were more motivated and had more opportunities to race. But according to the authors, racing provides an important stimulus to develop not only physiological capacity, but also the mental, technical and tactical capabilities needed to compete and perform at the World Tour level.

4.5.3 Training Characteristics of Men and Women

In another retrospective case study, a group of researchers (Van Erp, Sanders & de Koning 2019, 2-21) describe the training characteristics of 20 male and 10 female professional cyclists over four consecutive years. Altogether 7319 training files from male cyclists and 2503 training files from female cyclists were analysed. All training files collected contained power data, 68% of the training sessions for both men and women also included heart rate data and 52% of the men's files and 82% of the women's training files included rate of perceived exertion scores (RPE) The studied revealed than professional men and women cyclist train very differently. This may be because the demands of the competitions are also very different. In men's racing the longest one-day race is around 300km and the biggest stage races are 21 days long. In women's cycling the longest one-day race is 160 km and the longest stage race is 10 days.

Some of the observations made in this study were that male professional cyclist typically race 70 to 90 days per year, with only a few riders able to race 100 days in a season. While women may race between 40 and 55 days per season. The training programs of professional men consist of more time spent in the low intensity (HR and Power) zones 1 and 2 compared with professional women cyclists who appear to train at a higher intensity than professional men, about 13% more training time in zones 4 and 5

A professional men's training program my consist of more low intensity and recovery rides because of the larger amount of race days, as easy or a recovery training are typically planed after a race. The authors of the study think this might contribute to the increased time spent at lower intensity zones in men's training compared to the women's training.

4.6 Conclusion

The case studies discussed above provide insight into how elite endurance athletes organize their training. First, a high training volume has shown to be prevalent in the training of successful endurance athletes (Seiler & Tønnessen 2009, 43-44; Seiler 2010, 288.) The best international runners are reported to train between 500–600 hours per year. While it has been shown that the training volume of the world's best XC skiers can reach almost 800 hours per year. (Tønnessen et al. 2014, 5) According to Seiler & Tønnessen (2009, 40, 43) and Svendsen et al. (2018, 4.) world class cyclists are typically on their bikes between 900-1000 hours per year. The large variations in annual training hours seen across sports almost certainly has something to do with the differences in muscular loading and stress associated with different activities (Tønnessen et al. 2014, 1.) Obviously, the best international athletes are really pushing the limits of human durability within their sport.

Secondly, it has been shown that training frequency plays an important role in the training process. The world's best XC skiers have been shown to complete upwards of 540 training sessions annually (Solli, Tønnessen & Sandbakk 2017, 10) An increase in frequency is responsible for the largest increase in yearly training volume. Typically, developing talent train between 5-8 times per week, while senior athletes may carry out between 10-13 training sessions per week. An exception to this may be cycling as it is more common to train once per day, with professional often extending the duration of their training sessions to between 4 and 6 hours. (Seiler & Tønnessen, 2009, 36-43.) From the training data of three U23 Finnish cyclist from (www.strava.com) it is possible to see that they have uploaded between 280 -360 activities as of November 2019.

Next, we see that endurance athletes tend to distribute their training in such a way that 80% of the training sessions are performed as low intensity training (LIT), defined as training below the first lactate turn point (Tønnessen et al. 2014,1) The other 20% is performed as bouts of high-intensity work, in the form of interval training at about 90% of VO2 max. (Seiler 2010, 276.) The running studies that were reviewed and the study by Van Erp, Sanders and de Koning (2019, 3-21) provided evidence that that professional women cyclists and world-class distance runners take a substantially different approach and organize their training, using a high intensity – low volume training intensity distribution. Van Erp, Sanders and de Koning (2019, 11) speculated that because women are not guaranteed a minimum salary some may be forced or would choose to work or continue their studies alongside their athletic career. Therefore, it may be that women simply don't have the luxury to train or recover like male cyclist and so they would naturally select lower volume and higher intensity to compensate for the lack of dedicated training time. Another reason could be that the racing is shorter and characterised by more time spent at high intensities and the way women choose to organize their training may require a different approach to be optimally prepared for the demands during races.

5 Case Study: From Junior to World Tour

5.1 Research Objective & Questions

The objective of this study was to investigate how the participant's training characteristics developed over an eight-year period, that saw the athlete develop from a 14-year-old junior mountain biker to a 22-year-old professional road cyclist, riding in the World Tour. This study attempts to provide a longitudinal description of the athlete's maturation to elite status.

Related to the objective are the research questions, this study was concerned with how the athlete's training had evolved between the years of 2012 – 2019 in terms of a) training volume, b) competition volume c) training intensity distribution and d) performance in competition. This study looks retrospectively at the athlete's training to answer the question how did the athlete developed from a junior to World Tour professional?

5.2 Data Collection

The study is based a retrospective analysis of a) self-reported training that the athlete made between the years of 2012 – 2019, b) publicly available race data that was collected from the web, and c) an interview with the athlete. In following sections is outlined how the data for each of the parts mentioned above were collected and how they relate to the aim and the research questions.

5.2.1 Training Data Collection

In terms of training data the athlete had kept excellent records of his training from 2012 when he started to document his training with a GPS device and a heart rate monitor. Between the years 2012 – 2019 the athlete had used several different GPS devices to collect training data as well as a number of online training platforms such as Training Peaks, which could be considered a type of online training dairy. Data was uploaded after every training session to the online training platform that was being used at the time and the training sessions were also saved on the GPS device.

There was training information that the athlete did not want published, and as a result there ended up being limited access to the actual training files. The solution was therefore to have the athlete report his training based off what we mutually agreed could be published. The athlete went through his training files in Novermber 2019 during a short break in regular training and reported the information to me. To keep it as simple as possible we looked at annual training hours across eight years and time spent in intensity zone which was based on a percentage of maximum heart rate. For most years the athlete used a 5 zone intensity scale but near to the end of the study he switches to a seven zone system. Finally the athlete was also asked to remark and provide details about the training for each year.

During the years 2016 – 2017 the athlete used an SRM head unit device on his road bike to record his training sessions. When the athlete went to collect data from this device, all the data had gone missing and he could not provide full records for these training years due to the malfunction with the device. These years are noted with an asteriks in the figures below. Where there were training gaps in the information the athlete was asked to comment about what he remembered. The final method used to fill in the gaps was to analyse training files that he had published on (www.strava.com) to get a general idea of the types of training the participant was making as well as the geography where the training was made.

5.2.2 Competition Data Collection

Competition data was collected in October 2019 from three websites for domestic races in Finland (http://www.tulospalvelu.profiili.fi/pyrilytuloksetresults) was used, for races in France (https://www.directvelo.com) was a source and for professional races data was collected from (www.firstcycling.com) The athlete also has his own personal webpage where he has published his race results from 2013 to present, this was used to cross check that the information was accurate. From these websites was collected the number of annual competition days, how long each race was in kilometres and how much time was used to finish the race.

5.2.3 Athlete Interviews

An interview was made in November 2019, during a small pause in training as part of the participant’s off-season. The interview was conducted over the phone and the call was recorded using the Cube ACR app and lasted approximately 90 minutes. During the interview several questions that the participant had been sent earlier were used to guide the conversation. The participant was told that the questions were meant to be starting points and the participant should tell his story in his own words. The participant has also made several interviews with different media outlets such as Finland's national public broadcasting company YLE. These interviews were collected and analysed as well.

5.3 The Participant

The data used in this study comes straight from the athlete or from sources that are publicly available. The participant gave consent for his data to be used in this case study and effort has been taken to respect his privacy and work within the ethical guidelines declared in the Helsinki Declaration.

The participant was born in April 1997. He comes from the municipality of Ruokolahti, situated in south-eastern Finland, in the region of South Karelia. His family own a dairy farm there and he grew up helping his family around the farm. Some of his childhood activities include floorball, scouting, violin, cycling and searching their property for trees to climb. Both parents were very supportive of the participant following his passion but also set rules such as limiting the children's screen time in hopes that they would find other ways to have fun outdoors.

Today he is 177cm tall and his body mass is between 58-61 kg. His strengths on the bicycle are steep hills, long climbs, technical courses and racing in hot conditions. In August 2019 he started his career as a World Tour professional racing for a French team. The participant has been cycling competitively since 2006 (9 years old) and has over 30 podium places in Finnish national championships across three cycling disciplines which are road racing, mountain biking and cyclocross. He is the 2013 U17 Nordic Champion in Cross Country (XCO) mountain biking and a bronze medallist in the 2018 UCI U23 World Championships road race. He is only the fourth Finnish male cyclist to race at the World Tour level.

5.4 Participant Background and Development

The participant started cycling competitively in 2006, as soon as it was possible for him to get a racing licence from the Finnish Cycling Union. He was attracted to cycling by his father and big brother who had started to race a few years earlier. He had been following them on rides and enjoyed cycling as well as spending time with his family. In the years before he could race, he joined the Tainionkosken Tähti cycling club from Imatra, Finland. His father and big brother were also members there and they would often go to race the traditional weekly "tempo" that he would do on a heavy old mountain bike.

This study starts in 2012, by this time the participant has been racing for already six years and “training” a lot with his big brother who is four years older than him. It is important to note that the participant and his brother truly enjoy riding and racing and that there was never any pressure from parents or club to choose cycling as their sport. The participant tells that his father encouraged and gave guidance if asked but tried very hard not to take on the role of coach to his children. In fact, the athlete in this study didn’t have his own coach until 2016 when he started riding for a development team in Finland as an U23 rider. The athlete told that during the early years he mainly coached himself and wrote his own training plans. If he had questions about the training, he could ask his father but he was also interested in trying to learn for himself about training and spent time studying this.

Between 14 – 16 the athlete’s first passion was mountain biking and he competed in both XCO and marathon events. In 2013, he was invited to be part of the Finnish national MTB team as a junior athlete. With this team he was able to give to participate in international races in Austria, Denmark and Sweden. At the end of 2013 he participated in the national cyclocross championships and won the M18 race. In 2014 he was recruited by Fincycling to join the road racing team. In this year he had the opportunity to participate in many of Finland’s top domestic races where the team raced in the elite men’s category on restricted gears that junior riders must race on. He was also given the chance to start a couple international races one being part of the Nation Cup race and the other being the Heroes of Tomorrow junior race in Norway. During this season his focus is still MTB, but he was also racing road and cyclocross events.

The year he turns 18, he really commits to road cycling, meaning his season goals become based around his road race calendar. 2015 is his last year as a junior and the Fincycling team has an even more ambitious race calendar that takes them to several of the biggest junior races in Europe. In this season he races La Coupe du President de la Ville de Grudziadz, Poland; SPIE Internationale Driedaagse van Axel Juniors, Netherlands; LVM Saarland Trofeo Juniors, Germany; GP Général Patton Juniors, Luxembourg; and Sint-Martinusprijs Kontich Juniors. In total, he gets about 25 days of racing at the top international level for junior riders.

In 2016 he graduates to the U23 category and joins TWD-Länken a Finnish team that has developed many of the country’s top exports. It is here he starts with his first coach. His goal for this year is to finish high-school and complete his army service. He decides to take a small step back from racing so he can move forward in life. The racing he does in

2016 is mostly domestic races but he does go abroad to competitions in Denmark, Sweden and Estonia. For the 2017 season, he makes the decision to pursue a professional career and gets connected with AC Bisontine, a Division Nationale 2 (DN2) team in France. The first spring in France was difficult for the athlete. The level of racing was a surprise, being much harder than he expected. Then he had to deal with living on his own for the first time in place where he could not speak the language. It took a few months for him to adjust and get used to the racing and by August he was making good results in a number of competitions. His performance this year earned him a spot a DN1 team for the next season. DN1 in France is just one step below the professional ranks.

The 2018 season he joined his new team Espoir Cycliste Saint-Etienne Loire and had a very successful season, that included several top 10 finishes in both one-day races and stage races. He took overall victories at Tour de Tarentaise, Ie and Tour de Chablais-Leman (stage races), a second place at the stage race Tour de Beaujolais and a notable fourth place finish at the prestigious one-day race Tour du Charollas which really put him on the map. To end the season, he earned a bronze medal at the U23 World Championship in Innsbruck, Austria, on what has been said to be one of the hardest courses in years. At the end of the 2018 season he announced that he would turn professional, signing with the World Tour team AG2R LA MONDIALE starting from August 2019.

The participant started off the 2019 season racing for his DN1 team. Season started off well but in May he was involved in a bad crash during a race broke his sternum and thumb which caused him to miss 5.5 weeks of training and racing. He came back from his injuries in the end of July, raced two more races with his DN1 team before making his World Tour debut at the Clasica Ciclista San Sebastian a one-day (227.3 km) race in Spain.

6 Results

6.1.1 Training Volume & Frequency

In total almost 5000 hours of training were calculated as part of this study. Annual training volume was observed to increase every year over the eight years. It was observed that the annual training hours increased from 403 to 850 hours (Figure 2.) between the ages of 14 – 22 years of age. In the first years of this study the athlete was doing many hours of physical work on his family's farm. These hours are not counted in the training volume, but it should be mentioned that he had an extremely active lifestyle from an early age. His training routine over the last few years has remained quite similar and the athlete told that he typically trains one

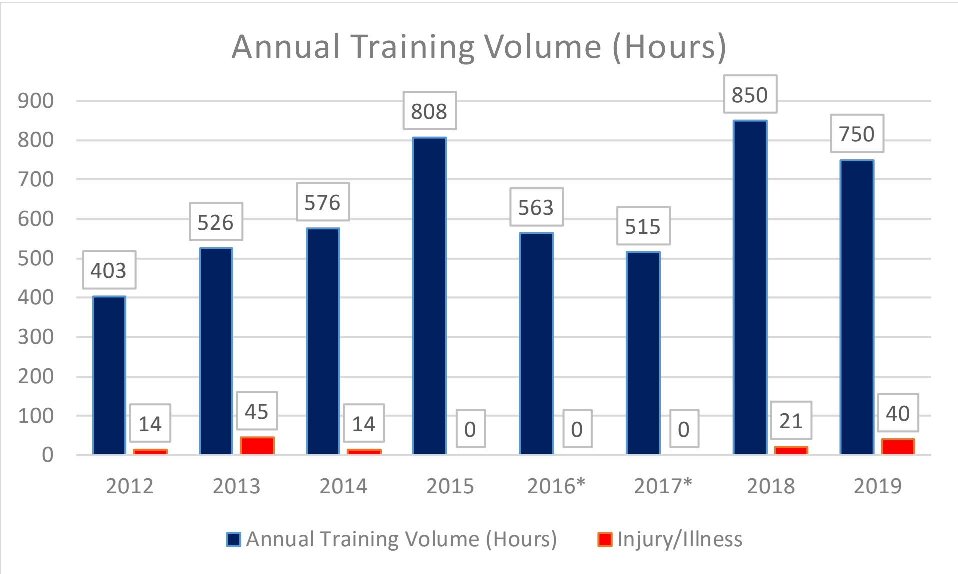


Figure 2. Training volume in hours (blue bars) compared to days of no training due to illness or injury (red bars) for years 2012 – 2019.

session per day and he is making something like 5 – 6 focused training sessions per week with 1 – 2 easy days that either take the form of active recovery or complete rest. This all depends on the time of year and what race he is aiming for. In general, though the athlete prefers active recovery over total rest. In a French language interview, he was asked about making two training sessions per day. I asked him about this as well, he told that he used to do this quite often for practical reasons since weather conditions and lack of sunlight in Finland during the winter make it difficult to ride outside for extended periods of time. Now that he lives in France and can ride comfortably all year around these double session days have become rarer. It’s estimated that since 2015 he has most likely performed over 300 training sessions per year.

The red bars in (Figure 2.) show days with no training due to injury and illness. In the first three years of the study most of the days off are due to upper respiratory tract infections picked up at school that kept him off the bike for around 3 days at a time. In 2013 the participant broke his arm playing floor ball at the start of the 2013 season. 2019 he was hit by a motorcycle during a race and broke bones which saw him off the bike for 5,5 weeks between May and July.

It should be noted that this study is missing a good deal of the participants road cycling data between the years of 2016 – 2017, His road bicycle was equipped with an SRM power meter and SRM computer. When he went back to collect data off this device it was missing and so that data could not be presented in this study. The data he provided for those years is from training made on his mountain and cyclocross bike.

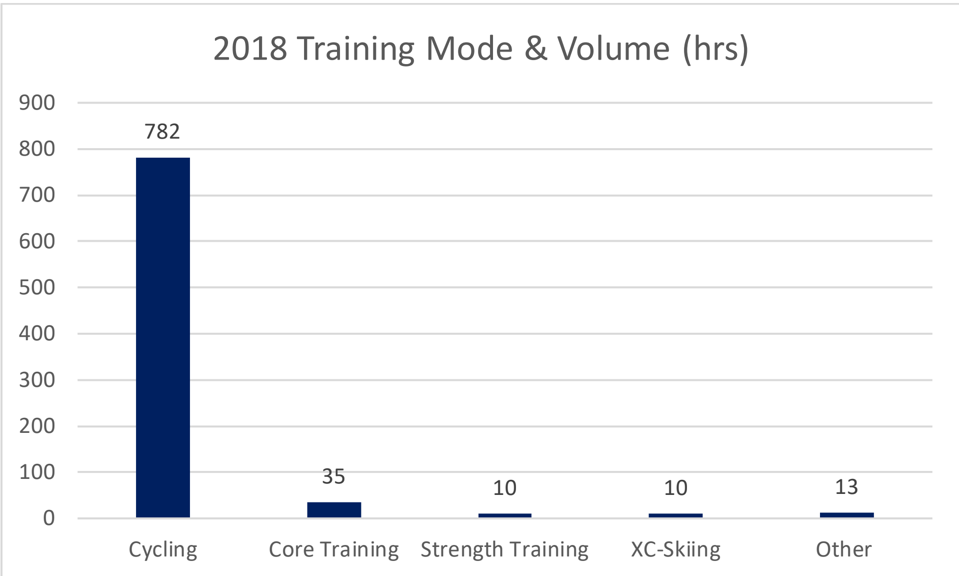


Figure 3. 2018 training modes broken down into hours spent on each type of activity.

In the participant’s best season so far, his annual training volume reached 850 hours. For this season he kept good records of training hours for all types of training were kept and can be seen from (Figure 3.) In this year 95% of his training was endurance training of that 92% was cycling specific training, the other 3% was comprised of non-specific endurance training like XC skiing. The remaining 5% was core strength and resistance training.

We can see that most of the training is performed as cycling specific training across three different disciplines road, MTB and cyclocross. Splitting the cycling specific training across three different cycling disciplines was observed in every year accept 2012.

6.1.2 Competition Volume

Another area the research looked at was his competition volume. The racing data collected provided information on how many competition days (Figure 4.) the athlete performed each year, as well as the number of racing hours and kilometres (Figure 5.) In total the participant had 295 race days between 2012 – 2019. Annual race days increased from 8 days per year in 2012 to 72 days per year in 2018. In 2019 the annual racing days were down but this is probably due to injuries he had in the middle of the racing season. The total amount of hours raced was almost 800 hours with the annual volume progressing from 11 – 200 hours. The study also calculated training volume in kilometres ridden, altogether the participant had accumulated about 28,500 km of racing between 2012 – 2019. The lowest amount of racing km came in 2012 with 283 km and the biggest volume was in 2018 when the participant had 72 race starts and racked up almost 7500 km of race kilometres. Big increases in all variables were seen in 2015, when the rider was 18 years of age, this was his last year in the junior category.

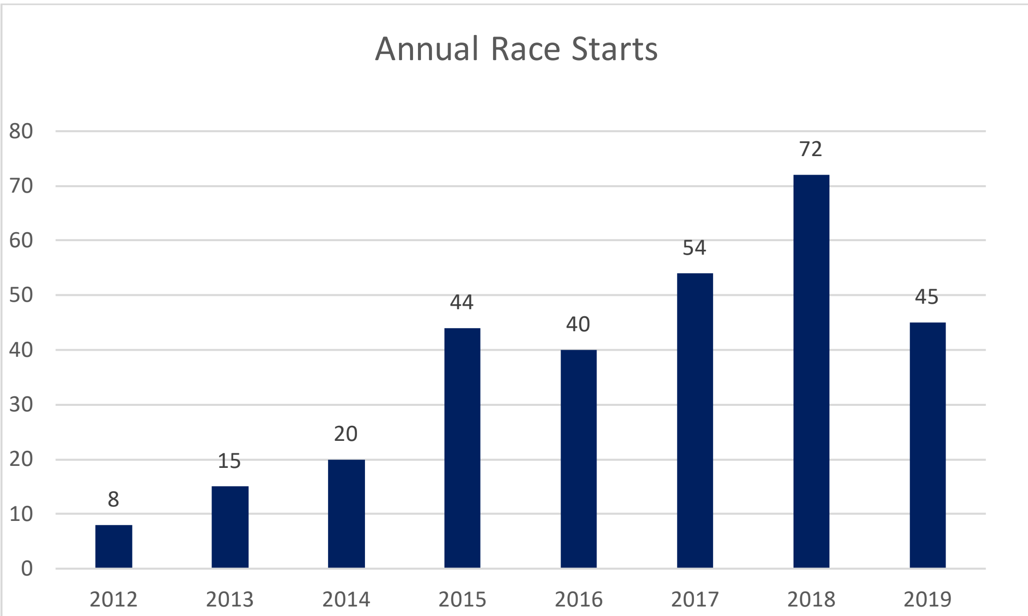


Figure 4. Athlete's annual race starts from 2012 – 2019.

There is a progression seen between 2012 – 2019. In 2016 there is a small decrease in the number of races, but this can be explained by his plans to finish high-school and his military service. There is a considerable reduction in racing in 2019 certainly the cause of this are the injuries he sustained in the middle of the season and the long recovery.

During the first three years of the study he is racing MTB events. There are considerably less races than the rest of the years but it's important to remember that the races are far away from where he lives and there relatively short events, so he is not travelling to a race unless it's a big race. The races he does compete in are the biggest races on the Finnish race calendar. Whether it's a conscious decision or not he ends up choosing quality over quantity.

In 2014 – 2015 he is invited to join Fincycling, a junior road race development team and he starts his transition over to road racing. In 2015 he races over 25 days of international competition against the best juniors around the world. The big junior stage races such as the UCI Nation Cup series typically provide 3-5 racing days each.
His race calendar for 2016 more than doubles his racing days from the previous year. In 2016 he mostly races domestic races and travels very little outside Finland. It has been previously explained that this decision was made to give him time to graduate from high school and finish his military service. There was a small reduction in the number of racing days, but the races are longer and faster in the U23 category and he races about 300 km more than in his junior year. The annual competition volume in hour and kilometres can be seen in (Figure 5.) This reduced race calendar also helps set him up for the next year and a move to French U23 team.

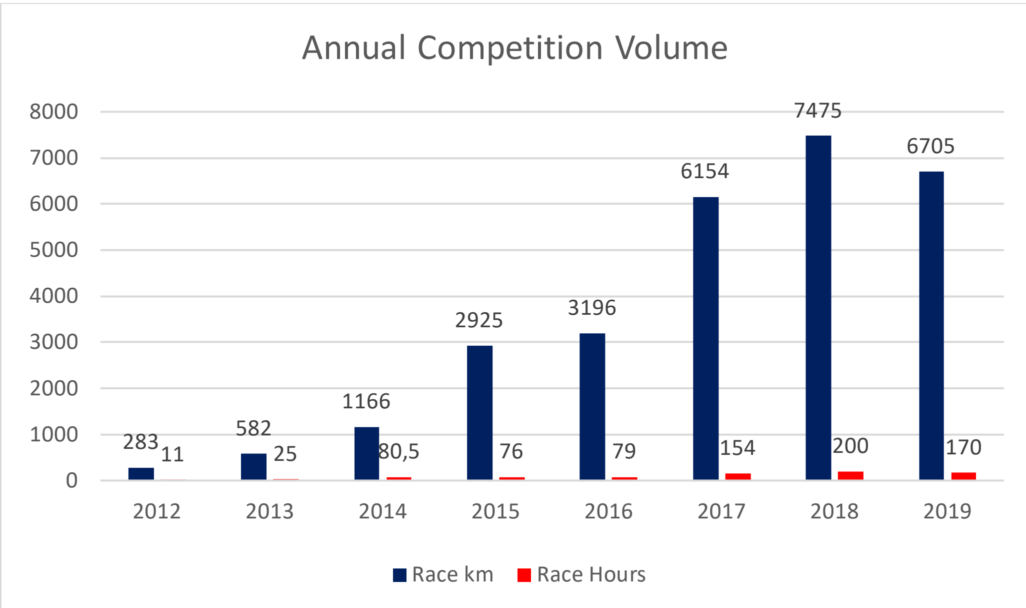


Figure 5. Athlete's annual competition volume measured in kilometres (blue bar) and hours (red bar) from 2012 – 2019.

His first year in France is 2017 and he races a lot, almost doubling the amount of racing he did in 2016. In total 154 hours of competition time in 2017 and over 6000 km of racing spread across 54 days of racing. In 2018 he totals 200 hours of racing and close to 7,500 km in competition in 72 racing days. In 2019 he has 45 race days, but this is explained by a crash in the middle of the season that sees him miss almost 2 months of racing. What is incredible about 2019 is that he starts his professional career on August 1 and between his first professional race and when he ends his season three months later, he races 27 times and accumulates almost 3400 km about 50% of his annual racing km in 27 race days.

It's also easy to see the progression he had when looking at the participants annual racing volume. In total he has raced 28,486 km in 298 days. The two biggest reasons for the increase in annual racing kilometres are obviously due to an increase in the number of competitions but also the races got much longer. In 2012 his longest one day race is 90 km. As a junior his longest stage races was 380 km over 5 stages which he did in a time of 8:58:13. Compare that to 2019 his longest one day race is 227 km and he finishes with a time of 5:49:27 and his longest stage race was 4 stages that totalled 710 km which took 18:31:19.

6.1.3 Training Intensity Distribution

The athlete's training intensity distribution over eight years is shown in Figure 6. From 2012 – 2017 the athlete used a five-zone training intensity scale and then switched to a seven-intensity zone scale in 2018. The intensity zones are based on a percentages of the athlete's maximum heart rate. Zone 1 and 2 represent LIT, Zone 3 is MIT and Zone 4 - 7 are considered HIT.

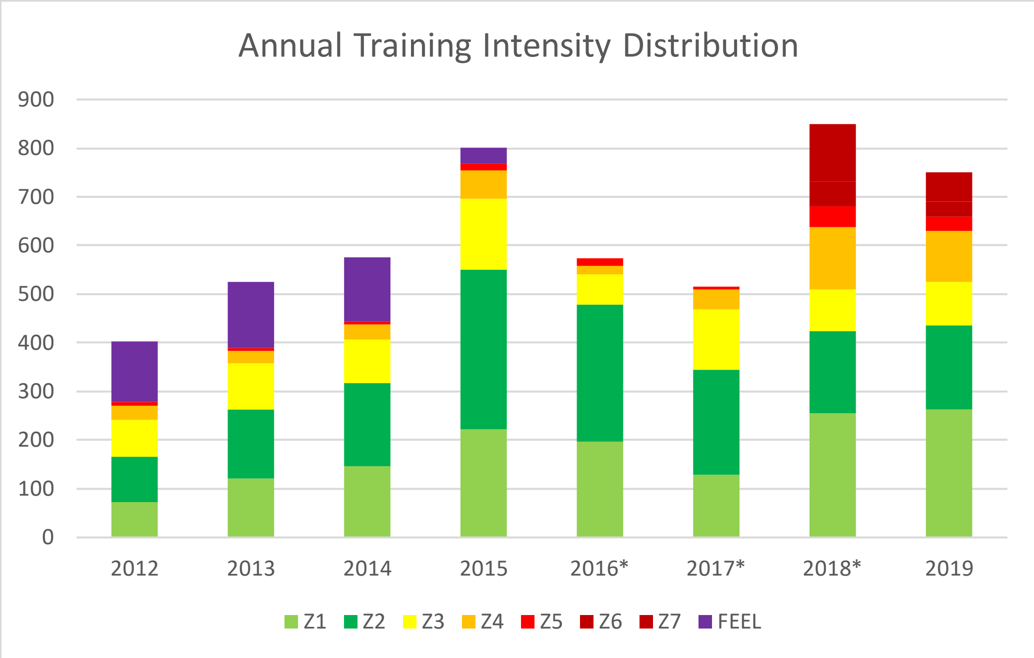


Figure 6. The athlete's annual training intensity distribution measured by time in intensity zone based on heart rate values. Green is LIT, yellow is MIT and red is HIT. Purple represents training by feeling without any device to monitor intensity.

The athlete appears to select a pyramidal TID where LIT makes up the greatest amount of training, MIT is the next largest portion of training and HIT makes up the least amount of the training. In Figure 6. low intensity training (zones 1 & 2) are coloured in green and make up largest percentage of the training. Zone 3 is coloured in yellow and is considered to be MIT, this makes up the next biggest volume of training. Finally, the HIT zones are 4, 5, 6 and 7 and these zones have been coloured in red. They make up the smallest portion of the training volume. It's interesting that this TID pattern emerged before the athlete had a coach, so this is probably what he feels works best for him. Also, interesting that in the first years a substantial part of the athlete's training was made by feel without the use of a heart rate monitor or power meter. This is obviously something that he felt would benefit him later.

6.1.4 Performance in Competition.

The author thought it would be interesting to compare the number of times each year that the athlete finished in the top 10 riders to the number of times he raced per season. See Figure 7. for more information. The thought behind this was it may be possible to measure performance by comparing top 10 placings with race days. The results were interesting if nothing else.

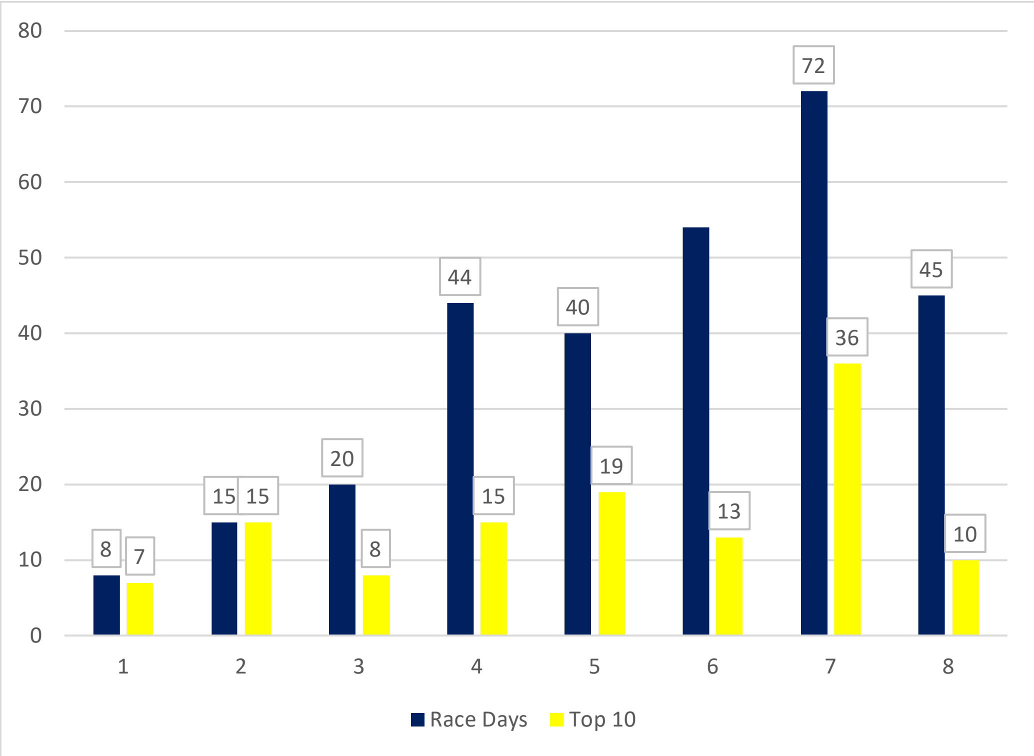


Figure 7. Race days (blue bars) compared to Top 10 places (yellow bars) as a measure of performance.

The first thing we see is that during the first two years the athlete finishes in the top 10 almost as many times as he races. This tells us two things he was a talent national rider at a young age and there may not have been that many boys his age racing in the same events with him. In 2015 he starts to race internationally in some pretty tough junior races. He gets a couple good results internationally, but the big change is he becomes an even stronger rider at the national level. In 2016 a lot of his races are in Finland and he is doing very well nationally, one of the top riders in the country at the time. His next challenge is going to France and as previously stated the first spring there is really hard, and the results take a while to come. When he gets used to the racing there, he starts to get some good results and 2018 he makes some really big results and starts to get noticed by professional teams. In cycling as you move through the ranks the selection of talented individuals gets more and more elite. By the time he reaches the World Tour he is with the elite of the elite and finishing in the top 10 of any races is very rare. The athlete's first season as a pro is only about three months long but he manages to grab a fourth-place finish in the UCI race Tour du Doubs.

7 Discussion

The purpose of this study was to investigate how the participant's training characteristics changed over an eight-year period. The training characteristics that were the focus of this study was a) training volume, b) competition volume, c) training intensity distribution, and then the study looked at competition results.

The main findings of this study were training volume and competition volume both increased every year accept in the final year of the study, but this may be due to a crash that kept the participant from regular training and competition for over five weeks during the race season. The study also showed that the athlete selected a training intensity distribution (TID) that most resembled a pyramidal TID where LIT>MIT>HIT (Treff et al. 2019, 7). there were no significant changes observed between 2012 – 2017

7.1.1 Training Volume and Frequency

To add some further discussion on the athlete's training volume from 2015 – 2019 it appears that the athlete's training volume is likely at higher end of what cyclists are doing in each of those years for example Svendsen et al. (2018, 12-13.) reported that juniors in their study that went on to become World Tour professionals were all training between 600 – 800 hours per year at age 18. The participant had just over 800 hours in 2015 when he was 18 years old.

The next step up is U23 and while the participant's road cycling data is missing from this study I looked at training data from strava (www.strava.com) of two U23 athletes coming from the same team as the participant, and who share the same coach and are on the same development pathway as the athlete in this study. Their data shows that they are training about 800-900 hours per year as U23 athletes. It was also told that the participant trains almost seven days a week and looking at his published strava data we can see that many of his rides are between 3 – 6 hours. With this in mind it seems reasonable that the athlete in this study has ridden between 800-900 hours per year between 2016 – 2017.

In terms of the practical application of training volume, there is probably a threshold of volume that must be surpased to be successful at different levels off the sport, a good rule of thumb could be 600-800 hours for juniors, 800-900 hours for U23 riders and 900-1000 hours for professionals.

7.1.2 Competition Volume

Over the study the number of racing days the athlete made increased from 8 to 72. Competition hours increased in almost every season from 11 to 200 hours per year. Where there were exceptions to this we see that kilometers raced went way up and of course it was observed that race kilometers increased from 283 km to almost 7,500 km.

According to Svendsen et al. (2018, 9) there was a noticeable difference in competition volume in junior riders that went on to the world tour. This difference appeared to be the result of those riders taking part in longer races and also the tendency for those riders to race a greater number of races. They also reported that those riders that went on to race at the World Tour level raced between 70-120 hours as juniors (Svendsen et al. 2018, 13). The participant in this study raced 76 hours in the year he was 18 years old and then 150-200 hours in the last two years in the U23 category. This shows the basic physical stress that this athlete had to handle every year and racing 200 hours and 7,500 km over a season requires durability. Young athletes and coaches should be aware of this and organize the training in away that builds that physiological durabily over time so that the athlete is able to handle that kind of training and competition load. This is obviously one reason why elite cyclists would select a high volume training plan

7.1.3 Training Intensity Distribution

As previously stated the athlete's training intensity distributuon most resembled the pyramidal model where LIT>MIT>HIT (Treff et al. 2019, 7). This is most clearly seen between the years of 2012 – 2017. When the athlete switches to the seven-zone intensity scale there seems to be a significant increase in HIT. I'm not sure how to explain the addition of so much high intensity training. On one hand it could be the number of races the participant was in. Although Sanders, Van Erp and de Koning (2018, 14) reported that the mean heart rate for men during a one-day race is 74% of heart rate max and stages races it is 69% of heart rate max. They also showed that men don't spend that much time in Zone 5 or above in races (Sanders, van Erp and de Koning, 2018, 20).

7.1.4 Competition Performance

The final thing that was investigated was the athlete's top 10 finishes over the eight years. This was compared to annual racing days to measure the athlete's performance. The results showed that the participant has always been an exceptionally good domestic rider which is no surprise. When the athlete goes to international competitions as a junior or moves to France and starts riding with some of the best U23 riders in Europe finishing in the top 10 of a race should get more and more difficult and by the time you reach the World Tour a top 10 race finish is already quite rare. The athlete in this study improves in every age group and does quite well to place in the top 10 riders quite often. His biggest result as a professional was a fourth-place finish in the Tour du Doub a UCI 1.1 race in his first three months of racing at the World Tour level.

7.1.5 Limitations and Trustworthiness

There are obviously some big limitations to this study, this was a case study and case studies are the weakest form of scientific evidence. Second professional athletes are busy and their training data is really valuable, in some cases it can be the difference between being employed or unemployed and this meant that there was limited access to the athlete and his training files. The most obvious problem with this study is the missing training data from 2016 and 2017. These are important years in the development of they cyclist and unfortunately this study can't present an accurate picture of those years. I'm also not sure what to make of the increase in high intensity training seen in 2018 and 2012.

I think that the athlete did a good job reporting his training data to me and I trust the information that was presented in this study. Sylta, Tønnessen, & Seiler (2014, 91) reported that elite endurance athletes do report their training data accurately. I believe that other than data that is missing, the information presented in this thesis can be trusted. My confidence in the training data is supported by the interview because that gave an opportunity to ask the athlete to fill in some of those gaps and then there was a good amount of publically available information such as previous interviews the athlete had done as well as training files that could be viewed from strava and analysed help give a fuller picture of what actually happened.

8 Conclusions

The purpose of this thesis was to investigate how the athletes training characteristics changed over an eight-year period. The aim was then to give a description of the athlete's maturation to elite status in regard to training volume, competition volume, training intensity distribution and competitive results. It's the authors opinion that this was accomplished in all the areas to a satisfactory level with exception to the performance in competition chapter which didn't really work the way it had been intended.

These kinds of descriptive studies are important because they help grow our understanding of the demands of professional cycling and roads that young athletes will have to follow to get there. There is a current lack of this kind of study, so more case studies that describe the training process of young individuals and their maturation to elite status are needed. As for what the author learned while doing this research, this thesis was really a chance to organize most of the things that I have learned over the last three years in a way that I hope is coherent and valuable for people who will read this thesis. The big take away for me is that training is really a process that evolves over many years and as coaches we should not get focused on individual sessions, we need to have a much broader perspective of training that allows an athlete to progress and become more durable over a number of years of training.

Acknowledgements

The author would like to thank the athlete for his participation and generosity. The author would also like to thank Fincycling for their support of this project.

References

Abt, J.P., Smoliga, J.M., Brick, M.J., Jolly, J.T., Lephart, S.M., and Fu, F.H. (2007). Relationship between cycling mechanics and core stability. Journal of strength and conditioning research, 21 4, 1300-4.

Bassett, D. R., Jr. (2002) Scientific contributions of A. V. Hill: exercise physiology pioneer. Journal of Applied Physiology 93: 1567–1582,

Billat V, Demarle A, Slawinski J, Paiva M, & Koralsztein JP (2001). Physical and training characteristics of top-class marathon runners. Med Sci Sports Exerc 33: 2089–2097

Billat V, Lepretre PM, Heugas AM, Laurence MH, Salim D, et al. (2003). Training and bioenergetic characteristics in elite male and female Kenyan runners. Medicine Science & Sports Exercise 35: 297–304.

Cheung, S.S. & Zabala, M. (2017). Cycling Science. Human Kinetics, United Kingdom

Conley DL & Krahenbuhl GS (1980). Running economy and distance running performance of highly trained athletes. Med Sci Sports Exercise 12, 357–360.

Costill D, Fink WJ & Pollock ML (1976). Muscle fiber composition and enzyme activities of elite distance runners. Med Sci Sports 8, 96–100.

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

Coyle, E.F., Feltners, M., Kautz, S., Hamilton, M., Montain, S., Baylor, A., Abraham, L. & Petrek, G. (1991). Physiological and biomechanical factors associated with elite endurance cycling performance. Medicine & Science in Sports & Exercise. 23:1, 93–107

Coyle EF, Martin WH 3rd, Sinacore DR, Joyner, MJ & Holloszy, JO (1984). Time course of loss of adaptations after stopping prolonged intense endurance training. Journal of Applied Physiology 57, 1857–1864

Coyle EF, Sidossis LS, Horowitz JF & Beltz JD (1992). Cycling efficiency is related to the percentage of type I muscle fibers. Med Sci Sports Exerc 24, 782–788.

Denis C, Dormois D, Lacour J. R. (1984). Endurance training, VO2 max, and OBLA: a longitudinal study of two different age groups. International Journal of Sports Medicine 5: 167–173

Edwards, A. M., and Polman, R. C. J. (2013). Pacing and awareness: brain regulation of physical activity. Sport Med. 43, 1057–1064.

Ekblom and, B & Hermansen, L. (1968) Cardiac Output in Athletes. Journal of Applied Physiology 25:5, 619-625

Elferink-Gemser, (2013). Olympia exists Pushing boundaries for talented athletes: Talent Identification and Development in Sports Research Group. HAN University of Applied Sciences Press, Arnhem, The Netherlands.

Elferink-Gemser, M.T., Jordet, G., Coelho-E-Silva, M.J., Visscher, C. (2011). The marvels of elite sports: how to get there? British Journal of Sports Medicine, 45:9, 683-684.

Esteve-Lanao, J., Foster, C., Seiler, S., and Lucia, A. (2007). Impact of training intensity distribution on performance in endurance athletes. Journal of Strength & Conditioning Research. 21, 943–949. doi: 10.1519/00124278-200708000-00048

Farrell P, Wilmore JH, Coyle EF, Billing JE & Costill DL (1979). Plasma lactate accumulation and distance running performance. Med Sci Sports 25, 1091–1097.

Foster C, Heiman KM, Esten PL, Brice G, Porcari J (2001). Differences in perceptions of training by coaches and athletes. South African Journal of Sports Medicine 8, 3-7

Foster, C., Hendrickson, K. J., Peyer, K., Reiner, B., Lucia, A., Battista, R. A., et al. (2009). Pattern of developing the performance template. British Journal of Sports Medicine. 43, 765–769

Foster C, Hoyos J, Earnest C, Lucia A (2005). Regulation of energy expenditure during prolonged athletic competition. Medicine and Science in Sports and Exercise 37, 670-675

Gaskill SE, Walker AJ, Serfass RA, Bouchard C, Gagnon J, Rao DC, Skinner JS, Wilmore JH, Leon AS. (2001) Changes in ventilatory threshold with exercise training in a sedentary population: the HERITAGE Family Study. International Journal of Sports Medicine 22:8, 586–92.

Ghosh, A. K. (2004). Anaerobic Threshold: Its Concept and Role in Endurance Sport. Malaysian Journal of Medical Sciences, 11:1, 24-36

Haugen, T., Paulsen, G., Seiler, S., and Sandbakk, Ø. (2018). New Records in Human Power. URL: http:// www.researchgate.net

Haugen, T., Paulsen, G., Seiler, S., and Sandbakk, Ø. (2018). New Records in Human Power.International Journal of Sports Physiology and Performance 13:6, 678-686

Haugen, T. A., Solberg, P. A., Foster, C., Morán-Navarro, R., Breitschädel, F., and Hopkins, W. G. (2018). Peak age and performance progression in world class track-and-field athletes. International Journal of Sports Physiology and Performance. 13, 1122–1129. Accessed manuscript from URL: http://www.researchgate.net on 15.11.2019

Hawley, J. A. & Stepto N.K. (2001). Adaptations to Training in Endurance Cyclists Implications for Performance. Journal of Sports Medicine; 31:7, 511-520

Hettinga, F. J., De Koning, J. J., and Foster, C. (2009). VO2 response in supramaximal cycling time trial exercise of 750 to 4000 m. Med. Sci. Sports Exerc. 41, 230–236. doi: 10.1249/MSS.0b013e3181831f0f

Hofmann P and Tschakert G (2017) Intensity- and Duration-Based Options to Regulate Endurance Training. Front. Physiol. 8:337. doi: 10.3389/fphys.2017.00337

Hopker, J., Coleman, D., Passfield, L., and Wiles, J. (2010). The effect of training volume and intensity on competitive cyclists' efficiency. Appl. Physiol. Nutr. Metab. 35, 17–22. doi: 10.1139/H09-124

Hopker, J & Jobson, S. (2012). Performance Cycling: The Science of Success. Bloomsbury Publishing Plc, London.

Haugen, T. A., Solberg, P. A., Foster, C., Morán-Navarro, R., Breitschädel, F., and Hopkins, W. G. (2018). Peak age and performance progression in worldclass track-and-field athletes. Int. J. Sports Physiol. Perform. 13, 1122–1129.

Holloszy JO, Rennie MJ, Hickson RC, Conlee RK & Hagberg JM (1977). Physiological consequences of the biochemical adaptations to endurance exercise. Annals of the New York Academy of Sciences 301, 441–450.

Holloszy JO & Coyle EF (1984). Adaptations of skeletal muscle to endurance exercise and their metabolic consequences. J Appl Physiol 56, 831–838.

Hutchinson, A. (2019) The Story of the Cyclist with the Highest-Ever VO2max. URL: https://www.outsideonline.com/2398524/highest-ever-vo2max-cyclist-oskar-svendsen, accessed November 27, 2019

Hutchinson, A. (2018). Endure: Mind, Body, and the Curiously Elastic Limits of Human Peformance. William Morrow, New York, NY.

Jones, A. M. (1998). A five-year physiological case study of an Olympic runner. British Journal of Sports Medicine, 32:1, 39–43.

Jones, A. M. (2006). The physiology of the world record holder for the women's marathon. International Journal of Sports Science and Coaching, 1:2, 101–116.

Jonker, L., Elferink-Gemser, M. T., and Visscher, C. (2010). Differences in selfregulatory skills among talented athletes: the significance of competitive level and type of sport. Journal of Sports Science 28, 901–908

Joyner, M. J. (1991). Modelling: optimal marathon performance on the basis of physiological factors. J. Appl. Physiol. 70:Z, 683-687,

Joyner, M. J. and Coyle, E. F. (2008), Endurance exercise performance: the physiology of champions. The Journal of Physiology, 586: 35-44.

Kindermann W, Simon G, Keul J. (1979) The significance of the aerobic-anaerobic determination of workload intensities during endurance training. European Journal of Applied Physiology. 42: 25–34.

Lambrick, D., Rowlands, A., Rowland, T., and Eston, R. (2013). Pacing strategies of inexperienced children during repeated 800 m individual time-trials and simulated competition. Pediatr. Exerc. Sci. 25, 198–211. doi: 10.1123/pes.25.2.198

Laursen, P & Buchheit, M. (2019). Science and Application of High-Intensity Interval Training: Solutions to the Programming Puzzle. Human Kinetics, USA.

Londeree BR. (1997) Effect of training on lactate/ventilatory thresholds: a meta analysis. Medicine Science and Sports Exercise. 29, 837–843.

Lucia, A., Hoyos, J., & Chicharro, J. L. (2001). Physiology of Professional Road Cycling. Sports Medicine, 31(5), 325–337.

Martin W 3rd, Coyle EF, Bloomfield SA & Ehsani AA (1986). Effects of physical deconditioning after intense endurance training on left ventricular dimensions and stroke volume. Journal of American College of Cardiology 7, 982–989.

Menting SGP, Hendry DT, Schiphof-Godart L, Elferink-Gemser MT and Hettinga FJ (2019). Optimal Development of Youth Athletes Toward Elite Athletic Performance: How to Coach Their Motivation, Plan Exercise Training, and Pace the Race. Front. Sports Act. Living 1:14, 1-8. doi: 10.3389/fspor.2019.00014

Micklewright, D., Angus, C., Suddaby, J., St. Clair, G. A., Sandercock, G., and Chinnasamy, C. (2012). Pacing strategy in schoolchildren differs with age and cognitive development. Medicine and Science in Sports Exercercise 44, 362–369.

Micklewright, D., Papadopoulou, E., Swart, J., and Noakes, T. D. (2010). Previous experience influences pacing during 20 km time trial cycling. Br. Journal of. Sports Medicine, 44, 952–960.

Millet G, Jaouen B, Borrani F & Candau R (2002). Effects of concurrent endurance and strength training on running economy and. VO2 kinetics. Medicine Science and Sports Exercercise 34, 1351–1359.

Moseley L, Achten J, Martin JC & Jeukendrup AE (2004). No differences in cycling efficiency between world-class and recreational cyclists. Int J Sports Med 25, 374–379.

Mujika, I & Padilla, S. (2001). Physiological and Performance Characteristics of Male Professional Road Cyclists. Sports Med. 31:7, 479-487

Nimmerichter, A. (2018) Elite Youth Cycling. Routledge, New York, NY.

Paavolainen, L., Häkkinen, K., Hämäläinen, I., Nummela, A. & Rusko, H. (1999). Explosive-strength training improves 5-km running time by improving running economy and muscle power. Journal of Applied Physiology, 86, 1527–1533.

Pinot, J & Grappe, F. (2015). A six-year monitoring case study of a top-10 cycling Grand Tour finisher, Journal of Sports Sciences, 33:9, 907-914,

Post, E. G., Trigsted, S. M., Riekena, J. W., Hetzel, S., McGuine, T. A., Brooks M. A., and Bell, D.R. (2017). The Association of Sport Specialization and Training Volume with Injury History in Youth Athletes, American Journal of Sports Medicine 45:6, 1405 – 1412.

Rønnestad, B.R. and Mujika, I. (2014) Optimising strength training for running and cycling endurance performance: A review, Scandinavian Journal of of Medicine and Science in Sport 24:4, 603-612.

Rønnestad, B.R., Hansen, J., Hollan, I., and Ellefsen, S. (2015) Strength training improves performance and pedaling characteristics in elite cyclits', European Journal of Applied Physiology, 25:1, e89-98

Rønnestad, B.R., Hansen, E. A., and Raastad, T. (2010) In-season maintenance training increases well-trained cyclists' performance, European Journal of Applied Physiology, 110:6, 1269-1282

Saltin, B. & Åstrand, P.O. (1967). Maximal Oxygen Uptake in Athletes. Journal of Applied Physiology. 23:3, 353-358

Sanders, D & Erp, T & de Koning, Jo. (2018). Intensity and Load Characteristics of Professional Road Cycling: Differences Between Men's and Women's Races. International Journal of Sports Physiology and Performance. 14. 1-23. 10.1123/ijspp.2018-0190.

Seiler, S. (2010). What is Best Practice for Training Intensity and Duration Distribution in Endurance Athletes? International Journal of Sports Physiology and Performance 5, 3, 276-291, available from: <https://doi.org/10.1123/ijspp.5.3.276> [Accessed 13 November 2019]

Seiler, K. S., and Kjerland, G. Ø. (2006). Quantifying training intensity distribution in elite endurance athletes: is there evidence for an "optimal" distribution? Scandinavian Journal of Med. Science. Sports 16, 49–56. doi: 10.1111/j.1600-0838.2004. 00418.x

Seiler, S & Tønnessen, E. (2009). Intervals, Thresholds, and Long Slow Distance: The Role of Intensity and Duration in Endurance Training. Sport Science. 2009; 13:11, 32-53.

Schiphof-Godart, L., and Hettinga, F. J. (2017). Passion and pacing in endurance performance. Front. Physiol. 8:83, 1-6. doi: 10.3389/fphys.2017.00083

Sjodin, B. & Svedenhag, J. (1985) Applied physiology of marathon running. Sports Medicine 2:2, 83 – 99.

Smits, B. L. M., Pepping, G.-J., and Hettinga, F. J. (2014). Pacing and decision making in sport and exercise: the roles of perception and action in the regulation of exercise intensity. Journal of Sport Medicine. 44, 763–775.

Solli GS, Tønnessen E and Sandbakk Ø (2017) The Training Characteristics of the World's Most Successful Female Cross-Country Skier. Front. Physiol. 8:1069. doi: 10.3389/fphys.2017.01069

Stöggl TL and Sperlich B (2015) The training intensity distribution among well-trained and elite endurance athletes. Front. Physiol. 6:295. doi: 10.3389/fphys.2015.00295

Stoter, I. K., MacIntosh, B. R., Fletcher, J. R., Pootz, S., Zijdewind, I., and Hettinga, F. J. (2016). Pacing strategy, muscle fatigue, and technique in 1500-m speedskating and cycling time trials. Int. J. Sports Physiol. Perform. 11, 337–343.

Svendsen, I. S., Tønnesen, E., Tjelta, L., and Ørn, S. (2018). Training, Performance, and Physiological Predictors of a Successful Elite Senior Career in Junior Competitive Road Cyclists.International. Journal of Sports Physiology and Performance 13, 10, 1287-1292, manuscript available from: http://www.researchgate.net accessed 13 November 2019

Tjelta, L. I. (2019).Three Norwegian brothers all European 1500 m champions: What is the secret? International Journal of Sports Science & Coaching. 0(0) 1–7, DOI: 10.1177/1747954119872321

Tønnessen, E. (2010) The Norwegian model: How do the best Norwegian endurance athletes train? Presentation Slides. URL: http://www.hunrowing.hu/files/Utholdenhetstrening%20-Ro-seminar(Januar2010)-Engelsk.pdf. Accessed 10.10.2019. 1-15

Tønnessen E, Sylta Ø, Haugen TA, Hem E, Svendsen IS, et al. (2014) The Road to Gold: Training and Peaking Characteristics in the Year Prior to a Gold Medal Endurance Performance. PLoS ONE 9(7): e101796. doi:10.1371/journal.pone.0101796

Treff G, Winkert K, Sareban M, Steinacker JM and Sperlich B (2019) The Polarization-Index: A Simple Calculation to Distinguish Polarized from Non-polarized Training Intensity Distributions. Front. Physiol. 10:707. doi: 10.3389/fphys.2019.00707

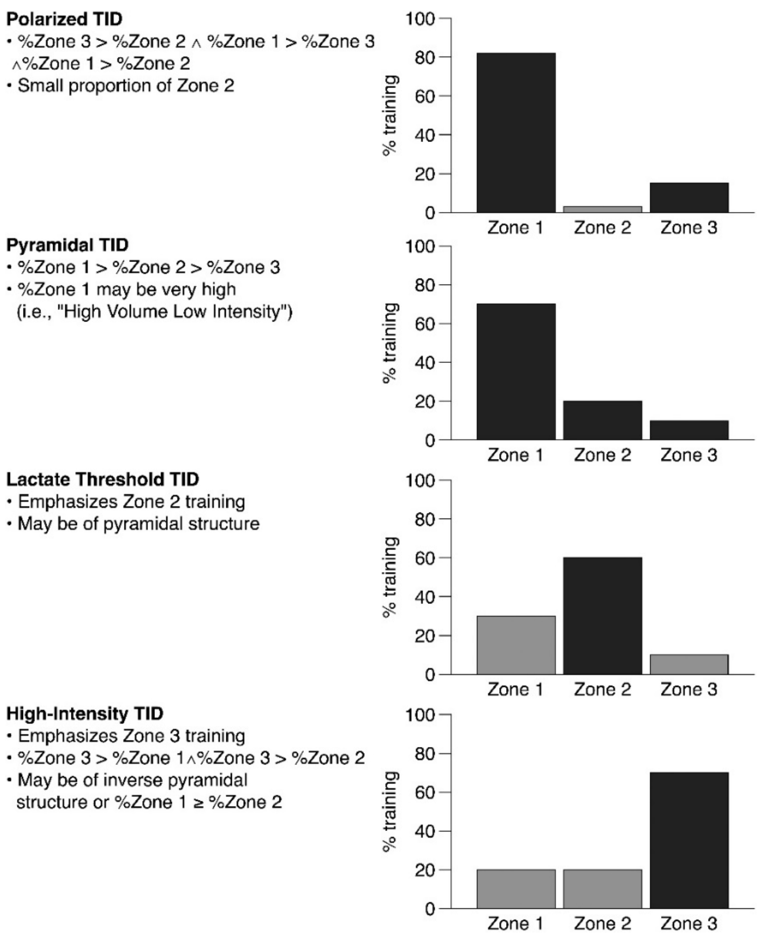
van Erp, T., Sanders, D., and de Koning, J. J. (2019). Training Characteristics of Male and Female Professional Road Cyclists: A 4-Year Retrospective Analysis. International Journal of Sports Physiology and Performance, 1-7, manuscript available from: http://www.researchgate.net accessed 13 November 2019

Wenger HA, Bell GJ (1986) The Interactions of Intensity, Frequency and Duration of Exercise Training in Altering Cardiorespiratory Fitness. Sports Med 3: 346–356

Weber, S. The Likely Physiology Behind INEOS 1:59 Project. 27/10/2019. INSCYD Blog. URL: https://www.inscyd.com/blog/2019/9/26/physiologyeliudkipchoge. Accessed 02 November 2019.

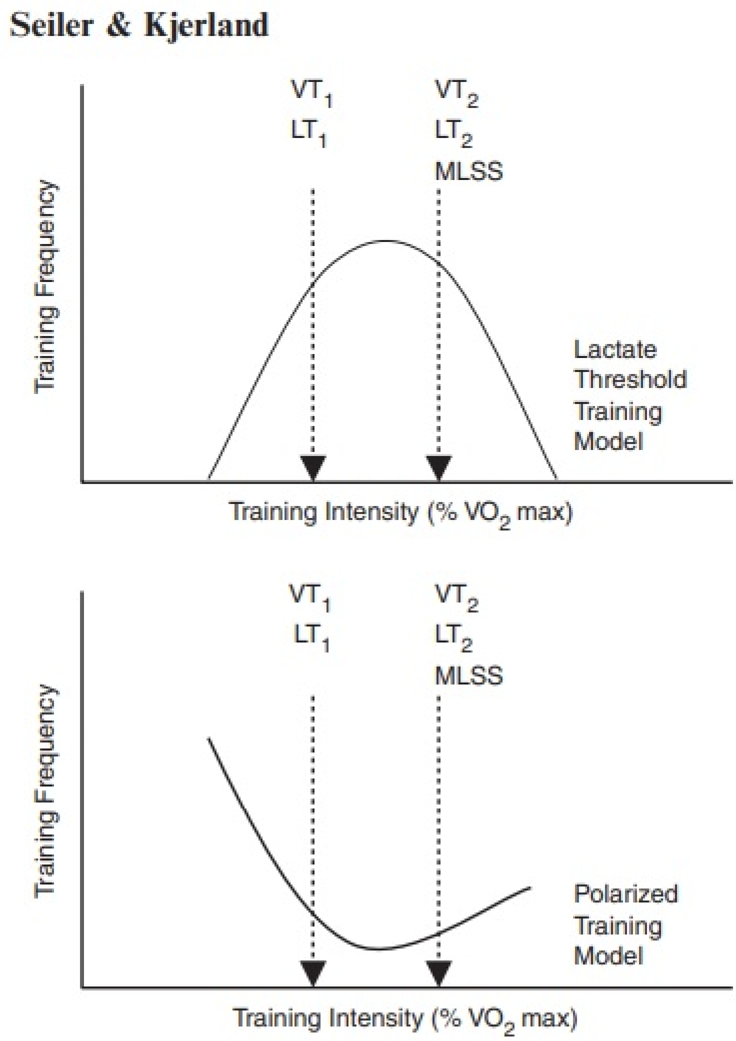
Appendices

Appendix 1. Training Intensity Distribution Models



Appendix 1: Various training intensity distributions (TID), and the representative proportions, and key characteristics (indicated by black bars). Zones refer to following intensities: Zone 1 (EASY/LIT), training performed under the first lactate or ventilatory threshold; Zone 2 (Moderate/MIT), training performed at or between the first and second lactate or ventilatory thresholds; Zone 3 (Hard/ HIT), training performed above the second lactate or ventilatory threshold. Taken from (Treff et al., 2019)

Appendix 2. Physiological bases for three zone intensity scale



Appendix 2. comes from (Seiler and Kjerland, 2006) “A conceptual training intensity distributions associated with (a) the threshold training model – emphasizing training between the first and second lactate/ventilatory thresholds and (b) the polarized training model – emphasizing a large volume of training below the first lactate or ventilatory threshold combined with significant doses of training with loads eliciting 90–100% of VO2max.”