Physiological demands of the Absa Cape Epic mountain bike race and predictors of performance.

by Marli Greeff

Thesis presented in partial fulfilment of the requirements for the degree of Master of Sport Science, at Stellenbosch University

Supervisor: Prof Elmarie Terblanche

December 2014

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature: **Marli Greeff**

Date: **19 November 2014**

Abstract

The purpose of this qualitative-quantitative study was to describe the exercise intensity and predictors of performance of a multi-stage mountain bike (MTB) race (2014 Absa Cape Epic) lasting 8 days. Twenty-three amateur mountain bikers (age 39 ± 9 years, height 178.8 ± 8.2 cm, body mass 74.7 ± 9.1 kg, VO_{2max} 54 ± 7 $ml.kg^{-1}.min^{-1}$) who completed the 2014 Absa Cape Epic were involved in the study. The participants were divided into two groups according to their MTB experience. The experienced group included participants who previously completed more than three 3-day multi-stage MTB events and the novices group included those who has completed less than 3-day multi-stage MTB events.

Prior to the event the participants completed a maximal aerobic cycling test and a simulated 40 km time trial (TT). The maximal aerobic test was used to determine 3 work intensity zones based on heart rate (HR) corresponding to blood lactate thresholds (LT: increase in blood lactate concentration of 1 $mmol.l^{-1}$ above baseline values and the onset of blood lactate accumulation (OBLA), a fixed blood lactate concentration of 4 $mmol.l^{-1}$). There were no statistically significant differences in the physical, physiological and performance variables measured in the laboratory between the two groups.

The exercise intensity during the Cape Epic was measured using telemetric HR monitoring sets. RPE values were noted after each stage of the race. The mean HR was 88.1 ± 5.3% (experienced) and 84.2 ± 11.0% (novices) of maximal HR during the race or 88.9 ± 3.5% (experienced) and 85.9 ± 10.6 (novices) of laboratory determined maximum HR. More time was spent in the “low” HR zone (43.1 % vs 58.5 %, respectively), while only a small amount of time was spent in the “hard” HR zone (7.4% and 6.1%, respectively). The experienced group spent statistically significantly more time in the “moderate” HR zone compared to the novices group (49.5 % vs. 35.4 %). The experienced group performed significantly better during the event compared to the novices group in both the total event time (P = 0.004) and the general classification (P = 0.01).

Relative and absolute power output (PO) at OBLA (P = 0.01 and 0.02, respectively) were statistically significant predictors of total event time, while relative peak power output was a significant predictor of general classification for the event (P = 0.02) . The total TT time was a significant predictor of average event HR (P = 0.03).

This study showed that this MTB stage race is physiologically very demanding and requires cyclists to have excellent endurance capacity, as well as strength and power. The parameters from the maximal aerobic capacity test correlated better with outdoor performance than parameters from the simulated 40 km TT. Therefore the standard maximal aerobic capacity test are sufficient for testing mountain bikers and sport scientists can continue using this test to prescribe exercise intensity zones for training and events.

Opsomming

Die doel van hierdie kwalitatiewe-kwantitatiewe studie was om die oefeningsintensiteit en voorspellers van prestasie tydens ‘n multi-dag bergfiets kompetisie (Absa Cape Epic) van 8 dae lank te bepaal. Drie-en-twintig bergfietsryers (ouderdom 39 ± 9 jaar, lengte 178.8 ± 8.2 cm, liggaamsmassa 74.7 ± 9.1 kg, VO_{2maks} 54 ± 7 $ml.kg^{-1}.min^{-1}$) wat die 2014 Absa Cape Epic voltooi het, het aan die studie deelgeneem. Die deelnemers is in twee groepe verdeel volgens hulle ervaring in multi-dag bergfiets kompetisies. Die ervare groep was al die deelnemers wat meer as drie 3-dae multi-dag bergfiets kompetisies voltooi het. Die onervare groep was al die deelnemers wat minder as drie 3-dag multi-dag bergfiets kompetisies voltooi het.

Voor die kompetisie het al die deelnemers ‘n maksimale aërobiese toets en ‘n gesimuleerde 40 km tydtoets in die laboratorium voltooi. Die maksimale aërobiese toets is gebruik om drie werk intensiteit sones volgens die hartspoed te bepaal, naamlik die hartspoed by die laktaatdraaipunt(‘n toename in bloed [laktaat] van 1 $mmol.l^{-1}$ bo die basislynwaardes) en die hartspoed by die aanvang van bloedlaktaat akkummulasie (‘n vaste bloed [laktaat] waarde van 4 $mmol.l^{-1}$). Daar was geen statisties betekenisvolle verskille in die fisiese, fisiologiese en prestasie veranderlikes tussen die twee groepe nie.

Die oefeningsintensiteit tydens die Cape Epic was gemeet deur gebruik te maak van hartspoedmonitors. Die RPE waardes was aan die einde van elke skof genoteer. Die gemiddelde hartspoed was 88.1 ± 5.3 % (ervare) en 84.2 ± 11.0 % (onervare) van maksimale kompetisie hartspoed, of 88.9 ± 3.5 % (ervare) en 85.9 ± 10.6 % (onervare) van die maksimale hartspoed soos in die laboratorium gemeet.

Die fietsryers het meer tyd spandeer in die “lae” hartspoed sone (43.1 % vs 58.5 %, onderskeidelik), in vergelyking met die “moeilike” hartspoed sone (7.4 % vs 6.1 %, onderskeidelik). Die ervare groep het statisties betekenisvol meer tyd in die “matige” hartspoed sone spandeer (49.5 % vs. 35.4 %) in vergelyking met die onervere groep. Die ervare groep het beter presteer tydens die kompetisie vir beide totale kompetisie tyd (P = 0.004) en algehele klassifikasie (P = 0.01).

Relatiewe en absolute krag by aanvang van bloed laktaat akkumulasie was statisties betekenisvolle voorspellers van totale kompetisie tyd (P = 0.01 en 0.02, onderskeidelik), terwyl maksimale krag ‘n statisties betekenisvolle voorspeller was van algehele klassifikasie in die kompetisie (P = 0.02). Die totale tydtoets tyd was ‘n statisties betekenisvolle voorspeller van gemiddelde hartspoed tydens die kompetisie.

Die studie het gewys dat hierdie multi-dag bergfiets kompetisie fisiologies baie uitdagend is en dat fietsryers uistekende uithouvermoë kapasiteit, sowel as krag en plofkrag moet besit. Die veranderlikes van die maksimale aërobiese toets het beter met prestasie in die veld gekorreleer as die veranderlikes van die gesimuleerde 40 km tydtoets. Daar word dus afgelei dat die standaard maksimale aërobiese toets voldoende is vir die toetsing van bergfietsryers en sportwetenskaplikes kan aanhou om hierdie toets te gebruik om oefeningsintensiteit sones voor te skryf vir oefensessies en kompetisies.

Acknowledgements

"Education means inspiring someone's mind, not just filling their head" – Katie Lusk

I always saw my Master's degree as an opportunity to gain more experience in my field, being theoretical and practical. This past two years have opened my mind into the wonderful wonders of applied sport physiology. This journey wouldn't be possible without certain people in my life that formed the basis of my support not just financially but also emotionally.

First and foremost, I want to give praise to our heavenly Father for my abilities and for the strength He provided throughout the year.

Secondly, I would like to thank my family for providing me with the hope, courage and a lot of emotional and financial support. Thank you for providing an environment where giving up is not an option. Thank you for the guidance and the numerous times I was spoilt, just because I am Master's student.

In these two years I have been led and assisted by a very knowledgeable expert in the field of Sport Science. I would like to offer my sincere thanks and appreciation to Prof. Terblanche for guiding me in the right direction and inspiring me to do more and achieve more. Thank you for making me believe there is more to life than just doing "okay".

I would also like to extend my greatest appreciation for the funding that was provided by the National Research Foundation.

Lastly I would like to thank my amazing group of participants that completed the laboratory tests and the 2014 Cape Epic. Thank you for going the extra mile for me, especially on the days that you were covered in mud and dead tired. You really helped me to achieve results that would be of significance to athletes all over the world. The relationships that I built with you will always be treasured.

"If you can't explain it simple, you don't understand it well enough" – Albert Einstein

Thank you

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°C	:	Degrees Celsius
#	:	Number
%	:	Percentage
µl	:	Micro litre
[La]	:	Lactate Concentration
ACSM	:	American College of Sports Medicine
ANOVA	:	Analysis of Variance
AT	:	Anaerobic Threshold
BMI	:	Body Mass Index
bpm	:	Beats Per Minute
cm	:	Centimetre
CO_2	:	Carbon dioxide
COR	:	Coefficient of repeatability
D_{max}	:	The point that yields the maximum perpendicular from a line joining the first and last lactate measurements
ECG	:	Electrocardiogram
GC	:	General Classification
HR	:	Heart Rate
HR_{max}	:	Maximum Heart Rate
HR_{OBLA}	:	Heart Rate at Onset of Blood Lactate Concentration
HR_{AVE}	:	Average Heart Rate
$HR_{max\ Lab}$	:	Maximum Heart Rate obtained in the Laboratory
$HR_{max\ Field}$	:	Maximum Heart Rate obtained in the Field
Int	:	International
ISAK	:	International Standards for Anthropometric Assessment

IAT	:	Individual anaerobic threshold
IET	:	Incremental exercise test
ICC	:	Intra class Reliability
Km	:	Kilometre
Kg	:	Kilogram
$Kg.m^{-2}$	:	Kilogram per square metre
L	:	Litre
LT	:	Lactate Threshold
MTB	:	Mountain Bike
MTBs	:	Mountain bikes
MTBing	:	Mountain Biking
m	:	Metre
mm	:	Milimetre
min	:	Minutes
min:sec	:	minutes and seconds
ml	:	Millilitres
$mmol.l^{-1}$	:	Millimol per Litre
$ml.min^{-1}$	:	Millilitres per Minute
$ml.min^{-1}.kg^{-1}$	:	Millilitres per Minute per Kilogram
MLSS	:	Maximal Lactate Steady State
N_2	:	Nitrogen
NAT	:	National
NORBA	:	National Off-Road Bicycling Association
Nr	:	Number
n	:	Sample Size
OBLA	:	Onset Blood of Lactate Accumulation
OHT	:	One Hour Test
O_2	:	Oxygen

PPO	:	Peak Power Output
PO	:	Power Output
PO_{OBLA}	:	Power Output at Onset of Blood Lactate Accumulation
PO_{LT}	:	Power Output at Lactate Threshold
PPO: W	:	Peak Power Output to Body Mass ratio
PO_{OBLA} : W	:	Power Output at Onset Blood of Lactate Accumulation to Body Mass
PO_{LT}: W	:	Power Output at Lactate Threshold to Body Mass
P	:	Probability
RPE	:	Rating of Perceived Exertion
rpm	:	Revolutions per Minute
r	:	Correlation coefficient
RER	:	Respiratory Quotient
R^2	:	Correlation coefficient squared
RCT	:	Respiratory Compensation Threshold
RPE_{AVE}	:	Average Rating of Perceived Exertion
s	:	Seconds
SD	:	Standard Deviation
SEE	:	Standard Error of Estimate
SRM	:	Schoberer Rad Messtechnik
TT	:	Time Trial
TRIMP	:	Training Impulse
UCI	:	Union Cyliste Internationale
USCF	:	United States Cycling Federation
VO_{2max}	:	Maximal Aerobic Capacity
VO_2	:	Oxygen Consumption
VT	:	Ventilatory Threshold
VT_1	:	First Ventilatory Threshold
VT_2	:	Second Ventilatory Threshold

W	:	Watts

CHAPTER ONE

INTRODUCTION

The Absa Cape Epic is a mountain bike (MTB) stage race that is annually held in the Western Cape, South Africa. The inaugural Cape Epic was in 2004, during which 550 riders from 20 different countries participated (21% international). The race typically covers 700 km and lasts eight days, which includes a prologue on the first day followed by seven stages. The Absa Cape Epic attracts elite professional mountain bikers from around the world, who compete in teams of two. The event has shown impressive growth and from 2007 the race accommodated 1200 riders (600 teams) each year. To qualify for a finish, the teams have to stay together throughout the duration of the event. The times taken to finish each stage are aggregated to determine the overall winning team in each category.

The Absa Cape Epic has been accredited as Horst category (beyond categorisation) by the Union Cycliste Internationale (UCI). In 2005 the Cape Epic was awarded UCI status. This was the first ever team mountain bike stage race and at the time the only mountain bike race in Africa to feature on the UCI calendar. Also in 2005 the Cape Epic surpassed 2500 hours of global television to become the most televised mountain bike race of all time. The ladies race was awarded UCI Horst category (HC) status in 2011, allowing ladies to also earn UCI points during the race. In 2011 the Grand Masters category was announced for 2013, allowing cyclists to compete in this category if both team members are 50 years or older.

This prestige event had 13 World Champions riding the 2013 Cape Epic, as well as gold, silver and bronze medallists from the 2012 London Olympics. The Absa Cape Epic was described by Bart Brentjens (1996 Olympic gold medallist in mountain biking and former Absa Cape Epic winner) as the “Tour de France of mountain biking”.

The first mountain bike (MTB) marathon event, held in Eschlikon, Switzerland on 11 August 1990, marked the beginning of long distance racing in MTBing and has since evolved into one of the biggest mass movements in the history of MTBing (Wirnitzer & Kornexl, 2008). The cross-country marathon discipline is a mass start event. These events are quite different from Olympic cross-country. Cross-country marathons are longer than Olympic cross-country and therefore, the total distance and altitude climbed is considerably more (Wirnitzer & Kornexl, 2008).

The first published research study on a multi-stage MTB event was done by Wirnitzer and Kornexl (2008) and involved the 2004 TransAlp Challenge. This race and the ABSA Cape Epic have the same race format. These competitions are multiple day events comprising eight consecutive stages. Each day is equivalent to a cross-country marathon (Wirnitzer & Kornexl, 2008). These events are therefore considered the most difficult cross-country competitions in the world. For this reason it is important for coaches and athletes to fully understand the physical and physiological demands of these types of events. Cyclists competing in these events, whether they are professional or amateur cyclists, are interested to know their optimal intensity that can be maintained throughout the race. This intensity should be high enough in order to be competitive, but also be maintainable for the predicted duration of the event, without creating a situation where the athlete is without energy and unable to continue at a competitive pace. Furthermore, the knowledge of the exercise intensity during real life multi-stage MTB events is essential to develop appropriate training and nutritional strategies to sustain the physical demands of these events.

Another important aspect in competitive cycling is the monitoring of laboratory-based performance predictors. Many coaches work with sport scientists and sport physiologists to monitor the athlete's performance and progression throughout the season. These laboratory-based tests normally consist of a maximal oxygen uptake capacity test and a time trial. The information gained from these tests is then used to design individualised training programs according to the athlete's own heart rate response and power output values. Therefore athletes need to be monitored throughout the season to ensure that the training heart rate and power output zones are adapted according to changes in their training status.

Many studies have also reported good relationships between parameters obtained during these types of tests and outdoor competition performance (Hawley and Noakes, 1992; Impellizzeri *et al*., 2005a, Impellizzeri *et al*., 2005b; Prins *et al*., 2007; Gregory *et al*., 2007). By identifying these variables the coach can assess whether the athlete is at his best physical level for a certain competition. If the athlete is lacking in a certain component of his training, the training program can be adapted to address the shortcomings.

To date no studies have been done on the Absa Cape Epic event and therefore the purpose of this study was to quantify and describe a group of cyclists' exercise intensity profiles during the event by measuring their heart rates. A further aim was to construct a mathematical model whereby performance in this event can be predicted using laboratory exercise test measures.

CHAPTER TWO

THE ASSESSMENT AND MONITORING OF THE PHYSIOLOGICAL DEMANDS OF MOUNTAIN BIKE RACING

A. INTRODUCTION

The first MTB marathon event was held in Switzerland in 1990 and since then it has evolved into one of the biggest mass movements in the history of mountain biking (Wirnitzer & Kornexl, 2008). The cross-country marathon discipline is a mass start event where the athletes have to cover at least 60 km lasting at least three hours. Cross-country marathon races are characterized by repeated technical climbs and descents over a difficult off-road terrain (Wirnitzer & Kornexl, 2008) and are different from Olympic cross-country events. A marathon cross-country event is longer in distance as well as in altitude climbed and covers a point-to-point distance, whereas an Olympic cross-country event involves the repetition of identical laps (Wirnitzer & Kornexl, 2008).

Multi-stage MTB races require the athletes to cover distances from 23 km to 150 km a day for several consecutive days. The physical and physiological demands of these kinds of races are very demanding (Wirnitzer & Kornexl, 2008). From a physiological point of view, it seems obvious that performances with highly variable intensities such as found in MTB races might require different qualities compared to constant-load exercise (Stapelfeldt *et al.,* 2004). The physiological reaction to interval-shaped exercise is mainly dependent on the duration and intensity of the high-workload bouts, as well as the length of the subsequent recovery period (Stapelfeldt *et al.,* 2004). It can be assumed that MTB races with variable work demands require higher oxygen-dependent and oxygen-independent capacities than constant workload cycling exercise with comparable average power output (Stapelfeldt *et al.,* 2004).

MTB races require high metabolic capacities. Therefore, training has to be as specific as possible to meet the physiological requirements of these races. In order to prescribe optimal guidelines for training programmes, the physical work and the physiological responses to that work should be understood by sport scientists and coaches (MacDermid & Stannard, 2012). There is a scarcity of scientific research regarding the nature of work demand during cross-country MTB racing with specific reference to the true physiological and physical requirements of the sport (MacDermid & Stannard, 2012).

In order to participate in these events, athletes need to follow a precise training program. These training programs should be individualised and routinely monitored to detect adaptations to training stimuli. Laboratory tests are needed to determine the physical and physiological characteristics of athletes and also test their abilities to perform at competitive levels. Another use for these tests is to determine predictors of performance in the field and to make sure these measures are at desirable standards before the competitive season. The nature of laboratory tests and competitions are different and should be fully understood by sport scientists in order for them to make the necessary analysis and predictions.

The main difference between competitions and laboratory tests is that cyclists freely choose their exercise intensity in the field, while it is fixed in most laboratory tests. Laboratory tests are either conducted at a constant submaximal workload (i.e., time to exhaustion tests), or exercise intensity is increased incrementally until the participant reaches exhaustion (i.e., the VO_{2max} test). In another type of test, cyclists have to cover a set distance in the shortest possible time (i.e., time trial tests), generating the greatest amount of power possible over a set distance. This type of test is more representative of actual field competitions (Schabort *et al.,* 1998).

Previously, outdoor road race performance was correlated to VO_2 at LT determined from an incremental test to exhaustion, as well as mean power output during a simulated indoor race (Coyle *et al.* 1991), while peak power output correlated with a simulated indoor race (time trial) (Hawley and Noakes, 1992). However, these findings refer to road cycling performances. Prins *et al.* (2007) reported that the mean power produced during a Wingate test, expressed relative to body mass, was the best laboratory predictor for uphill cycling over either 1 km or 6 km (performed on a treadmill with a gradient of 12% and 6%, respectively). Therefore it remains to be seen which laboratory measures predicts cross-country MTBing in the field.

B. THE PHYSIOLOGICAL DEMANDS OF MOUNTAIN BIKE RACING

1. The importance of exercise intensity monitoring

The principle of training specificity with regard to the intensity at which cyclists train cannot be met unless the intensity and physiological demands of competitions are determined (Padilla *et al.,* 1999). The exercise intensity profile can thus be useful to understand the physiological demands of cycling competitions. Furthermore, there is enormous variability in the physiological demands of all types of cycling competitions, albeit road cycling or MTBing. There is not only variability on a day-to-day basis, but within a single stage and cyclists must be able to adapt to this variability through appropriate training programmes. It is, therefore, necessary to evaluate the exercise load during actual cycling competitions (Padilla *et al.,* 2001) to obtain a comprehensive picture of the actual demands that will be placed on a cyclist. This information can be applied, from a practical point of view, to help design proper training and nutritional programmes. A better knowledge of the physiological demands of the various parts of stage races can be extremely useful for the development and optimization of suitable training strategies (Padilla *et al.,* 2008).

1.1 A comparison between road cycling and mountain biking

In road cycling, races can vary in format from single-day events to three-week stage races (Lee *et al.,* 2002). The terrain can vary from predominantly flat to extremely mountainous (Lee *et al.,* 2002). In contrast, cross-country MTB races are usually mass-start competitions completed within a single day. Competitors complete several laps of a circuit course (±10 km per circuit, ranging from three to six circuits, lasting between 105 and 135 minutes) over diverse off-road terrain, consisting of dirt and gravel roads, narrow wilderness trails and open fields (Lee *et al.,* 2002). MTB races typically include technical descents and a significant proportion of hill climbing (Lee *et al.,* 2002).

During off-road cycling, intense and repeated isometric contractions of the arm and leg muscles are necessary to absorb shock and vibrations, and for bike handling and stabilization. This might lead to permanently elevated heart rates, especially in downhill sections performed on rough terrains (Wirnitzer & Kornexl, 2008). MacDermid & Stannard (2012) illustrated that the mechanical work performed and the physiological responses required by cross-country MTB cyclists are of a discontinuous nature as a result of the changes in the terrain and course features. Thus cross-country MTB racing is characterized by high-force, low-velocity pedalling during ascent, which, combined with high oscillating work rates, necessitates high oxygen-dependent energy provision with intermittent oxygen-independent contributions. Additional stress is caused by the downhill sections where cyclists have less opportunity for recovery compared with other cycling disciplines.

The start of cross-country MTB competitions is fundamentally important to the strategy of the whole race. The cyclists try to start in the first position to avoid slowing down when the road narrows so that they can enter in the single-track trails in a good position, because overtaking can be difficult on these tracks. A "starting loop" is added at the start of many cross-country competitions to spread out the riders in this initial part of the course. This allows the best cyclists to start in the front positions. For these reasons, mountain bikers are used to starting the race at very high exercise intensities (Impellizzeri *et al.,* 2002).

Impellizzeri *et al.* (2002) reported that the average HR of four different cross-country competitions with the added "starting loop" was 90 ± 3% of HR_{max} that corresponded to 84 ±3% of VO_{2max}, showing the high intensity that is required by these types of events. Stapelfeldt *et al.* (2004) also concluded that cross-country circuit races are performed at very high exercise intensities, with average competition HR close to 90% of HR_{max} for races up to two hours (Stapelfeldt *et al.,* 2004) and with power output values reaching 250 to 500 W during uphill cycling. These exercise intensities are similar to short road cycling time trials, but higher than road cycling stages of longer duration (Impellizzeri *et al.,* 2002). For example, the mean HR of professional cyclists during semi-mountainous and high-mountainous stages (mean duration of 302 ± 57 min and 355 ± 67 min, respectively) was 58 ± 6% and 61 ± 5% of HR_{max} respectively (Padilla *et al.,* 2001). On the other hand, the average exercise intensity of cross-country competitions lasting 147 ±15 min is similar to the exercise intensity reported by Padilla *et al.* (2001) for road cycling time trials lasting 10 ± 2 min (89 ±3% HR_{max}) and 39 ±11 min (85 ±5% HR_{max}), respectively (Impellizzeri *et al.,* 2002).

Impellizzeri *et al.* (2002) also reported that cyclists spent 44 ± 21 min in a HR zone above the onset of blood lactate accumulation threshold (OBLA) during the four cross-country MTB competitions that they investigated. This is more than the time spent at and above OBLA combined (9 ±8 min and 7 ±10 min, respectively) during short time trials during road cycling (Impellizzeri *et al.,* 2002). Similar findings were reported by Padilla *et al.* (2001) who investigated road cycling events of longer duration (> 302 min). In their study cyclists spend 16 min in a HR zone above OBLA during a high mountainous stage. This shows that cross-country competitions are conducted at higher intensities than road cycling of similar duration.

The cross-country marathon discipline is a mass-start event, generally covering an off-road circuit of at least 60 km in distance and three hours in duration. Events are characterized by repeated technical climbs and descents over different off-road terrains (Impellizzeri and Marcora, 2007; Lee *et al.,* 2002). In these races, riders have to cover a single course only once according to the UCI classifications rules (point-to-point event in the UCI classification: Rules UCI Mountain Bike Races [2008]). To my knowledge no published study has been done so far on the physiological demands of cross-country marathon events and therefore the comparison between cross-country MTB and road cycling are not possible.

Based on the model of road cycling stage races, the first Transalp MTB Challenge was organized in July 1998. This competition is a multiple-day event during which professional and amateur cyclists are required to cross the Central Alps in eight consecutive stages, consisting of one cross-country marathon each. For this reason, the Transalp Challenge is considered one of the most difficult cross-country marathon races in the world (Wirnitzer & Kornexl, 2008). The 2004 Transalp Challenge was characterized by a total altitude climb of 22 500 m and a total distance of 662 km. This resulted in a daily average altitude climb of 2810 m and a distance of 83 km. The longest uphill climb and downhill section as one unit was 1 700 m and 1 400 m in altitude difference, respectively. The total distance climbed was 315 km and 275 km in the downhill section (Wirnitzer & Kornexl, 2008).

The HR values recorded during the 2004 Transalp Challenge showed that this multi-day cross-country marathon competition was physiologically very demanding, involving both the oxygen-dependent and the oxygen-independent energy systems. The average HR was 88% during uphill climbs and 78% during downhill cycling (percentage of maximum HR obtained in the field [HR_{max} Field]). This high average HR during downhill sections compared to uphill during mountain biking may partially explain the higher average HR during a MTB event compared to road cycling (Wirnitzer & Kornexl, 2008).

Coaches and mountain bikers are in agreement that cross-country is an intense activity for which a near maximal effort is necessary. The research on cross country MTB thus far confirms these subjective observations and shows that in most instances, cross-country competitions are performed at higher intensities than road stage races. Reasons for this include the shorter duration of cross-country competitions compared to on-road stage races, relatively lower overall speeds, larger tires, terrain conditions, and continuous climbs and descents. This means that off-road cyclists spend the most part of their effort against the force of gravity and presumably greater rolling resistances (Padilla *et al.,* 1999). In addition, far less drafting takes place during off-road cycling compared to on-road cycling, which may contribute to higher energy expenditure (Anderson *et al.,* 1990).

1.2 Monitoring of exercise intensity in the field

Since competitions represent a unique experience for each athlete and it is the focal point of training, a better understanding of the physiological responses during competition will be valuable. Exercise intensity can be monitored in the field in terms of speed (km/h), PO (W), the RPE Borg scale (6-20 or 0-10) and HR (bpm).

1.2.1 Speed

Padilla *et al.* (1999) monitored 18 international-level professional cyclists during the 1993-1995 three-week stage race time trials (Tour de France, Vuelta a Catalunya, Vuelta a Castilla, Giro d'Italia, Vuelta a Espana, Dauphinée-Libéré). They found that the physiological demands of these time trials were not reflected fairly by the average TT speed. This may be because cycling speed depends on multiple factors, such as the type of terrain, environmental conditions and the physiological and anthropometrical characteristics of the cyclists (Padilla *et al.,* 1999). This is unlike swimming and running, where speed can be a good indicator of exercise intensity (Jeukendrup & Diemen, 1998).

The few studies that monitored speed only used it to characterise the profile of the course. Wirnitzer and Kornex (2008) found that the average speed for the 2004 TransAlp Challenge was 15 ± 2 km/h, the average speed for the uphill section was 11 ± 3 km/h and for the downhill section 31 ± 16 km/h. Gregory *et al.* (2007) reported an average speed of 15 ± 2 km/h for a cross-country time trial. They also found strong correlations between time trial speed, relative VO_{2max} (r = 0.80) and relative PPO (r = 0.93). However, environmental factors have a large impact on cycling speed. Factors such as wind, air temperature, air density, humidity and terrain may change the speed at a given PO. This can either result in a higher PO that is reflected by the lower speed (for example in uphill sections), or a lower PO that is reflected by a high speed in cases of wind from the back leading to an increased speed, or during downhill sections.

Another reason for the disturbed speed-intensity relation is "drafting". When one cyclist is drafting behind another , the cyclist at the back will have the same speed as the cyclist in front but the PO, HR and oxygen consumption will be lower (Anderson & Hagberg, 1990) indicating a flaw in this relationship.

1.2.2 Rating of perceived exertion

Using the RPE response to describe exercise intensity may reflect a conscious sensation of how hard or heavy and strenuous the exercise is as experienced by the athlete relative to the combined physiological, biomechanical and psychological fatigue imposed on the athlete

(Bucheit & Laursen, 2013). RPE responses are gender-independent and knowledge about the athlete's fitness level is not required when using it to describe intensity. RPE is a universal exercise regulator irrespective of locomotor mode and variation in terrain and environmental conditions (Bucheit & Laursen, 2013).

Wirnitzer and Kornex (2008) used RPE as one of the methods to monitor exercise intensity during each stage of the 2004 TransAlps Challenge. The average RPE for the event was 16.1 ± 0.5. Gregory *et al.* (2007) used RPE to describe the physical response during a cross-country MTB time trial and reported an average score of 17 ± 1.

1.2.3 Power output

The most direct variable to determine the demands during cycling is the mechanical PO that is produced by the cyclists to propel the bike (Coyle *et al.,* 1991). This variable can be measured directly and more precisely on the bicycle using a mobile crank dynamometer (Vogt *et al.,* 2006), although its use is mainly limited to professional cyclists. Measuring PO via the portable power-meter is the most direct indicator of exercise intensity (Vogt *et al.,* 2006). This system, which is claimed to be accurate within 1%, consists of a number of strain gauges mounted within a deformable disc between the crank arm and the chain ring. The signals are transferred to a computer mounted on the handlebars. Although several manufacturers have developed power measuring devices (e.g., Look MaxOne, France), the current most reliable and commonly used system is the SRM training system (Schoberer Rad Messtechnik SRM, Jülich, Germany), which can be mounted on a bicycle. It is able to record power and store the data in its memory together with information about speed, distance covered, cadence and heart rate.

By using this device, it is possible to estimate exercise intensity by monitoring the actual outcome of muscular work; that is PO. PO may be the best direct indicator of exercise intensity because gross efficiency is believed to be relatively constant (Jeukendrup & Diemen, 1998). PO, measured directly on the bike seems to be least influenced by internal factors such as cardiac drift, dehydration and glycogen depletion, and external factors, such as weather and terrain factors, unlike HR which is sensitive to these factors. The use of power meters might also provide some interesting information; for example, the relationship between HR and PO.

Few studies have been done where direct measurements of PO during road or MTB races are reported (Golich & Broker, 1996; Smith *et al.,* 2001; Lim *et al.,* 2002; Weber *et al.,* 2005). Although PO may be a more direct indicator of the instantaneous exercise intensity during the event, HR can give a more overall indication of the exercise-induced stress placed on the body for the whole duration of the event. Although PO may decrease with downhill parts of the route, the physical concentration necessary contributes to the overall exercise–induced stress placed on the body (Jeukendrup & Diemen, 1998). This stress will be reflected by relatively high HR values for specifically downhill sections of the route.

1.2.4 Heart rate

Over the past decade, the advent of accurate portable telemetric HR monitors has made it possible to estimate exercise intensity both during training and competition by relating individual HR values measured in the field with those previously obtained in a laboratory setting (Padilla *et al.,* 1999). Although several methods based on HR values have been described to quantify the load undertaken by athletes during training, the principle of training specificity with regard to the intensity at which a cyclist trains cannot be met unless the intensity and physiological demands of competitions are determined (Padilla *et al.,* 1999). As there is a fairly linear relationship between exercise intensity and HR, HR monitoring has become an established means for exercise physiologists, coaches and athletes to describe and monitor exercise and training intensities (Rodriguez-Marroyo *et al.,* 2003).

HR monitors are also used to motivate athletes to work at high intensities (at or above the lactate threshold) (Gilman, 1996), or to prevent athletes from training at too high intensities (Jeukendrup & Diemen, 1998). The advantages of continuous HR monitoring are that athletes get immediate feedback and data can be thoroughly analysed at a later stage.

In recent years, HR monitoring has formed the basis for the quantification of the physiological demands of professional road cycling. This has been done by relating individual competition HR values with those previously obtained in a laboratory test (Palmer *et al.,* 1994; Lucia *et al.,* 1999; Padilla *et al.,* 1999; Andez-Garcia *et al.,* 2000; Padilla *et al.,* 2001; Lucia *et al.,* 2003; Rodriguez-Marroyo *et al.,* 2003). This method has been used to estimate not only exercise intensity during competition but also the exercise load during competitive training situations by using the training impulse (TRIMP) as a unit that integrates exercise intensity and duration (Padilla *et al.,* 2008).

Wirnitzer and Kornexl, (2008) showed that multi-day cross-country marathon competitions are physiologically very demanding because they involve both oxygen-dependent and oxygen-independent energy systems. They found that cyclists maintained an average HR of 79% of the maximal HR determined in the laboratory and 85% of the maximal HR determined in the field during the 2004 TransAlp competition. The high intensity was maintained throughout the race with 27-36% of the total race time spent in the high and very high intensity zones, showing the importance of both oxygen-dependent and oxygen-independent endurance for successful performance. This information can be very valuable for cyclists and their coaches to tailor their training programmes according to the effort that will be required during a competition.

However, the potential limitations in using HR as an indicator of exercise intensity during cycling competitions are well-known and reported by almost all studies. These limitations are related to factors that can alter the oxygen uptake-HR relationship, such as cardiovascular drift (caused by dehydration), environmental temperature and humidity or glycogen depletion (Padilla *et al.,* 2008). Systemic dehydration and plasma volume shifts during competitive events, resulting in a decline in plasma volume, have been defined as confounding factors influencing the HR response during actual events (Bescós *et al.,* 2011).

HR values also depend on the position of the cyclist on the bicycle, which is a function of the specific style of handlebars. Aerodynamic handlebars vary from narrow, bolt-on extensions that draw the body forward into a tucked position, pursuit bars that spread the arms of the rider but drop the torso into a slightly lower position, to integrated units that combine elements of both designs. When using aero bars the frontal area of the body will be lower and the drag coefficient will be reduced. This is not necessarily the most efficient position, as oxygen uptake and HR have been shown to be higher during a laboratory test in this position compared with an upright position (Gnehm *et al.,* 1997). In the aerodynamic position, HR can be on average five (5) bpm higher than in the upright position.

The phenomenon of cardiac drift (an upward trend in HR during exercise over time) is another factor that may affect the use of HR monitors in training. HR has been shown to drift upwards by as much as 20 bpm during exercise lasting 20–60 minutes despite unchanged work rates and in the presence of steady or decreasing plasma lactate concentrations (Faude *et al.,* 2009; Mognoni *et al.,* 1990).

Exercising in hot environments and dehydration increases cardiac drift even further. In a study by Montain and Coyle (1992), in which subjects exercised at 62–67% of $VO_{2\,max}$ in the heat (33 °C, 50% relative humidity), HR increased by 40 bpm after 100 minutes of exercise when no fluid was ingested. Fluid ingestion helped to restrict the increase in HR, but it was still increased by 13 bpm. Although dehydration increases cardiac drift, euhydration or hyper hydration may not always prevent cardiovascular drift (Montain & Coyle, 1992).

Altitude also affects the relationship between HR and energy expenditure. When exercising at a set work rate in hypoxic conditions, HR will be elevated compared to the same work rate at sea level and normoxic conditions. This implies that training at a certain HR at sea level may result in positive training effects, whereas, at high altitude, this training may result in overtraining (Jeukendrup & Diemen, 1998).

All the above findings indicate that the relationship between HR and exercise intensity is susceptible to variations independent of muscular work (Jeukendrup & Diemen, 1998). HR may thus be a better indicator of overall exercise-induced stress (Jeukendrup & Diemen, 1998), more so than actual work done.

C. PHYSIOLOGICAL DIFFERENCES BETWEEN ROAD CYCLISTS AND MTB CYCLISTS

For more than 60 years, scientists examined the characteristics of successful athletes (Salting & Astrand, 1967). Information on competitive male road cyclists has been reported frequently (Burke *et al.,* 1977; Coyle *et al.,* 1991) and extensive physiological data has been published for world-class male road cyclists (Lucia *et al.,* 1999a, 2000 Padilla *et al.,* 1999; Jeunkendrup *et al.,* 1998; Padilla *et al.,* 2001). Data such as this are invaluable, as it establishes prerequisites for a successful career in cycling (Lee *et al.,* 2002).

Several investigations have quantified the physiological demands of professional road cycling competitions (Andez-Garcia *et al.,* 2000; Lucia *et al.,* 1999, 2003; Padilla *et al.,* 1999, 2001), showing the high oxygen-dependent demands of the sport. To meet these demands, professional road cyclists have been reported to exhibit quite impressive maximal and submaximal oxygen-dependent capacities (Lucia *et al.,* 1999; Padilla *et al.,* 1999, 2001).

Wilber *et al.* (1997) investigated the differences in physiological characteristics between mountain bikers and road cyclists. The data were representative of the NORBA (National Off-Road Bicycle Association) cross-country team and the USCF (United States Cycling Federation) national road team. Each group consisted of 10 men and 10 women. The physiological characteristics at LT are presented in Table 2.1 and the physiological characteristics at maximal aerobic capacity are presented in Table 2.2.

Table 2.1 Physiological characteristics of NORBA and USCF cyclists at lactate threshold.

Variables	Women		Men	
	NORBA	USCF	NORBA	USCF
VO_2 (ml.kg^{-1}.min^{-1})	48.4 ± 3.0**	53.3 ± 3.8	53.9 ± 4.6	56.4 ± 4.4
% VO_{2max}	83.8 ± 5.6	83.6 ± 2.7	77.1 ± 6.4	80.1 ± 3.2
[La] (mmol.l^{-1})	2.6 ± 0.7	3.0 ± 0.6	2.9 ± 1.1	2.7 ± 0.4
HR (bpm)	155 ± 8**	165 ± 12	166 ± 13	169 ± 13
% HR_{max}	87.2 ± 2.7	87.9 ± 2.5	86.4 ± 4.2	84.69 ± 4.3
PO (W)	204 ± 20**	224 ± 8	271 ± 29*	321 ± 17
PO (W.kg^{-1})	3.6 ± 0.3	3.7 ± 0.3	3.8 ± 0.3*	4.4 ± 0.3

VO_2, oxygen consumption; VO_{2max}, maximal aerobic capacity; [La], blood lactate concentration; HR, heart rate, PO, power output. *Significantly different from USCF men ($p < 0.05$); **Significantly different from USCF women ($p < 0.05$). Table amended from Wilber *et al.* (1997).

Table 2.2 Physiological characteristics of NORBA and USCF cyclists at maximal aerobic capacity.

Variables	Women		Men	
	NORBA	USCF	NORBA	USCF
VO_{2max} (ml.kg^{-1}.min^{-1})	57.9 ± 2.8**	63.8 ± 4.2	70.0 ± 3.7	70.3 ± 3.2
VO_{2max} (l.min^{-1})	3.33 ± 0.27**	3.85 ± 0.30	4.99 ± 0.44	5.09 ± 0.43
[La] (mmol.l^{-1})	8.7 ± 2.2	10.2 ± 2.5	10.4 ± 2.7	11.8 ± 1.7
HR (bpm)	178 ± 7**	188 ± 11	192 ± 12	200 ± 11
PO (W)	313 ± 24	333 ± 21	420 ± 42**	470 ± 35
PO (W.kg^{-1})	5.4 ± 0.4	5.5 ± 0.5	5.9 ± 0.3**	6.5 ± 0.3

VO_{2max}, maximal aerobic capacity; [La], blood lactate concentration; HR, heart rate, PO, power output. *Significantly different vs men USCF ($p < 0.05$); **Significantly different vs women USCF ($p < 0.05$). Table amended from Wilber *et al.* (1997).

According to the findings of Wilber *et al.* (1997), the women cyclists from both NORBA and USCF, were similar but for two exceptions: USCF women had greater absolute and relative VO_{2max} values and higher maximal HR during the test. The men from NORBA and USCF were similar except for a significantly greater absolute and relative PO at LT for the USCF cyclists and also significantly greater absolute and relative PPO. Wilber *et al.* (1997) concluded that elite off-road cyclists possessed similar physiological profiles compared to elite road cyclists.

Lee *et al.* (2002) compared the physiological characteristics of successful mountain bikers and professional road cyclists of seven (7) national and international Australian cyclists. The maximal exercise responses and the exercise response at the D-max modified threshold are presented in Table 2.3.

Table 2.3 Maximal exercise and D-max modified threshold responses of mountain bikers and road cyclists (mean ±SD).

Variables	Mountain Bikers	Road Cyclists	% Absolute Diff.	d
W_{max} (W)	413 ± 36	431 ± 12	4	0.66
W_{max} ($W.kg^{-1}$)	6.3 ± 0.5	5.8 ± 0.3	9*	1.15
VO_{2peak} ($l.min^{-1}$)	5.1 ± 0.5	5.4 ± 0.1	7	0.92
VO_{2peak} ($ml.kg^{-1}.min^{-1}$)	78.3 ± 4.4	73.0 ± 3.4	7*	1.14
HR_{max} (bpm)	189 ± 5	191 ± 9	1	0.16
[La_{max}] $mmol.l^{-1}$	10.1 ± 2.6	10.6 ± 1.4	5	0.22
D-max$_{mod}$ (W)	339 ± 31	348 ± 16	3	0.37
D-max$_{mod}$ ($W.kg^{-1}$)	5.2 ± 0.6	4.7 ± 0.3	11*	1.15
% W_{max}	81 ± 4	81 ± 3	2	0.43
% VO_{2peak}	86 ± 6	88 ± 4	2	0.39
[La_{D-max}] $mmol.l^{-1}$	3.3 ± 0.7	3.1 ± 0.8	8	0.34
HR_{D-max} (bpm)	172 ± 11	170 ± 11	1	0.15

W_{max}, maximal power output; VO_{2peak}, peak oxygen uptake; [La_{max}], maximal lactate concentration; HR, heart rate; d, effect size. Table amended from Lee *et al.* (2002).

Lee *et al.* (2002) found that the most distinguishing characteristic of mountain bikers was a high PO relative to body mass, measured in the laboratory, when compared with road cyclists who usually are not specialist hill climbers. There were no significant differences between highly competitive mountain bikers and road cyclists in maximal power output, VO_{2max} in absolute terms, but when these parameters were expressed relative to body mass, the mountain bikers excelled. The results by Lee *et al.* (2002) confirms that cross-country mountain biking is a demanding endurance sport that requires extremely high fitness levels.

When the physiological parameters are normalized to body mass, it provides a better description of the cyclists' climbing ability compared to the values expressed in absolute terms. Therefore, the results found by Lee *et al.* (2002) showed that mountain bikers possessed a physiological profile similar to all-terrain cyclists and climbers. Due to the variable terrain of cross-country MTB events, much time is spent ascending and descending, leading to large variations in PO. These intermittent high-power outputs recorded in mountain bikers were substantially higher than those reported for professional road cyclists (Tanaka et al., 1993; Padilla et al., 1999), making body mass a far more important variable in mountain bikers than in road cyclists.

D. LABORATORY PERFORMANCE TESTING IN CYCLING

1.1 Maximal incremental exercise test

Graded exercise tests (GXTs) are popular laboratory tests to assess, among others, VO_{2max}, PPO and LT in combination with submaximal variables for the purposes of training prescription, to quantify the effects of training and to predict endurance performance in the field (McNaughton *et al.,* 2006). VO_{2max} is considered a valid indicator of the integrated function of the respiratory, cardiovascular and muscular systems during exhausting exercise and an important determinant of endurance performance (Bassett & Howley, 2000), while PPO and LT have been established as good predictors of performance in the field. However, the latter is based on the premise that standardized exercise protocols are used.

A general methodological contrast in all studies examining the LT and PPO is the length of each work interval during the graded exercise test (McNaughton et *al.,* 2006). The modification of graded exercise test design, i.e. interval size and duration, has implications for the data calculated from the test variables, such as PPO and the LT, as well as how these variables correlate with endurance performance (McNaughton et *al.,* 2006). Thus, changing the exercise protocol will lead to either an over- or underestimation of the predictors of performance.

1.1.1 Maximum aerobic power

Bentley and McNaughton (2003) compared the physiological responses of nine national and international male triathletes, obtained during two different test protocols (60s vs 3 min increments) to a 90-minute laboratory TT (Table 2.4).

Table 2.4 Correlation coefficients between each variable obtained in the short (60 s) and long (3 min) increment exercise tests and the average PO during a 90-min laboratory TT

Characteristics	Short (60 s)	Long (3 min)
VO_{2peak} (l.min^{-1})	0.75 **	0.37
VO_{2peak} (ml.kg^{-1}.min^{-1})	0.76 **	0.48
PPO (W)	0.56	0.94 **
VT (l.min^{-1})	0.36	0.45
VT (%VO_{2peak})	-0.27	0.18
VT (W)	0.60	0.75*
VT (%peakW)	0.31	0.47

VO_{2peak}, maximal aerobic capacity; PPO, peak power output; VT, ventilatory threshold. *P < 0.05; ** P < 0.01
Table amended from Bentley and McNaughton (2003).

Although there were no significant differences in the absolute (4.85 ± 0.20 vs. 4.74 ± 0.28 l.min^{-1}) and relative VO_{2max} values (62.8 ± 4.7 vs. 61.6 ± 5.8 ml.kg^{-1}.min^{-1}) (P > 0.05) of the cyclists on the two tests, there was a better correlation between VO_{2max} and endurance performance during the short-stage test compared to the long-stage test (Bentley & McNaughton, 2003). This may suggest that the short-stage test may be more suitable for some subjects than others. The fact that PO at VT differed significantly between the two incremental exercise tests seems to indicate that the submaximal responses were affected by the differences in increment duration. Furthermore, in contrast to the VO_{2max} values, PO at VT determined from the long stage (3 min) incremental test correlated better with TT performance. These findings reiterate the importance of using standardised exercise protocols, otherwise results within, and between cyclists cannot be compared.

1.1.2 Maximum work rate

If maximum power output (PPO) is protocol-dependent, it may negatively affect the validity of this variable to predict maximal oxygen-dependent power or performance (McNaughton et *al.,* 2006).

Bentley and McNaughton (2003) found that PPO and PO at the VT were higher with a short-interval incremental stage (60 s) compared to a long-interval (3 min) test (424 W and 344 W vs. 355 W and 313 W). Similarly, McNaughton et *al. (*2006) recorded higher PPO values with a 3 min incremental test than a 5 min incremental test in eleven moderately to well-trained cyclists competing in regional- and national-level cycling and triathlon events. These findings suggest that shorter duration increments lead to higher PPO values; however McNaughton et *al. (*2006) found that the physiological measures obtained from both graded exercise tests of 3-min and 5-min stage increments correlated well with a 30-min laboratory TT performance (Table 2.5). On the other hand, Bentley and McNaughton (2003) found that the PPO value, from 60-second stage increments, was not significantly correlated to the average PO during a 90 minute laboratory cycling time trial. In these two studies, the duration of the performance test differed, and this may be the reason for the differences in findings. Weston *et al*. (1996) and Lucia *et al*. (2000) also showed that in short-term training studies, PPO measured from long stage tests (2.5-min stages) was more sensitive to training induced changes than PPO measured from 60 s stages.

Table 2.5 Correlations coefficients (r) between the average power (W) of a 30-min laboratory cycle time trial test of $GXT_{3\text{-min}}$ and $GXT_{5\text{-min}}$.

Variable	**$GXT_{3\text{-min}}$**	**$GXT_{5\text{-min}}$**
PPO	0.96**	0.96**
LT	0.88**	0.86*
D_{max}	0.89**	0.91**
OBLA	0.82*	0.90**

$GXT_{3\text{-min}}$, graded exercise test of 3-minute workload increments; $GXT_{5\text{-min}}$, graded exercise test of 5-minute workload increments; PPO, peak power output; LT, lactate threshold; D_{max}, maximum displacement threshold; OBLA, onset of blood lactate accumulation. *P< 0.01, **P<0.001. Table amended from McNaughton *et al.* (2006).

On the one hand, shorter increments lead to higher PPO values, but it may not have as much predictive power as long increment tests, and it may also not be the best measure to record training progress. Nevertheless, McNaughton *et al*. (2006) contends that regardless how PPO is measured, it represents a valid physiological variable that is related to endurance of performance.

1.1.3 Submaximal physiological parameters

During incremental exercise tasks, differences in lactate accumulation at work intensities above the LT may influence the exercise time and number of stages completed by a subject, especially during graded exercise tests with longer stages (McNaughton *et al.,* 2006). PO (W) corresponding to LT was significantly lower when the length of stages during a graded exercise test was increased from 3 minutes to 8 minutes (Bentley *et al.,* 2001). McNaughton *et al. (*2006) also found that the physiological measures obtained from 3-min and 5-min stage increments correlated well with each other (Table 2.6) and that there was no difference in PO and HR values corresponding to lactate parameters between the two incremental tests. Thoden (1991) also considered 3-6 min stages optimal to determine the desired metabolic inflection points. Thus it seems that in order to obtain a valid measure of submaximal blood [lactate], longer exercise protocols are needed to allow lactate diffusion before an increment in work occurs. However this will compromise the VO_{2max} and PPO measurements.

Table 2.6 Correlation coefficient (r) between the physiological measures of $GXT_{3\text{-min}}$ and $GXT_{5\text{-min}}$.

Variable	**r**
PPO	0.98**
HR_{max}	0.88**
PO_{LT}	0.66*
PO at D_{max}	0.86**
PO_{OBLA}	0.94**
HR_{LT}	0.82**
HR_{Dmax}	0.85**
HR_{OBLA}	0.77**

$GXT_{3\text{-min}}$, graded exercise test of 3-minute workload increments; $GXT_{5\text{-min}}$, graded exercise test of 5-minute workload increments; PPO, peak power output; LT, lactate threshold; D_{max}, maximum displacement threshold; OBLA, onset of blood lactate accumulation; HR_{max}, maximal heart rate; HR_{Dmax}, heart rate corresponding to D_{max}; HR_{LT}, heart rate corresponding to lactate threshold; HR_{OBLA}, heart rate corresponding to OBLA. *P< 0.01, **P<0.001. Table amended from McNaughton *et al.* (2006).

Other factors that may influence the relationship between the physiological variables and cycle TT performance are the distance and nature of the TT (laboratory or field), the ability level of the subjects, as well as the sample size of the study (McNaughton *et al.,* 2006).

1.1.4 Reproducibility and validity of physiological parameters measured during incremental stage protocols

Weltman *et al.* (1990) did a study on 15 male runners to determine the reliability of a continuous incremental running protocol, with 3-min stages, for LT and fixed blood [lactate] (2-, 2.5- and 4 $mmol.l^{-1}$) assessment. The test-retest reliability coefficients for velocity at LT, 2-, 2.5- and 4 $mmol.l^{-1}$ were r = 0.89, 0.91, 0.95 and 0.95, respectively. The test-retest reliability values ranged from 0.7 m/min to 6.0 m/min and the standard errors of measurement were less than ± 10 m/min. Similar results were observed for VO_2 values. The test-retest reliability coefficients ranged from r = 0.82 to r = 0.88 and the standard errors of measurement were less than ± 2.95 $ml.kg^{-1}.min^{-1}$. It can be concluded that a continuous horizontal treadmill protocol using 3-min stages results in reliable and valid measurements of velocity and VO_2 at LT and fixed blood [lactate].

Jensen and Johansen (1998) also showed high reproducibility and validity for an incremental exercise test protocol on a cycle ergometer completed by seven male club cyclists (5-min stage durations). The coefficient of variance (CV) were below 3% for HR_{max}, VO_{2max}, HR at 2 $mmol.l^{-1}$ blood [lactate] and HR at 4 $mmol.l^{-1}$ blood [lactate] and between 3 and 10% for parameters which were estimated by linear interpolation to correspond to a blood lactate increase of 2 and 4 $mmol.l^{-1}$, as for W, VO_2 and VCO_2. This shows that physiological parameters measured with this test protocol are reliable and valid.

The same results were found by Wergel-Kolmert *et al.* (2002) who calculated the coefficients of repeatability (COR) on a cycle ergometer, using two tests separated by 5 - 6 weeks. The COR was given as percentage of the mean for the two measurements. The COR was 11 % for VO_{2max}, 6 % for HR, 7 % for RPE and 9 % for PO. The same results were found by Baba *et al.* (1999), namely 16 % for VO_{2max} for 19 healthy volunteers who were tested twice within a week on a cycle ergometer. Bingisser *et al.* (1997) also reported a COR of 8 % and 13 % for VO_{2max} in well-trained and untrained healthy subjects.

2. Laboratory time trials

In 3-week professional road cycling stage races, performance in the TT is of paramount importance to the final overall standings of the race (Padilla *et al.,* 1999). This racing format in which cyclists often race individually and attempts to achieve the shortest possible time to cover a fixed distance has often been simulated under laboratory conditions, usually with the aim of predicting cycling performance in the field (Padilla *et al.,* 1999).

Jeukendrup *et al.* (1996) compared two TT protocols where cyclists had a clear end-point with a time to exhaustion test. The TT tests consisted of 45 minutes at 70% PPO followed by 15 minutes at a self-selected pace and the one hour test (OHT) as suggested by Coyle et al (1991). Both tests were highly reproducible (CV = 3.5% and 3.4%, respectively), compared to the time to exhaustion tests (CV = 26.6). The latter test's poor reproducibility was explained by the fact that the riders had no clear end-point and psychological factors, such as boredom, motivation and monotony may have affected the subjects' performances. Thus, TT's over a fixed distance or time are ecologically more valid than time to exhaustion tests.

There are only a few reports on TT intensity in road cycling. This lack of data is mainly due to the technical difficulties of determining VO_2 and blood [lactate] during competitions, which are two of the main methods used by exercise scientists to quantify exercise intensity (Padilla *et al.,* 1999). However, despite the influence of extraneous factors (see 1.2.5), exercise intensity can be reliably quantified by HR measurements.

Palmer *et al.* (1996) reported an average HR of 90.3 ±2.4% HR_{max} during a 20-km simulated TT in the laboratory and 94% HR_{max} for a 16.6 km field TT in ten well-trained, competitive cyclists. A strong correlation was also found between the laboratory 40 km TT and an actual road 40 km TT (r = 0.98). It was also found that both the 20 km and 40 km laboratory TT was highly reproducible (CV = 1.1 ± 0.9 % and CV = 1.0 ± 0.5%, respectively). This showed that the performance from a 40 km laboratory TT can be used to predict performance of outdoor 40 km road TT performance. These results not only illustrate the high exercise intensity that cyclists maintain during a TT, but also that the physiological demands of road time trials can be simulated in laboratories and that laboratory time trials can be used to assess and predict TT performance of cyclists.

Another form of TT protocol was introduced by Coyle *et al.* (1991) that required cyclists to generate the highest PO over 60 min. They called it the 1-h test (OHT). The average PO generated during this test by "elite-national class" (i.e., group 1; N = 9) and "good-state class" (i.e., group 2; N = 6) cyclists showed a strong correlation (r = -0.88, P < 0.001; n = 15) with actual 40-km road TT performance. The 1-h power output was related to each cyclists' VO_2 at the blood lactate threshold (r = 0.93; P < 0.001). The "elite-national" cyclists (group 1) was able to cycle at 90 ± 1 % of their VO_{2max} and had an average PO of 346 ± 7 W for the 1-h laboratory test. The close associations between performance during the actual 40 km TT and the 1-h laboratory test indicates that the laboratory test simulated a TT reasonably well and that these laboratory data generally describe the demands of this cycling event.

It can be concluded that TT tests in laboratories are highly reproducible. It was also found that the physiological demands of road time trials can be described by the physiological demands of laboratory time trials and that physiological laboratory variables correlate well with outdoor TT performance. Therefore, TT tests in the laboratory are valid and reliable for determining and predicting the demands of road time trials.

E. LABORATORY PERFORMANCE MEASURES

1. Maximal aerobic capacity

Previous research has shown that a high VO_{2max} is an important determinant of cycling performance, both on- and off-road (Impellizzeri *et al.,* 2002). Typically, road cyclists ride between 25000 to 35000km per season (training and competition distances). Therefore one of their most outstanding characteristics is their high oxygen-dependent capacities. However, the high oxygen-dependent demand of MTBing means that off-road cyclists also have above average VO_{2max} values. Impellizzeri *et al. (*2005a) reported oxygen-dependent capacities ranging from 66.5 to 78 $ml.kg^{-1}.min^{-1}$ for various levels of mountain bikers. These values are slightly less than those reported by Mujika and Padilla (2001), namely 69.7 to $84.8 ml.kg^{-1}.min^{-1}$ for 24 professional road cyclists. Tanaka *et al.* (1993) found that 38 (32 men and 6 women) competitive category II road cyclists had higher absolute and relative VO_{2max} values than category III and IV cyclists, respectively, indicating that training status and genetic prowess greatly determines maximal exercise capacity.

It is also true that a high VO_{2max} value do not guarantee successful performance. Coyle *et al.* (1988) are of the opinion that individuals with similar VO_{2max} values can greatly differ in actual performance (Coyle *et al.,* 1988). They found that a group of individuals with similar VO_{2max} values displayed an approximately twofold difference in blood lactate concentration, glycogen utilization and time to fatigue during exercise at similar absolute work rates and percentages of VO_{2max}. These findings suggested that endurance during submaximal exercise was closely related to the factors that controlled muscle glycogenolysis and blood [La] (Coyle *et al.,* 1988). This indicated that it was more accurate to express an individual's metabolic capacity for endurance exercise in terms of VO_2 at lactate thresholds, rather than just the VO_{2max} value. This viewpoint was confirmed in two studies. Lucia *et al.* (1999) reported that VO_{2max} was not significantly related to TT performance in the Tour de France and Prins *et al.* (2007) found that neither absolute nor relative VO_{2max} ($r = -0.35$ and $r = -0.59$, respectively) correlated with outdoor performance.

High oxygen-dependent capacities are well-known characteristics of both road and MTB cyclists (Lee *et al.,* 2002); despite this fact not many studies have found it to be a good predictor of performance in the field (Impellizzeri *et al.,* 2005a; Impellizzeri *et al.,* 2005b;

Prins *et al.,* 2007). More studies show that better correlations are found between VO_2 values and performance when VO_2 values are expressed in terms of lactate thresholds (Impellizzeri *et al.,* 2005a; Impellizzeri *et al.,* 2005b; Prins *et al.,* 2007).

2. Power output

An important performance component for off-road cyclists is oxygen independent power (Baron, 2001). The ability to generate relatively high PO in quick time plays a vital role in mass start events, during steep climbing and when sprinting to pass slower riders or sprinting to the finish (Baron, 2001). These specific aspects of off-road cycling involve short bursts of high-intensity oxygen-independent efforts.

It has been shown that PPO obtained during a maximal incremental cycling test can be used as a predictor of performance in cyclists (Hawley & Noakes, 1992; Bentley *et al.,* 1998). Bentley *et al.* (1998) reported a significant correlation between PPO and the cycling time during a short-course triathlon race ($r = -0.87$; $P < 0.01$). Tanaka *et al.* (1993) found that PPO tended to increase with the ability/category level of the individuals, probably due to years of strenuous interval training. In the Wingate anaerobic test the cyclists in UCI category II had the highest oxygen independent capacity (PPO and mean PO) compare to category III and IV cyclists. The difference in mean PO between category II and IV cyclists was statistically significant ($p < 0.05$).

The above findings support the notion that PPO is a valid assessment of cycling performance (Bentley *et al.,* 1998).

3. Cycling efficiency

Coyle *et al.* (1992) defined cycling efficiency (CE) as the submaximal VO_2 per unit of body mass required to perform a task. This means that when an individual has a good CE, he/she will have a lower VO_2 at any given submaximal work rate. Professional cyclists display a remarkably higher CE compared to amateur cyclists despite their similar VO_{2max} values (Lucia *et al.,* 2002). Since VO_{2max} values do not necessarily distinguish professional from amateur cyclists, they recommended that a constant-load exercise test is used to measure CE throughout the season (Lucia *et al.,* 2002). It was also suggested that a high CE might compensate for a relatively low VO_{2max} value (Lucia *et al.,* 2002). Faria *et al.* (2005) also considered CE a useful measure for the evaluation of cycling performance.

Factors that may influence gross efficiency include pedalling cadence, diet, overtraining, genetics and fibre-type distribution (Faria *et al.,* 2005). World class cyclists have demonstrated an inverse correlation to VO_{2max} for both CE and gross efficiency (Lucia *et al.,* 2002). Thus, improvement in cycling performance is best related to the submaximal variable of gross efficiency at the LT or at the respiratory compensation point rather than gains in VO_{2max} values (Moseley & Jeukendrup, 2001).

From these findings it can be suggested that CE and gross efficiency in cycling should be regular measurements included in physiological tests done on cyclists. The only problem is that the measurement of CE requires a separate, long duration exercise test and that it cannot be performed on the same day as an incremental or TT test.

4. Lactate parameters

4.1 Identifying the anaerobic, lactate and ventilatory thresholds

Although it has been traditionally considered that maximal aerobic capacity is the "golden standard" for evaluation of endurance capacity (Salting & Astrand, 1967), it has been suggested since that the anaerobic threshold (AT) provides a better index of aerobic endurance and may therefore be a better predictor of endurance performance. In practice, however, it is difficult to use AT as there are numerous definitions of and methods to determine this threshold.

The original definition was proposed by Wasserman (1986) who defined AT as the critical performance intensity that an endurance athlete can maintain throughout an endurance event. Beaver *et al,* (1986) explained that as exercise intensity increases above a certain work rate, the oxygen independent component of metabolism causes the blood lactate concentration to increase significantly. This increase in blood lactate concentration is accompanied by an almost equal reduction in bicarbonate concentration in the blood, causing a rapid increase in carbon dioxide production leading to increased respiratory carbon dioxide. The threshold at which this switch-over begins is called AT. Baldari and Guidetti (2000) defined the individual AT as the metabolic rate where the elimination of blood lactate from the blood is maximal and equal to the rate of diffusion of lactate from exercising muscle to blood so that higher exercise intensities lead to progressively increasing lactate values.

AT is commonly determined by using either blood lactate measures, called the lactate threshold (LT), or by means of a non-invasive method using gas exchange measures (i.e. minute ventilation or carbon dioxide production). In the latter case, some authors would refer to the ventilatory threshold (VT). Whether these thresholds (AT, LT and VT) are physiologically related, or whether it can be regarded as the same threshold, are beyond the scope of this thesis.

Five common methods are used to identify the lactate threshold:

(1) The AT is determined according to the changes in lactate concentrations during and after (1, 3, 5 and 10 min post) exercise. A line is drawn from the final lactate measurement where the exercise was stopped (A) to the point where the recovery lactate concentration is equal to the end lactate concentration (B). From point B the line is drawn back to meet the initial rise in blood [lactate] response during exercise to determine where point B meets the original lactate curve. (Stegmann & Kindermann, 1982);

(2) The AT corresponding to the PO of the stage antecedent to the second lactate increase of at least 0.5 $mmol.l^{-1}$ above the previous value, where the second increase is greater than, or equal to, the first value (Baldari & Guidetti, 2000);

(3) The PO at a fixed blood lactate concentration of 4 $mmol.l^{-1}$, also known as the onset of blood lactate accumulation (OBLA) (Mader *et al*., 1976)

(4) PO at the intersection of a tangent to the lactate curve that is parallel to the slope of a 1 $mmol.l^{-1}$ increase in 3 minute (Keul *et al.,* 1979);

(5) The PO that immediately precedes the first 1 $mmol.l^{-1}$ rise that is followed by a similar or larger increase (< 1$mmol.l^{-1}$) (US Olympic Committee protocol).

Five common methods that are used to identify the ventilatory threshold (VT):

(1) The PO at which the respiratory exchange ratio (RER) is equal to 1.0 (Yosida *et al.,* 1987);

(2) the PO where RER = 0.95 (Wasserman *et al.,* 1994);

(3) The ventilator equivalent method (VE/VO_2): the PO corresponding to a systematic increase in the ventilatory equivalent of oxygen (VE/VO_2) without a concomitant increase in the ventilatory equivalent of carbon dioxide (VE/VCO_2) (Wasserman & McIlroy, 1964);

(4) the V-slope-method: the PO at which there is a non-linear increase in VCO_2 (CO_2 output) in relation with VO_2 (Beaver *et al.,* 1986; as described in Hoogeveen & Hoogsteen, 1999);

(5) The PO at which a first clear breakpoint on the VE/VCO_2 plot occurs (Caiozzo *et al*., 1982).

The determination of blood [lactate] during exercise has been traditionally used for the estimation of workload intensity during exercise (Santos-Concejero *et al.*, 2013). However, there are also many different methods to determine the lactate threshold. Yoshida *et al*. (1987) compared four lactate-related thresholds and found that they were highly correlated to one another. These were the LT (where blood [lactate] begins to increase above the resting value, LT1 (where blood [lactate] rise by 1 mmol.l^{-1} above resting value), LT2 (where blood [lactate] reach a value of 2 mmol.l^{-1}) and OBLA (where blood [lactate] reaches 4 mmol.l^{-1}).

Workloads less than or equal to the aerobic threshold should not elicit blood [La] above baseline measures, whereas workloads above the aerobic threshold should elicit a stable increase in blood [La] above baseline measures (Rusko *et al.,* 1986). Similarly, workloads less than or equal to the anaerobic threshold should show a stable increase in blood [La] with a slight decrease towards the end of the exercise bout. Workloads above the anaerobic threshold should result in a progressive increase in blood [La] (Rusko *et al.,* 1986).

Another lactate parameter that is used by researchers is the maximum lactate steady state (MLSS). This is defined as the maximal exercise intensity which elicits a constant blood [lactate] (or less than a 1 mmol.l^{-1} rise) in the last 20 min of a 30 min constant work rate test. Santos-Concejero *et al*. (2013) considers the MLSS as the highest exercise intensity where there is a balance between the rate of lactate production and lactate clearance. The acidosis associated with lactate accumulation has several adverse effects on the contractile processes in skeletal muscle (Baldari & Guidetti, 2000). This makes the determination of the work rate at MLSS a very attractive parameter for training prescription purposes (Baldari & Guidetti, 2000). Thus, the MLSS response provides a very useful guideline for high-intensity or low-intensity endurance training (Baldari & Guidetti, 2000).

The detection of MLSS is affected by the length of the constant-load exercise and the maximum acceptable increase in blood [La] that is applied (Beneke, 2003). Since MLSS must be determined through several constant load exercise tests, it is not always a practical parameter to use. Nevertheless, during running exercise, the exercise intensity at a [lactate] of 4 mmol.l^{-1} (OBLA) was reported to be associated with the exercise intensity at MLSS and consequently, different researchers have proposed the use of OBLA as a reference value for the MLSS (Santos-Concejero *et al*., 2013).

The controversy continues regarding the relationship between LT and VT. Some believe there is a strong physiological link between VT and LT (Anderson & Rhodes, 1991; Burke *et* *al.,* 1997), while others are of the opinion that there is no relationship between the two thresholds (Gladden *et al.,* 1985). Nevertheless, it is almost universally accepted that LT and VT and its associated variables (PO, HR, VO_2) may be useful predictors of endurance exercise performance (Amann *et al.,* 2006).

4.2 The blood lactate response as a predictor of performance

Prediction of physical performance from laboratory measures has been a frequent concern for exercise physiologists, athletes and coaches (Boulay et al., 1997). The capacity to maintain a high submaximal oxygen-dependent workload (i.e. at lactate threshold) is also an important determinant of off-road cycling (Impellizzeri et al., 2005b). Many definitions of this workload (at a certain threshold) have been published and it is therefore difficult to compare findings.

The difference in endurance performance between athletes and the improvements from training programs can be largely explained in terms of the LT-VO_2 relationship and economy. The oxygen consumption maintained during competition is related to the oxygen consumption at which the lactate begins to accumulate in the blood (LT-VO_2), which is interpreted to be reflective of muscle glycogenolysis and blood [La] (Coyle et al., 1988). Coyle et al. (1988) reported that individuals with similar VO_{2max} can display an approximately twofold difference in blood [La], glycogen utilization and time to fatigue during exercise at similar absolute work rates and percentage of VO_{2max}. These findings suggest that endurance is closely related to the factors that control muscle glycogenolysis and blood [La]. Therefore by looking only at the VO_{2max} values of cyclists to assess cycling endurance would not be sufficient. More focus should be placed on VO_2 values corresponding to submaximal lactate parameters like LT and VT.

Numerous studies have found good correlations between PO corresponding to lactate parameters (LT and OBLA) and outdoor race performance. Impellizzeri et al. (2005a) found good correlations between relative PO at LT and race time (r = -0.89) and relative PO at OBLA and race time (r = -0.86) for a national cross-country competition. Impellizzeri *et al.* (2005b) found good correlations between relative PO at OBLA and race time (r = -0.64) and also strong correlations between relative PO at OBLA and final rankings (r = -0.88) and between relative PO at LT and final rankings (r = -0.92) of an international level cross-country competition. Prins *et al.* (2007) found good correlations between relative PO at

OBLA and outdoor TT performance (r = - 0.74) and the same for a regional cross-country championship race time (r = -0.64).

Meyer *et al.* (1999) found that exercise prescription at fixed percentages of VO_{2max} or HR_{max} corresponds to wide ranges of exercise intensities, as opposed to exercise intensities related to the AT. Exercise intensity determined solely on VO_{2max} or HR_{max} ranged above 20% in trained individuals. This variation can be especially relevant at critical intensities near the transition from oxygen-dependent to oxygen-independent metabolism, or the range from moderate intensive to high intensive (anaerobic) exercise. With this information Meyer *et al.* (1999) concluded that training prescription should not be based solely on the exercise intensity at percentages of VO_{2max} and HR_{max}. Individualized training intensities based on blood lactate measurements are preferable and for the confirmation of which metabolic pathway is used in each zone, either oxygen-dependent of oxygen-independent, blood lactate measurements can be used (Meyer *et al.,* 1999).

These results from previous published studies indicate that determining PO values corresponding to lactate parameters during laboratory tests can be used to predict outdoor race performance in MTBing. It can also help to determine more specific determinants of cycling endurance, which can also be used to monitor training adaptations. It is therefore important to continue doing these laboratory tests to determine whether an athlete is at his/her optimal physiological capacity to deliver his/her best performance during competitions. These tests and correlations can also be used to help coaches and sport scientist to better advice and design training programs that will have specialized focus on improving performance.

4.2.1 Lactate threshold

Determining blood [lactate] during exercise has always been accepted as a practical measure of oxygen-dependent capacity (Davis *et al*., 1985; Yoshida *et al*., 1981). However, there has been considerable discussion on the significance of using LT as an index of oxygen-dependent capacity, as well as the relationship between the increases in [lactate] in blood and in muscle during exercise (Yoshida et al., 1987).

In a study by Coyle *et al.* (1991) on 15 male competitive USCF categories I and II cyclists, the average PO during a 1-hour laboratory TT were highly related to the cyclists' VO_2 at LT (r = 0.93; P < 0.001). The same results were found by Yosida *et al.* (1987). It was found that LT (first rise in blood [lactate] above baseline values) correlated strongly with VO_{2max} and 12 minute run performance (r = 0.84 and 0.73, respectively). They also reported that various estimates of LT (see section D. 4.1 for definitions) are not only related to each other (r = 0.62 to 0.97), but are also related to VO_{2max} and 12 minute run performance (r = 0.66 to 0.84).

A reason why LT had the strongest correlation with oxygen-dependent capacity and endurance performance might be that the absolute value of blood lactate varies during exercise under different conditions (Yoshida *et al.,* 1987). Absolute blood [lactate] at rest and during exercise appears to be affected by the free fatty acids in the blood, glycogen content in muscles, the acid-base status in the blood, the intake of carbohydrate rich diet, hypoxic conditions and endurance training condition (Yoshida *et al.,* 1987). This means that because LT_1, LT_2 and OBLA are based on fixed values, these parameters would be influenced not only by endurance training status, but also by the metabolic status of the individual (Yoshida *et al.,* 1987). The authors concluded that lactate parameters may be used as indicators of both oxygen-dependent capacity and endurance performance, but that LT might be the best indicator of exercise performance.

Previous research has demonstrated that muscle oxidative capacity is one of the most important determinants of endurance performance (Davies *et al*., 1984). Oxidative capacity also appears to play an important role in determining the lactate threshold; therefore, lactate parameters that are more closely related to muscle oxidative capacity may be better predictors of endurance performance (Baldari & Guidetti, 2000). It was found that individual anaerobic threshold (IAT_a; In the lactate VO2 curve, each lactate value was assigned to the workload immediately before that of its measurement so that each workload value was plotted versus the assigned lactate value. We called IAT_a the IAT determined by this method. The IAT_a, was defined as the workload corresponding to the second lactate increase of at least 0.5 $mmol.l^{-1}$ from the previous value, where the second increase was greater (or equal) than the first one) was the AT that was more closely related to oxidative threshold.

Some studies (Yoshida *et al.,* 1987; Coyle *et al.,* 1988, 1991) have reported that the exercise intensity, which induces an optimum qualitative stimulus, should elicit a steady state blood [lactate] of approximately 4 $mmol.l^{-1}$ and therefore OBLA has been adopted by many coaches all over the world as a useful index of athletes' training status and fitness.

There are, however, some researchers who are against the utilization of OBLA as an indirect marker of the MLSS (Kilding *et al.,* 2005; Van Schuylenbergh *et al.,* 2004), because the blood [lactate] corresponding with MLSS may be reduced as a result of oxygen-dependent training. It is also acknowledged that the 4 $mmol.l^{-1}$ value does not take into account inter-individual variability in the MLSS.

From the above it is clear that it is still not known which lactate parameter is the best predictor of endurance performance in the field.

4.2.2 Ventilatory threshold

The VT, which can be determined during progressive exercise testing, has also been considered an important determinant of performance and fitness levels of endurance exercise (Lucia *et al.,* 1999). For instance, a strong relationship was found between VT and both the cycling and running stages of the Olympic triathlon distance (Schabort *et al.,* 2000; Zhou *et al.,* 1997).

In contrast to these studies, O' Toole *et al.* (1989) did a study on 24 participants (14 men, 10 women) in the 1985 Hawaii Ironman Triathlon and reported that cyclists' peak $\dot{V}O_2$ was inversely correlated with bike finish time during the event (r = -0.68; $P < 0.0002$). VO_2 and HR, as well as the respective percentages of maximum, were higher at all lactate thresholds than at VT in triathletes. They also found that $\dot{V}O_2$ values at the lactate and ventilatory thresholds were not highly related to bike finish time (r = -0.26 to -0.58).

Laursen *et al.* (2002) showed that ultra-endurance triathletes performed the cycling phase of the ultra-endurance triathlon at a mean PO that is significantly lower than their PO at VT; however, the cyclists' HR during the event was close to the HR at VT. This showed that the athletes couldn't sustain a mean PO similar to PO at VT for the event, but their HR response was similar to their HR at VT. These findings are important as they couldn't be explained by the conventional models of exercise physiology (Noakes, 2000). Laursen *et al.* (2002) couldn't find evidence that triathletes selected a PO that was similar to their PO at VT (i.e. ultra-endurance threshold) for a prolonged ultra-endurance cycling at self-selected pace. Therefore it is important that further research is done to investigate the determinants of endurance performance outcomes in elite athletes.

Lucia *et al.* (1999) found that mean HR values corresponding to the physiological markers of performance (LT and VT) remained stable during the course of a training year, despite significant training-induced adaptations where the LT and VT shifted to higher workloads. This implies that the HR values corresponding to the LT and VT can be used throughout the training year to adequately prescribe training loads. Nevertheless by looking at the weak correlation for variables at VT and the fact that PO at VT couldn't be maintained during a self-selected pace cycling section the use of VT is still questionable.

Despite the widespread use of blood and plasma [lactate] and ventilatory thresholds in performance assessments and training prescription, the interpretation and application of changes in lactate levels have varied considerably (Bishop *et al.,* 2000). Therefore more research is necessary to explain these contrasting findings.

F. LABORATORY PREDICTORS OF PERFOMANCE

Maximal and submaximal parameters that are measured in a laboratory are widely used as measures of oxygen-dependent fitness. Sports scientists and coaches use these parameters to evaluate oxygen-dependent fitness levels in athletes and to accurately establish their exercise training intensities. Direct measurements of VO_2 during outdoor exercise are difficult. Thus, most athletes must rely on extrapolations of laboratory measurements to estimate energy expenditure in the field (Palmer *et al.,* 1994) and thus the laboratory determinants of exercise performance.

A commonly used laboratory performance test for road cyclists is the maximal oxygen-dependent test, also called the "progressive incremental test to exhaustion" to determine PPO and VO_{2max} values. These values can be accompanied by submaximal values related to plasma lactate concentrations that include LTs and OBLA. These variables are commonly used to predict cycling performance. Good correlations have been found between road cycling performance and maximal oxygen uptake (VO_{2max}), PPO and ventilatory or lactate thresholds (Hawley & Noakes, 1992; Hopkins & McKenzie, 1994; Coyle, 1995; Lindsey *et al.,* 1996; Nichols *et al.,* 1997; Westgarth-Taylor *et al.,* 1997; Bishop *et al.,* 2000; Hoogeveen & Hoogsteen, 1999; Balmer *et al.,* 2000; Bentley *et al.,* 2001).

It has been shown that the absolute PPO obtained during a maximal aerobic capacity test can be used as a predictor of performance in endurance road cyclists (Coyle *et al.,* 1991; Hawley & Noakes, 1992) and that PPO is in fact a better predictor than VO_{2max} (Hawley & Noakes, 1992). A high correlation ($r = -0.91$; $P < 0.01$) was found by Schabort *et al.* (2000) when comparing PPO obtained during an incremental test to exhaustion and 40 km TT performance during the National Triathlon Championships.

Davison *et al.* (2000) are of the opinion that the best predictor for hill climbing performance in road cycling is the mean power per unit body mass obtained during the Wingate test ($r = -0.90$). This is in agreement with the finding of Padilla *et al.* (1999) that the cyclists who can be considered good climbers in an event such as the Tour de France had the highest PPO relative to body mass, compared with cyclists who specialize as sprinters or endurance (flat terrain) cyclists.

Prins *et al.* (2007) conducted a study on eight competitive male cross-country cyclists and found a weak correlation (r = -0.35 and r = -0.59) between absolute and relative VO_{2max} values and outdoor performance times. It was also found that absolute PPO showed a moderate to good correlation (r = -0.65 and r = -0.66 respectively; $P > 0.05$) with outdoor competition and outdoor time trial (TT), although it was not significant. This was not the case with relative PPO. The latter correlated with both outdoor competitions time and outdoor TT time (r = -0.83 for both correlations; $P < 0.05$). The main finding of the study was that both competition and outdoor time trial performances showed a better relationship to PPO in relation to body mass than to absolute PPO or any other physiological variable or performance measure in laboratory tests. This indicates that mountain biking are very similar to uphill or hill road cycling (Prins *et al.,* 2007). The fact that PPO relative to body mass correlated well to outdoor competition performance and outdoor time trial performance indicated that the typical incremental test to fatigue used for many years by sport scientists is sufficient to predict mountain bike performance and there is no need for a more sport-specific laboratory test (Prins *et al.,* 2007).

In a study done by Impellizzeri *et al.* (2005), VO_{2max}, PPO, the LTs and OBLA expressed in both absolute and relative terms correlated significantly with cross-country competition time. The results are presented in Tables 2.7 and 2.8.

Table 2.7 Pearson correlation coefficients (r) between race time and physiological parameters expressed in absolute terms and scaled to body mass (n = 13).

Variables	**Race Time vs Absolute Values**	**Race Time vs Values. BM^{-1}**	**Race Time vs Values. $BM^{-0.79}$**
VO_{2max}	-0.66 *	-0.62 *	-0.68 *
PPO	-0.71 **	-0.76 **	-0.87 ^
OBLA	-0.71 **	-0.89 ^	-0.94 ^
LT	-0.73 **	-0.86 ^	-0.90 ^

VO_{2max}, maximal aerobic capacity; PPO, peak power output; OBLA, onset of blood lactate accumulation; LT, lactate threshold; * $P < 0.05$; ** $P < 0.01$; ^ $P < 0.001$. Table amended by Impellizzeri *et al.* (2005).

Table 2.8 Spearman rank correlations between ranking and physiological parameters expressed in absolute terms and scaled to body mass (n = 13).

Variables	**Final Ranking vs Absolute Values**	**Final Ranking vs Values. BM^{-1}**	**Final Ranking vs Values. $BM^{-0.79}$**
VO_{2max}	-0.72 **	-0.66 *	-0.81 ^
PPO	-0.69 **	-0.81 ^	-0.91 ^
OBLA	-0.65 *	-0.88 ^	-0.96 ^
LT	-0.73 **	-0.92 ^	-0.94 ^

VO_{2max}, maximal aerobic capacity; PPO, peak power output; OBLA, onset blood lactate accumulation; LT, lactate threshold; * $P < 0.05$; ** $P < 0.01$; ^ $P < 0.001$. Table amended by Impellizzeri *et al.* (2005).

Impellizzeri *et al.* (2005a) found that peak oxygen uptake; PPO, the LT and OBLA expressed both in absolute terms and normalized to body mass were significantly correlated to competition time. They also determined the relationship between VO_{2max}, PPO and OBLA, and final race ranking and found significant correlations expressed in both absolute and relative values. The high correlations (r > 0.90) between the laboratory-determined maximal and submaximal parameters of oxygen-dependent fitness indicated that the most important factors affecting off-road performance in this study were oxygen-dependent and oxygen-independent capacity normalized to body mass, which explained about 80% of the variance in race performance. The results of this study supported the widespread use of including the conventional maximal (VO_{2max} and PPO) and submaximal (LT) measures of oxygen-dependent fitness in the physiological assessments of off-road cyclists.

Gregory *et al.* (2007) compared absolute and relative physiological measures to MTB cross-country race performance in twelve elite and national male cross-country cyclists (Table 2.9). The strongest correlation was observed between PPO relative to body weight and cross-country TT speed (r = 0.93). It showed the importance of the mountain bike cyclists to produce high efforts relative to body mass in determining overall cross-country TT performance. A strong relationship was also present between relative maximal aerobic capacity and time trial speed (r = 0.80). This is in contrast to weak relationships reported by Coyle *et al.* (1991) during a road TT. This suggests that maximal aerobic capacity, as a predictor of performance, may be a more sensitive predictor of MTB cross-country performance than road TT performance. This could be explained by the frequent changes in course direction and gradient, forcing riders to frequently accelerate from slow speeds and climb steep grades typically presented by MTB races. Thus, relative physiological measures may well be more predictive of MTB cross-country race performance than road TT performance (Gregory *et al.,* 2007).

Table 2.9 Correlations between the physiological variables obtained from the maximal progressive exercise test and cross-country time trial.

Variables	**Average Cross-country TT**	**Cross-country TT Ascending Time**
PPO (W)	0.64 *	-0.61 *
PPO:W ($W.kg^{-1}$)	0.93 *	-0.87 *
VO_{2max} ($l.min^{-1}$)	0.66 *	- 0.67 *
Rel. VO_{2max} ($ml.kg^{-1}.min^{-1}$)	0.80 *	-0.72 *
PO at IAT (W)	0.50	-0.48
PO at IAT:Mass ($W.kg^{-1}$)	0.78 *	-0.75 *

PPO, peak power output; PPO:W, peak power output to body mass; VO_{2max}, maximal aerobic capacity; Rel. VO_{2max}, maximal aerobic capacity divided by body mass; IAT, individual anaerobic threshold. * $P < 0.05$. Table amended by Gregory *et al.* (2007).

G. EXERCISE PRESCRIPTION FOR TRAINING AND COMPETITION

During a marathon run, a triathlon or cycling race the athlete tries to complete the distance in the shortest possible time with the least amount of effort (Boulay *et al.,* 1997). This is best done through a pacing strategy whereby the athlete adjusts his/her work rate in response to factors such as the distance that must be covered, the racing strategy, the terrain and the competition. Through experience athletes gets better at pacing themselves. However, there are also some laboratory indicators that may assist athletes and coaches to find this optimal exercise intensity.

Exercise intensity can be quantified in various ways; e.g., cycling speed (minimum, maximum and average speed for the duration of exercise), heart rate (maximal HR, percentage of HR_{max}, HR corresponding to LT and OBLA, or HR reserve), PO (PPO, PO corresponding to LT and OBLA, the average PO over a fixed distance), the percentage of VO_{2max}, the percentage of lactate threshold (LT), maximal lactate steady state (MLSS) and velocity/power associated with maximal oxygen uptake, also called maximal aerobic speed/power (v/pVO_{2max}), oxygen consumption reserve (VO_2R) (Jeukendrup & van Diemen, 1998; Meyer *et al,* 1999; Buchheit and Laursen, 2013; Mann and Lambert, 2013).

Although various methods have been investigated to determine appropriate exercise training intensities, Meyer *et al*. (1999) contends that the lactate threshold concepts promises the best differentiation between oxygen-dependent and oxygen independent exercise training zones. The exercise intensity of 36 trained male cyclists and triathletes at their LT was 75 % of VO_{2max} and 85 % of $HR_{max.}$ This intensity ranges from moderately extensive to highly intensive oxygen independent exercise that would cause a rapid increase in blood [lactate]. OBLA and individualized concepts share the assumption that, at intensities beyond the threshold, an accumulation of lactic acid leads to premature exhaustion (Meyer *et al.,* 1999).

Many previous studies have applied various formats of the lactate threshold to determine exercise training zones. Palmer *et al.,* (1994), Lucia *et al.,* 1999; Andez-Garcia *et al.,* 2000; Padilla *et al.,* 2001; Neumayr *et al.,* 2002; Rodriquez-Marroyo *et al.,* 2003; Neumayr *et al.,* 2003, applied the threshold concepts in cycling stage racing, and Lee *et al.,* 2002; Impellizzeri *et al.,* 2002; Stapelfeldt *et al.,* 2004; Impellizzeri *et al.,* 2005a; different thresholds for off-road training prescription. Markers such as %HR_{max}, training impulse or the time distribution in relation to different metabolic zones [i.e., HR corresponding to OBLA (HR_{OBLA}) and LT (HR_{LT})] seems be more accurate indicators of the physiological demands of cycling competitions (Lucia *et al.,* 1999). The exercise intensity zones were defined as the

HR corresponding to a fixed concentration of 2 $mmol.l^{-1}$ (LT2) and 4 $mmol.l^{-1}$ (LT4) and at 6 $mmol.l^{-1}$ (LT6). The latter was also assessed in order to describe an exercise intensity zone which better reflected very high demanding efforts. At and above this level, energy supply is increasingly met by oxygen independent sources (growing recruitment of type IIa fibres (Gilman *et al.,* 1996). Wirnitzer and Kornexl, (2008) used the following threshold points to describe the exercise intensity profile of the Transalp Challenge in 2004: LOW zone for intensities below the HR corresponding to LT2; MODERATE zone for intensities between the HR at LT2 and LT4; HIGH zone for intensities between the HR at LT4 and LT6; VERY HIGH zone for intensities above the HR corresponding to LT6.

Impellizzeri *et al.* (2002) also used LT and OBLA to define certain exercise intensity zones for off-road cycling competition. Here LT was defined as the intensity that elicited a 1 $mmol.l^{-1}$ increase in blood [lactate] above values measured during exercise at 40-60% of VO_{2max}. OBLA4 was identified as the intensity corresponding to a [lactate] of 4 $mmol.l^{-1}$. HR, PO, and VO_2 at LT and at OBLA were identified by straight-line interpolation between the two closest points to LT and OBLA. This data was used to establish the three exercise intensity zones to describe intensity profiles of cross-country competitions: EASY for intensities below HR corresponding to LT; MODERATE for intensities between HR corresponding to LT and OBLA; and the HARD zone for intensities above HR corresponding to OBLA.

Determination of the specific HR associated with one or more of these lactate parameters is of great use in prescribing training loads. This methodology is, in fact, frequently employed by elite endurance athletes (e.g., professional cyclists) to evaluate the level of intensity attained during training sessions and competitions (Lucia *et al.,* 1999; Lucia *et al.,* 2003). HR training zones are usually defined in relation to power output or blood lactate levels which are obtained from laboratory tests.

Other methods to establish training and competition zones include: HR corresponding to the first ventilatory threshold (VT_1) and HR corresponding to AT (anaerobic threshold) and the second ventilatory threshold (VT_2) (see section D.4.1 for definitions) (Lucia *et al*., 2000). The disadvantage of these methods is that it relies on visual inspection of the relevant graph and determining the threshold manually (Impellizzeri *et al.,* 2005b). To make sure that this disadvantage is minimized, the VT_1 and V_2 should be detected by two independent experienced investigators. If the average value of two investigators is within 3 %, the average can be used. If the average exceeds 3 %, a third investigator should be asked to determine the V_1 and $V_{2.}$ The combination of these three methods of gas exchange threshold detection has been shown to improve the accuracy and reliability of VT identification (Gaskill *et al.,* 2001).

Vogt *et al.* (2006) studied six professional road cyclists during the Regio-Tour International (5-day stage race). They compared the exercise intensities of the cyclists using two different methods, namely the traditional HR measurement and direct measurements of PO. The data were divided into three zones: Zone 1: below LT (the workload that corresponds to the start of the increase in blood [lactate]), Zone 2: between LT and LT + 1 (1mmol.l^{-1} above LT) and Zone 3: above LT + 1. The HR and PO corresponding to each of these zones were identified and the percentage time spent in each zone was determined for the duration of the event.

The distribution of exercise time spent in the different zones according to PO was 58% for zone 1, 14% for zone 2 and 28% for zone 3. According to HR, the cyclists spent 38% in zone 1, 38% in zone 2 and 24% in zone 3. It seems that the description of exercise intensity through HR tends to underestimate the time spent in Zones 1 and 3, and to overestimate the time spent in Zone 2. Vogt *et al.* (2006) explained that the regulation of the cardiovascular system is slower to adapt to the quick changes in high and low PO in decisive race simulations. During descents, for instance, HR can be in Zone 2 while PO is already in Zone 1. Or during intermittent sprints, PO is already in Zone 3 while HR is still in Zone 2. The cardiovascular drift can be another explanation for underestimation of the time spent in Zone 1, using HR measurements, specifically in hot and humid conditions.

For the daily training routine, this might indicate that, because of the delay in the response of HR to rapid changes in workload, workload prescription in watts might be more suitable to monitor the pace of shorter intervals or sessions with frequent pace changes (Vogt *et al.,* 2006). On the other hand, monitoring of overall stressed induced by the duration of the competitions, HR indices would be more acceptable.

Regular oxygen-dependent training reduces the submaximal HR response at a specific absolute workload, but leaves the maximal HR relatively unaltered regardless of training status in a given population (Neumayr *et al.,* 2002). Thus, if athletes train or compete with a HR monitor, they should take these adaptations to training into account. Therefore target HR recommendations are often based on results of previous laboratory exercise tests and should be regularly updated. When training prescription is based on HR data, periodic readjustment of target PO (i.e., at LTs) is necessary through repeated testing during the season.

H. CONCLUSION

Competitions are normally the main focus point of a training season. A lot of time is spent on training for these specific competitions and therefore to adequately prepare for such events knowledge of the demands of real life competitions is crucial. By determining the exercise intensity at which these competitions are completed would give sport scientists and coaches better insight to the physical and physiological demands of specific events.

It is evident from the literature that MTB racing happens at intensities that require well developed oxygen-dependent and oxygen independent systems. In order to develop both systems, training programs should be focussed and specific, but care should also be taken to prevent overtraining. Therefore the monitoring of exercise intensities during training and competitions can provide coaches and sport scientists with useful information. Although there are various methods to monitor exercise intensities, where some methods may be more accurate than others, one is sometimes limited to the most practical and financially feasible methods. For real-time competition monitoring, HR and RPE measurements fit both criteria.

The literature discussed in this chapter suggests that both oxygen-dependent and oxygen independent power are important determinants for competitive cycling performance (Tanaka *et al.,* 1993). Although it is widely accepted that maximal oxygen-dependent power (VO_{2max}) is a major determinant of success in endurance cycling, the results of Baron (2001) showed that a cyclist's performance should be assessed in terms of both oxygen-dependent and oxygen independent components.

Various amounts of laboratory based tests have been developed to test the physical and physiological capacities of athletes. These tests have been adapted to better accommodate athletes and also to better detect physiological changes that occurred with adequate training stimuli. Along with these tests came the different parameters and laboratory variables that are used to determine physiological capacity. These laboratory variables where also used to correlated with outdoor performance to see which variable best correlated to outdoor performance.

Despite all the different techniques for determining these variables and all the different definitions for the variables, sport scientists and sport physiologists all over the world still use these tests and variables to assess athletes in the laboratory. By looking at all the literature discussed in this chapter, it is safe to say that laboratory tests can be done to determine physical and physiological characteristics of cyclists and that the laboratory variables can be used to predict outdoor performance for this type of sport.

CHAPTER THREE

PROBLEM STATEMENT

A. SUMMARY OF THE LITERATURE

South Africa annually hosts one of the premier MTB stage events in the world, namely the ABSA Cape Epic. The field ranges from highly ranked international mountain bikers who compete for honors and UCI points, to recreational cyclists whose only desire it is to complete the race. No matter what the cyclist's status, substantial amounts of training is required to prepare for this race and cyclists often consult sport scientists for advice. However, there is currently not enough information available to adequately advise and assist mountain bikers in their preparations. A few studies focused specifically on the exercise intensity of professional road-races consisting of long durations and difficult mountain passes (Andez-Garcia *et al.,* 2000; Padilla *et al.,* 2001; Padilla *et al.,* 2008). However, to my knowledge this is the first study to describe the efforts of cyclists during the ABSA Cape Epic multi-stage race.

In recent years, a small but growing number of physiological studies have been published on competitive MTBing (Impellizzeri *et al.,* 2002; Wirnitzer & Kornexl, 2008). Very few of these studies focused specifically on actual MTB events (Impellizzeri *et al.,* 2002) and only one investigated a MTB multi-stage event (Wirnitzer & Kornexl, 2008). In contrast, several investigators quantified the physiological demands of professional road cycling competitions (Andez-Garcia *et al.,* 2000; Padilla *et al.,* 1999; Padilla *et al.,* 2001; Lucia *et al.,* 2003a, 2003b), showing among others, the high aerobic demands of the sport (Padilla *et al.,* 2008). Physiological data for competitive elite and international male road cyclists have been extensively reported (Coyle *et al.,* 1991; Mujika & Padilla, 2001), however, similar data relating to MTB cross-country biking is lacking (Gregory *et al.,* 2007).

The laboratory assessment of physiological variables such as lactate threshold and maximal aerobic capacity and its relevance to endurance performance are important information for coaches and athletes (Bentley *et al.,* 2001). Furthermore, exercise intensity profiling of specific events plays an important role in the planning of training programs and preparation of competitions. Training prescription can further be optimized if objective measures can be employed to predict performance outcomes (Lamberts, 2014). The two most commonly used methods to predict cycling capacity is PPO and 40-km TT time. Both these tests have been shown to be good indicators of a cyclist's training status and are able to detect small meaningful changes in training status in trained to elite cyclists (Lamberts, 2014). In many ways there is a difference between MTBing and road cycling. Specific physiological requirements may differ from MTBing compared to road cycling, because of the different terrain conditions and different cycling strategies incorporated in the sport. Therefore the laboratory performance predictors that are used for road cycling may not be applicable for mountain bikers (Prins *et al.,* 2007).

Various studies have shown that absolute and relative VO_{2max} is not a good indicator of cycling ability (Lucia *et al.,* 1999; Impellizzeri *et al.,* 2005b) and that VO_{2max} is not a good predictor of 40-km cycle or 8-km running performance in triathletes (Bentley *et al.,* 1998). Similarly, Prins *et al.* (2007) found that neither relative nor absolute VO_{2max} values correlated with outdoor MTB performance.

On the other hand, it has been shown that PPO obtained during a maximal incremental cycle test can be used as a predictor of performance for endurance road cyclists and that it is a better predictor than maximal aerobic capacity (Coyle *et al.,* 1991; Hawley & Noakes, 1992). It seems that the same holds true for MTBing. Prins *et al.* (2007) reported strong correlations between PPO, PO at OBLA (expressed relative to body mass) and MTB outdoor performance (r = - 0.83 and r = - 0.74, respectively). Similar results were found in road cycling where uphill stages were included (Davison *et al.* 2000). The average power during the Wingate test per unit of body mass correlated to the time it took to complete the 6 km uphill ride (r = -0.90) and the time it took to complete the 1 km uphill ride (r = - 0.92). These findings suggest that the physiological requirements for road cycling over hilly terrain and MTBing may be comparable.

The physiological and performance information gathered from MTBing events, coupled with the data obtained from laboratory tests can be used to gain insight into the importance of physiological measures as predictors of MTB race performance. The current study will thus expand on the study of Prins *et al.* (2007) in which the predictors of performance in a cross-country marathon were described.

B. MOTIVATION

The 2014 ABSA Cape Epic event took place over eight days, covered 729 km and involved 14 850 m of climbing. This multi-stage race demands a distance of between 85km and 134km per day. The ABSA Cape Epic is therefore an extreme test of power and endurance that requires a well-planned and well executed training program.

Exercise intensity profiling of actual competitions can be useful to understand the physiological demands of these particular cycling events. From a practical point of view, this information could also help to design proper training programs. Furthermore, as many coaches include some races as part of training, the exercise intensity profile could be useful to understand the training load imposed on athletes (Impellizzeri *et al.,* 2002). This information can be used to ensure proper training intensities for effective training adaptation, but also to prevent overtraining. The lack of sport-specific guidelines in training and competition often seduces athletes to "bonking" in terms of performance and health (Schenk *et al.,* 2010). Although the number of professional and amateur participants in cross-country marathon stage events is increasing, to the best of our knowledge, only one study (Wirnitzer & Kornexl, 2008) has examined the exercise intensity during this specific kind of competition.

The information gained by this research will also assist medical teams and organisers with planning, as it will provide more objective information about the physical demands on the cyclists. For instance, this information may assist with decisions on the number of water points necessary en route, as well as the timing of the event in the race calendar. Novice cyclists, elite cyclists, nutritional teams, recovery teams and coaches will be able to apply effective training programs that will ensure adequate preparations and therefore lead to better performance. Furthermore, conclusions made from performance tests in the laboratory can be used to determine which tests and measures are better to use as performance predictors for this particular event. This will help cyclists determine if they are physically and physiologically prepared for the event. This will be a huge contributing factor to the quality of world-class multi-stage races such as the Cape Epic and even the Tour de France.

To date no study has been done to describe the profile of exercise intensities of the ABSA Cape Epic to provide cyclists and coaches with essential information to prepare for the event.

C. THE AIMS OF THE CURRENT STUDY

The primary aim of the study was to describe the physiological demands and predictors of performance of a multi-day MTB event.

Specific aims

1. To monitor the heart rates of cyclists during each stage of the 2014 Cape Epic race.
2. To compare the profile of exercise intensities between two groups (novice and experienced).
3. To correlate the cyclists' performance during the event with laboratory performance parameters obtained from the incremental exercise test and the 40 km time trial.

CHAPTER FOUR

METHODOLOGY

A. STUDY DESIGN

This study followed a qualitative-quantitative design to describe the physiological demands and predictors of performance of a multi-day MTB event. Participants performed laboratory exercise tests within 8 weeks prior to the event. During each stage of the event they wore heart rate monitors and kept daily diaries. There was no control group in this study and no interventions were employed.

B. SUBJECTS

Twenty-five men and women (>18 years) participated in the study. Subjects were recruited through advertisements that were placed on various cycling related websites. All participants underwent a screening procedure to ensure they met the inclusion criteria. Participants also completed a pre-event questionnaire (Appendix A, D, E, F) and a health questionnaire (Appendix C) as part of the screening process.

For inclusion, participants had to be healthy and older than 18 years, had to have proof of a 2014 Absa Cape Epic entry and have their own downloadable HR monitor set. They had to complete the pre-event performance tests (VO_{2max} and 40 km TT) and questionnaires (Appendix A, C, D, E, F). They were excluded from the study if they didn't complete all the stages of the Cape Epic. Participants were also excluded if they used medication that could affect their blood lactate and HR responses during the exercise tests.

Twenty three of the 25 participants completed all the stages of the 2014 Absa Cape Epic event. Two cyclists had to withdraw from the event due to injuries.

1. Assumptions

It was assumed that participants gave all-out efforts during the laboratory exercise tests. It was also assumed that participants were honest in reporting daily activities and the use of caffeine, tobacco and other medication in the event questionnaire (Appendix G), as well as being honest in completing the event diaries.

2. Delimitations

The participants included in the study were from the same geographic location (Cape Town, Stellenbosch, Strand, Paarl and Somerset-West) and the sample was further limited to those with a valid 2014 Absa Cape Epic entry at the time of recruitment.

3. Limitations

During the event certain information was obtained from the cyclists through a questionnaire (Appendix G). This information relied on their memory of the day's events.

C. EXPERIMENTAL DESIGN

1. Laboratory tests

The participants were required to visit the laboratory on two occasions. The following is a summary of what was done during the separate visits:

Visit 1

The study protocol and aims of the study were explained to the volunteers. A pre-event questionnaire (Appendix A, D, E, F) and a health questionnaire (Appendix C) were completed and the consent form was explained in their language of preference (Afrikaans or English). Time was given for questions, where after the participants singed the consent form. The participant's body composition was measured using a BodyMetrix BX2000 device, followed by an incremental exercise test to fatigue on the cycle ergometer. The cyclist's capillary blood lactate concentrations were determined after each workload increment.

Visit 2

The second visit was at least 72 hours after visit one, but no more than one week apart. Cyclists completed a 40 km simulated time trial (TT) (see D.3.) on the cycle ergometer in the shortest possible time. The cyclist's capillary blood lactate concentration was assessed each 5 km interval, as well as their rating of perceived exertion (RPE) (Borg scale 6-20) (Appendix H).

All laboratory tests were completed in the Sport Physiology laboratory at the Department of Sport Science at Stellenbosch University. All tests were done at temperatures between 18 and 20°C.

2. Monitoring during the event

Participants wore heart rate monitors during the event. After each stage the heart rate data were downloaded onto a portable computer. Data analysis took place after the event in the Sport Physiology laboratory. Participants did not receive any feedback during the event regarding their heart rate data.

The participants completed an event questionnaire (Appendix G) of their daily food and fluid consumption, medicine or supplements used during the day, as well as smoking during the day at the end of every stage. At the end of each stage the cyclists also gave a description of the stage where they included information about any technical difficulties experienced with their bikes during the stage. The official race times for all participants were obtained from the race office.

2. Ethical aspects

The study protocol was approved by the Ethics Committee for Human Research (Humanities) at Stellenbosch University (Reference number: DESC_Greeff2013) (Appendix B). During the first visit the study protocol and informed consent (Appendix A) form were explained to each participant. Participants were given the opportunity to read through the form and ask questions. The study did not involve any invasive procedures and cyclists were informed that their participation was completely voluntary and that they could withdraw from the study at any time.

D. MEASUREMENTS AND TESTS

All participants completed a body composition screening, a maximal graded exercise test to exhaustion and a 40 km simulated time trial within 8 weeks prior to the event.

1. Anthropometric measurements

Anthropometric measurements included stature, body mass and BodyMetrix Analysis, as well as limb circumferences to assess percentage body fat.

a. Body mass

Body mass was determined with a calibrated electronic scale (UWE BW - 150, 1997 model, Brisbane Australia) and recorded to the nearest 0.1 kilogram (kg). Subjects were asked to stand in the middle of the scale, distributing weight evenly on both legs. Subjects were barefoot and clothed in light-weight clothing.

b. Stature

Stature was measured with a sliding stadiometer (Seca, Germany). Measurements were taken to the nearest 0.1 centimeter (cm). The subjects stood barefoot with heels together and upper back, buttocks and heels against the stadiometer. The head was placed in the Frankfurt plane. The Frankfurt plane is achieved by positioning the lower edge of the eye socket (Orbitale) in the same horizontal plane as the notch just above the tragus of the ear (Tragion). The measurement was taken from the inferior aspect of the feet to the vertex of the skull (the highest point on the skull).

c. BodyMetrix analysis

The subject's lean and fat masses were measured with a BodyMetrix BX2000 device (Hosand Technologies, Verbania). The BodyMetrix BX2000 uses ultrasound technology that can validly measure a single body point, with a tenth of a millimetre precision to give fat tissue thickness as a percentage of the whole body and how it's distributed. Ultrasound waves travel in the tissue and a strong reflection occur at the boundary of different tissue types, for example, fat to muscle and muscle to bone. Subjects voided their bladders prior to the measurements and were asked to refrain from exercise and smoking and drinking diuretics such as caffeine or alcohol for at least four hours before the tests.

Three anatomical points were identified where the thickness of the fat layer was measured according to the 3-site skin fold test (Jackson *et al.,* 1979; 1980). For the men the three measurements were taken on the chest (midway between the anterior axillary line and the nipple), the waist (5 cm horizontally to the right hand side of the omphalion) and the thigh (midway between the patella and the crease of the hip on the anterior midline of the thigh). For the women the measurements were taken on the hip (the most superior point on the iliac crest where a line, drawn from the middle of the armpit on the longitudinal axis of the body, meets the ilium), the waist (5 cm horizontally to the right hand side of the omphalion) and the triceps (the point on the posterior surface of the arm, on the mid-line, at the level of the marked mid-acromiale-radiale landmark (the point at the proximal and lateral border of the head of the radius of the elbow)).

The BodyMetrix probe was covered with ECG gel and placed one by one on the different sites. The probe was slid about 1 cm to either side of the anatomical point. Fat tissue thickness as a percentage of the whole body was noted.

2. Maximal aerobic capacity

The results of this test were used to describe the endurance capacity of the participants and to determine the exercise intensity zones for the aerobic and anaerobic components of the race.

A progressive incremental exercise test to exhaustion was performed on the Velotron Dynafit Pro (Racer Mate, USA) to determine maximal aerobic capacity (VO_{2max}). The Cosmed CPET (Cosmed Quark CPET, Rome, Italy) metabolic analyser was used for breath by breath analysis of cardiorespiratory variables throughout the test.

The participants first performed a 10 min warm up at 80 W and a cadence of their choice. The participants were allowed to drink water after the warm up and then the face mask and heart rate monitor were fitted. Men started at 120 W for 60 sec, where after the workload was increased by 30 W every 150 sec. Women started at 80 W and then the workload was increased by 30 W every 150 sec. Participants kept the cadence between 80-100 rpm. In the last 30 sec of each step, a capillary blood sample (0.3 µl) was taken from the finger and immediately analyzed using the Lactate Pro 2 LT-1730 (Japan). The test was terminated upon voluntary exhaustion, which was verified if three of the following five criteria were reached: (i) the VO_2 did not increase by more than 150 ml per successive workload, (ii) a respiratory quotient (R) value equal or above 1.15 was reached, (iii) heart rate was more than 90 % of the age-predicted maximal heart rate, (iv) the rating of perceived exertion (RPE) was above 19 on the 6 – 20 Borg scale (Appendix H) and (v) the final blood lactate concentration was above 8 $mmol.l^{-1}$.

Throughout the test breath by breath expired gases were sampled through the turbine flow meter and gas sampling line and analysed by a cardio-pulmonary metabolic system (Cosmed Quark CPET, Rome, Italy). The gas analysers were calibrated with atmospheric gas and known gas concentrations (16 % O_2, 4 % CO_2 balance N_2) and the turbine flow meter was calibrated with a 3 L calibration syringe prior to each test. Heart rate was measured through telemetry (COSMED wireless HR monitor, Italy) which was interfaced with the metabolic system.

Lactate threshold (LT) and onset of blood lactate accumulation (OBLA) were used to analyze the data obtained from the maximal aerobic capacity test. LT was defined as the point where the blood [lactate] increased by 1 $mmol.l^{-1}$ from the baseline values, whereas OBLA was defined as the point where blood lactate concentration was equal to 4 $mmol.l^{-1}$. The thresholds were determined by using a software program that calculates blood lactate endurance markers (Newell et al., 2007). In Figure 4.1 the determination of both LT and OBLA are illustrated.

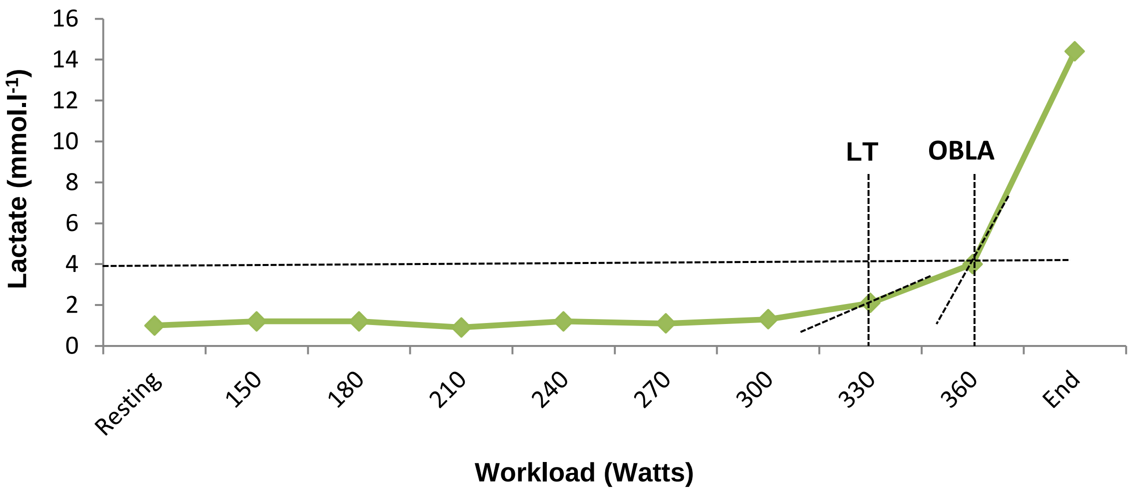


Figure 4.1 Determination of LT and OBLA for each cyclist during the maximal aerobic capacity test.

3. 40 km simulated time trial

The test was performed on the Velotron Dynafit Pro (Racer Mate, USA) cycle ergometer. Prior to the trial subjects completed a self-selected warm-up and then cycled at a self-selected pace for 40 km in the fastest possible time. The time trial consisted of a total of 880 m uphill and 880 m downhill. The cyclist's capillary blood lactate concentrations were assessed after every 5 km interval and rating of perceived exertion (RPE) values (Borg scale 6-20 (Appendix H)) were also recorded every 5 km. Heart rate was continuously monitored using a Suunto (Suunto, Finland) heart rate monitor. Visual feedback in the form of heart rate (bpm), elapsed time (min:sec), distance covered, cadence (rpm), speed (km/h), gradient (%), power output (W), average torque angle (degrees), cross-section of the entire route, their current position on the route and their gear ratio were visible on a computer screen during the test. The participants were allowed to drink water *ad libitum* during the time trial. Participants received no encouraged by the researcher during the time trial.

To determine the reliability of the simulated 40 km TT seven volunteers, that was not part of the participants of the study, completed the TT on two occasions. The two tests were at least

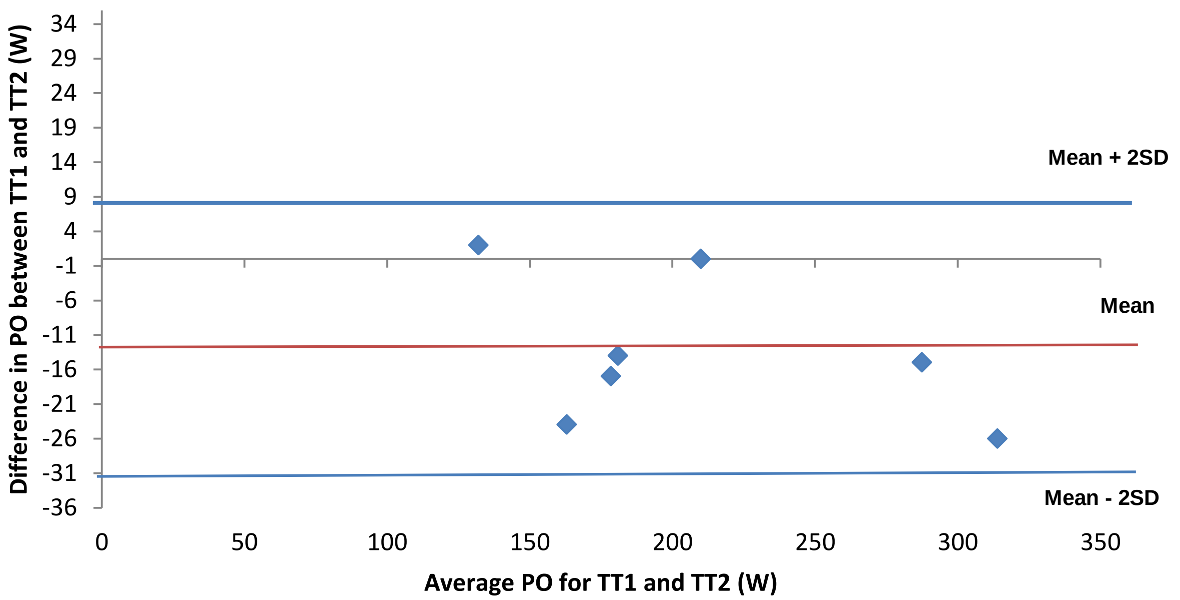
72 hours apart, but not more than 7 days. The volunteers were not externally motivated and were allowed to drink water *ad libitum*. The reliability (ICC) and correlations with confidence limits are presented in Table 4.1. Moderate correlations were observed for the average power output (PO) of the two time trials and high correlations were found for both average HR and total TT time. The interclass reliability for average power output, average HR and total TT time were also high ($R_1 > 0.90$).

Table 4.1 The test-retest reliability of the 40km simulated TT in the laboratory.

Variable	r-value	ICC	Confidence limits	
			Lower	Upper
Average PO	0.72	0.92	-0.07	0.96
Average HR	0.90	0.92	0.46	0.99
Total time	0.86	0.92	0.30	0.98

Bland-Altman (Bland & Altman, 1986) plots of the difference in PO between TT1 and TT2 showed a bias ± standard deviation error of -13.43 ± 34.66 W (Fig.4.2a), and the difference in average HR between TT1 and TT2 showed a bias ± standard deviation of 1 ± 16.97 bpm (Fig.4.2b).

A.



B.

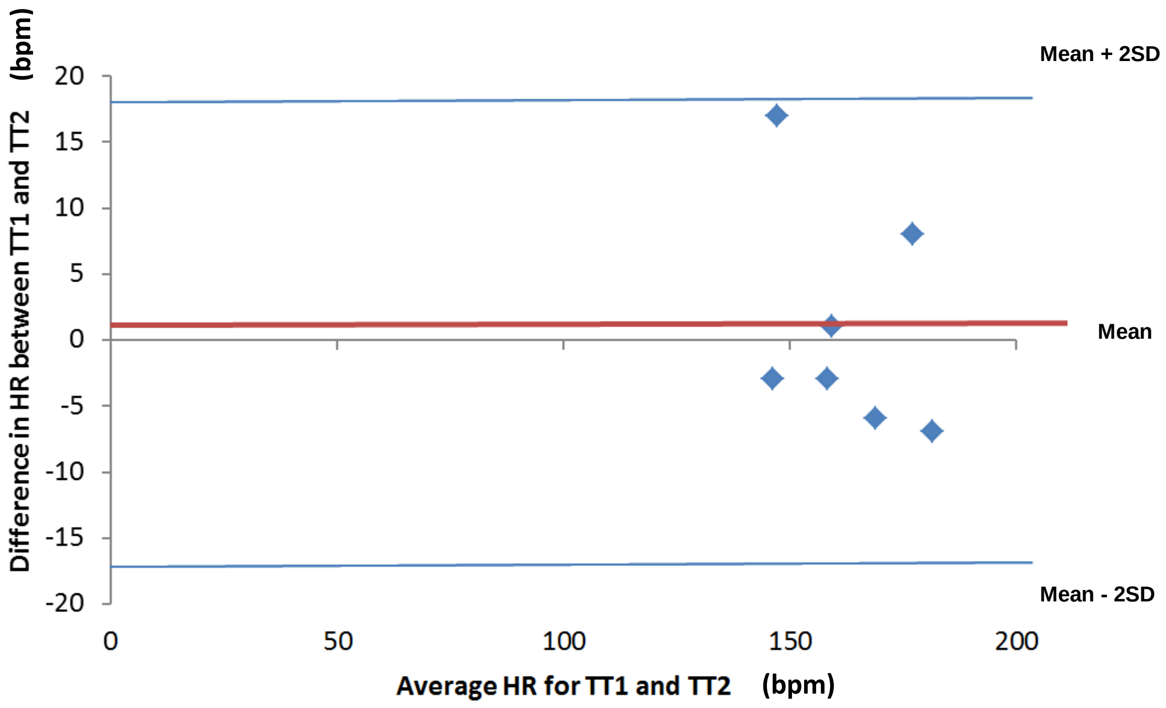


Figure 4.2 (A & B) Bland-Altman plots for the differences in (A) PO and (B) HR between TT1 and TT2. The red line shows the bias and the blue line indicates the 95% limits of agreement.

E. DATA ANALYSIS

Statistical analysis was performed using Microsoft Office Excel (Windows Office 2010) and Statistica 12.0. Descriptive statistics are reported as means and standard deviations (±SD) unless otherwise specified. Unpaired T-tests were performed to assess for statistically significant differences between groups and Spearman Rank-order correlations were calculated to describe relationships between physiological characteristics obtained in the laboratory and performance parameters from the event. Correlations were classified as follow: 0.90 to 1.00 very high, 0.70 to 0.90 high, 0.50 to 0.70 moderate, 0.30 to 0.50 low and 0.00 to 0.30 negligible (Mukaka, 2012). Single factor analysis of variance (ANOVA) was used to calculate the interclass reliability of the 40 km simulated TT. Pearson correlations coefficients were used to describe the test-retest reliability. The exercise intensity zones were determined based on lactate parameters (LT and OBLA) for the oxygen-dependent and oxygen independent components of the race (Impellizzeri *et al.,* 2002). Three zones were determined namely:

(1) EASY HR zone for intensities below HR corresponding to LT.
(2) MODERATE HR zone for intensities between HR corresponding to LT and OBLA.
(3) HARD HR zone for intensities above HR corresponding to OBLA.

Bland-Altman plots were drawn to illustrate the agreement between the repeated time trials. Best subsets regression analysis with a criterion of $P < 0.05$ was performed to identify laboratory predictors associated with event performance. The best subsets regression procedure was used to identify statistically significant independent variables of cyclists' performances in the field. Two dependent variables were considered, namely overall race time and final classification. The best subsets method assesses all possible models using the specified predictors, which in this case were the physiological and performance measures obtained from the laboratory exercise tests. The best fitting models were identified as those with the largest R^2, taking into account the number of variables included in the regression model. The best subsets method was restricted to include only combinations with 5 variables or less. Eventually the best models selected had only 3 predictor variables giving an acceptable ratio of parameters versus number of observations. The level of significance was set at $P < 0.05$ for all analysis.

CHAPTER FIVE

RESULTS

A. THE COURSE PROFILE OF THE 2014 ABSA CAPE EPIC

Participants in the 2014 ABSA Cape Epic competed over a distance of 729 km with 14 850 m of climbing over the 8 day stage race (Table 5.1). The distance (km) per day ranged from 24 km (day 1) to 134 km (day 4). The weather conditions are reported for the time the cyclists spent in the field every day from 7 am to 5 pm (Table 5.2). The weather conditions are representative of the closest nearby town and weather station where each stage took place.

Table 5.1 Characteristics of the course profile of the 2014 Absa Cape Epic.

	Prologue	Stages							Mean (± SD)
		1	2	3	4	5	6	7	
Distance (km)	24	113	103	134	88	115	85	67	91 ± 34
Altitude (m)	700	2450	1550	1800	1850	2900	1800	1800	1856 ± 642
Cut-off time hours)	3.0	10.0	8.5	10.0	8.5	10.0	8.0	6.5	8.1 ± 2.4

Table 5.2 Weather conditions during the 2014 Absa Cape Epic.

Stages	Temperature (°C)	Range (°C)	Humidity (%)	Range (%)	Rain (mm)
Prologue	18.4 ±1.5	16.4 – 20.6	75.5 ±8.9	63.0 – 88.0	0.0
1	17.6 ±1.1	16.3 – 19.4	79.6 ±7.2	68.0 – 87.0	2.0
2	18.4 ±1.7	15.5 – 20.5	64.4 ±16.5	44.0 – 85.0	0.2
3	16.5 ±2.1	14.2 – 19.1	75.2 ±8.4	63.0 – 84.0	2.6
4	20.8 ±4.2	13.8 – 25.7	67.4 ±12.7	55.0 – 89.0	0.0
5	21.9 ±6.1	10.9 – 27.5	65.4 ±18.9	46.0 – 94.0	0.0
6	19.3 ±3.3	13.1 – 22.2	69.8 ±13.1	58.0 – 90.0	0.0
7	19.4 ±1.4	16.4 – 21.4	67.0 ±5.9	61.0 – 79.0	0.2

B. DESCRIPTIVE CHARACTERISTICS OF THE STUDY SAMPLE

1. Subject characteristics

25 participants (23 men and 2 women) volunteered to participate in the study. The physical characteristics of the participants are represented in Table 5.3 Their ages ranged between 22 and 56 years, and both the youngest and oldest participants were men. According to Otto (2006) the men were classified in the very lean (95th percentile) fitness category (according to their percentage body fat) and the women were classified as good (70th percentile).

Table 5.3 Physical characteristics of the cyclists.

Variable	Men (n = 23)	Range	Women (n=2)	Range
Age (years)	39 ±9	22 - 56	34 ±6	30 - 38
Height (cm)	179.7 ±7.8	158.0 - 196.0	168.5 ±4.9	165.0 - 172.0
Body mass (kg)	76.1 ±8.1	63.1 - 93.3	59.1 ±0.9	58.4 - 59.7
BMI (kg.m^{-2})	23.6 ±1.8	19.5 - 27.3	20.8 ±0.9	20.2 - 21.5
Body Fat (%)	11.9 ±2.1	7.8 - 14.9	19.0 ±0.1	18.9 - 19.1
Lean body mass (%)	88.1 ±2.1	85.1 - 92.2	81.0 ±0.1	80.9 - 81.1

The cyclists' mountain bike (MTB) experience and their number of training sessions per week prior to the event are represented in Table 5.4. The women were more experienced in MTB stage races while the men were more experienced in terms of competitive years. Men and women reported the same amount of training per week prior to the race. .

Table 5.4 Mountain bike (MTB) experience of the cyclists.

Variable	Men (n = 23)	Range	Women (n=2)	Range
# Cape Epic races	2 ±2	1 - 9	3 ±3	1 - 5
# other MTB events (≥3 days)	3 ±4	0 - 11	6 ±3	4 - 8
# Competitive years	8 ±6	1 - 25	3 ±2	2 -5
# Training sessions/week	6 ±2	4 - 9	6 ±0	6 - 6

MTB, mountain bike

2. The maximal exercise capacity of the cyclists

The physiological characteristics of the participants are illustrated in Table 5.5. There were statistically significant differences in the absolute maximal aerobic capacity between the men and women (P = 0.02), as well as the absolute peak power output (P = 0.03). Although all the values relative to body mass were higher in the men than the women, the differences were not statistically significant.

Table 5.5 The physiological characteristics of the cyclists.

Variable	Men (n=23)	Women (n=2)	P-value
Absolute VO_{2max} ($l.min^{-1}$)	4.1 ±0.7	3.1 ±0.2	0.02*
Relative VO_{2max} ($ml.min^{-1}.kg^{-1}$)	53.8 ±7.4	53.0 ±2.8	>0.05
HR_{max} (bpm)	184 ±9	174 ±11	>0.05
La_{max} ($mmol.l^{-1}$)	15.0 ±3.2	11.8 ±1.1	>0.05
PPO (W)	350 ±47	258 ±20	0.03*
PPO:W ($W.kg^{-1}$)	5.0 ±0.0	4.4 ±0.3	>0.05
PO_{OBLA} (W)	320 ±43	215 ±28	>0.05
PO_{OBLA} :W ($W.kg^{-1}$)	4.2 ±0.5	3.6 ±0.4	>0.05
PO_{LT} (W)	296 ±44	197 ±35	>0.05
PO_{LT} :W ($W.kg^{-1}$)	3.9 ±0.6	3.3 ±0.5	>0.05
HR_{OBLA} (bpm)	167 ±11	164 ±15	>0.05
HR_{OBLA} as % of HR_{max}	91.0 ±2.1	93.9 ±2.4	>0.05

VO_{2max}; maximum aerobic capacity; $ml.min^{-1}$, milliliter per minute; $ml.min^{-1}.kg^{-1}$, milliliters per minute per kilogram; W, watts; PO_{OBLA}, power output at onset of blood lactate accumulation; PO_{OBLA}: W, power output at onset of blood lactate accumulation to body mass ratio; PO_{LT}, power output at lactate turnpoint; PPO: W, peak power output to weight ratio; PO_{LT}: W, power output at lactate turnpoint to weight ratio; $W.kg^{-1}$, watts per kilogram; $mmol.l^{-1}$, millimol per liter; bpm, beats per minutes; HR_{max}, maximal heart rate, *P < 0.05

The absolute VO_{2max} values for the men ranged from 3.0 to 5.2 $l.min^{-1}$ and for women from 3.0 to 3.3 $l.min^{-1}$. The PPO values for the men ranged from 270 to 454 W and the women ranged from 244 to 272 W. According to the ACSM guidelines for exercise testing and prescription the men were classified in the excellent (90th percentile) category for maximal aerobic capacity (VO_{2max}), while the women were classified in the good (85th percentile) category (Otto, 2006).

3. 40 km TT performance

Due to technical difficulties with the cycle ergometer two men did not complete the TT and their data were not included in the results. The men completed the TT in a shorter time (10.8 %) and a higher average PO (36.4%) than the women, however, these differences were not statistically significant.

Table 5.6 Physiological responses and performance of cyclists during the 40 km TT.

Variable	Men (n = 21)	Women (n=2)	P-value
HR_{AVE} (bpm)	159 ±20	161 ±18	>0.05
PO_{AVE} (W)	236 ±35	200 ±18	>0.05
Time (min:sec)	74:34 ±6:28	82:35 ±5:59	>0.05

Due to the fact that there were no significant differences in the relative performance of the men and women on both the maximal exercise test and the 40 km TT, the two groups were pooled. The participants were then divided into two groups (novice and experienced) according to their MTB experience. The median number of events in which the group participated were calculated (= 3) and novices were classified as those having completed three or less 3 - day multi-stage MTB events. The experienced group included those who have completed more than three 3 - day multi-stage MTB events. Both women were included in the experienced group.

C. DESCRIPTIVE CHARACTERISTICS OF THE NOVICES AND EXPERIENCED CYCLISTS

1. Subject characteristics

The MTB experience of two groups is compared in Table 5.7. The experienced cyclists participated in more Cape Epic races and other 3-day multi-stage events than the novice cyclists. They also had more competitive years in the sport.

Table 5.7 MTB experience of the novices and experienced participants.

Variable	Novices (n=14)	Experienced (n=11)
# Cape Epic events	1 ±0	4 ±3
# other MTB events (≥3 day stage)	1 ±1	8 ±2
# Competitive years	6 ±4	10 ±8
# Training sessions per week (3 months prior to event)	6 ±1	6 ±1

The physical characteristics of the novice and experienced cyclists are presented in Table 5.8. The experienced riders were slightly older, taller and heavier than the novices, however, these differences were not statistically significant. The experienced riders had significantly more body fat and less lean body mass than the novices.

Table 5.8 Physical characteristics of participants (means ± SD).

Characteristics	Novices (n=14)	Experienced (n=11)	P-values
Age (years)	37 ±10	41 ±6	> 0.05
Height (cm)	177.0 ±8.0	181.0 ±8.2	> 0.05
Body mass (kg)	72.5 ±6	77.6 ±11.6	> 0.05
BMI ($kg.m^{-2}$)	23.2 ±1.6	23.6 ±2.3	> 0.05
Body Fat (%)	11.5 ±2.1	13.6 ±3.2	0.047*
Lean body mass (%)	88.5 ±2.1	86.4 ±3.2	0.047*

2. The maximal exercise capacity of the cyclists

Table 5.9 shows that there were no statistically significant differences in the maximal exercise capacity of the novice and experienced cyclists, neither in absolute or relative terms The experienced group had a slightly higher PPO and PO at LT and OBLA, but when it is expressed relative to body mass, the values were practically the same.

Table 5.9 The physiological characteristic of the cyclists (means ± SD).

Variable	Novices (n=14)	Experienced (n=11)	P-value
VO_{2max} (l.min^{-1})	3.9 ±6.3	4.1 ±0.8	> 0.05
VO_{2max} (ml.min^{-1}.kg^{-1})	54.4 ±6.5	52.8 ±8.0	> 0.05
HR_{max} (bpm)	184 ±10	181 ±9	> 0.05
La_{max} (mmol.l^{-1})	14.6 ±2.6	14.9 ±4.0	> 0.05
PPO (W)	329 ±43	359 ±60	> 0.05
PPO:W (W.kg^{-1})	4.5 ±0.4	4.6 ±0.4	> 0.05
PO_{OBLA} (W)	302 ±35	324 ±66	>0.05
PO_{OBLA}:W (W.kg^{-1})	4.2 ±0.3	4.2 ±0.7	> 0.05
PO_{LT} (W)	283 ±39	295 ±64	>0.05
PO_{LT}:W (W.kg^{-1})	3.9 ±0.4	3.8 ±0.7	> 0.05
HR_{OBLA} (bpm)	168 ±11	165 ±11	> 0.05
HR_{OBLA} as % HR_{max}	91.0 ±2.5	91.6 ±1.9	>0.05

VO_{2max}; maximum aerobic capacity; l.min^{-1}, liter per minute; ml.min^{-1}.kg^{-1}, milliliters per minute per kilogram; W, watts; PO_{OBLA}, power output at onset of blood lactate accumulation; PO_{OBLA}: W, power output at onset of blood lactate accumulation to body mass ratio; PO_{LT}, power output at lactate turnpoint; PPO: W, peak power output to weight ratio; PO_{LT}: W, power output at lactate turnpoint to weight ratio; W.kg^{-1}, watts per kilogram; mmol.l^{-1}, millimol per liter; bpm, beats per minutes; HR_{max}, maximal heart rate.

3. 40 km TT performance

Two participants from the experienced group did not finish the time trial due to technical difficulties with the cycle ergometer and their data were not included in this analysis. Table 5.10 depicts the physiological responses of the two groups during the TT test. Although the experienced group completed the TT in a slightly better time (5.8 %) and at a higher average PO (24.9 %) than the novice group, the differences in performance were not statistically significant. The average PO during the TT was statistically significant ($p < 0.05$) lower (30 %) than the PO at OBLA during the maximal aerobic test for the novices group. The average PO during the TT was also lower (20 %) than the average PO at OBLA for the experienced group, but not statistically significant. The average HR expressed as a percentage of maximal HR obtained in the laboratory and the field was above 80 % for both groups.

Table 5.10 Physiological responses and performance of cyclists during the 40 km TT (means ± SD).

Variable	Novices (n=14)	Experienced (n=9)	P-value
Time (min:sec)	76:54 ±6:33	72:42 ±6:27	> 0.05
HR_{ave} (bpm)	157 ±22	162 ±12	> 0.05
HR_{ave} as % $HR_{max\ Lab}$	85.9 ±10.6	88.9 ±3.5	> 0.05
HR_{ave} as % $HR_{max\ Field}$	84.2 ±11.0	88.1 ±5.3	> 0.05
PO_{ave} (W)	227 ±35	244 ±34	> 0.05
PO_{ave} as % PPO	68.6 ±4.1	72.1 ±8.1	> 0.05
[La] ($mmol.l^{-1}$)	4.7 ±1.4	6.4 ±1.8	0.04*
RPE	15 ±2	15 ±1	>0.05

HR_{AVE}; average heart rate; PO_{AVE}, average power output; % $HR_{max\ Field}$, as a percentage of maximal heart rate obtained in the field; % $HR_{max\ Lab}$, as a percentage of maximal heart rate obtained in the laboratory; W, watts; PPO, peak power output; min:sec, minutes and seconds, [La], lactate concentration, $mmol.l^{-1}$, millimol per liter; RPE, rating of perceived exertion.

Figure 5.1 shows that the experienced cyclists had a statistically significantly higher average blood lactate concentration compared with the novice cyclists (6.4 ± 1.8 $mmol.l^{-1}$ vs 4.7 ± 1.4 $mmol.l^{-1}$; P = 0.04). This corresponds to the higher average PO that was maintained by the experienced riders throughout the TT. Participants had to refrain from any strenuous exercise 24 hours before the time trial to prevent them from having sore muscles that could affect the lactate responses during the test.

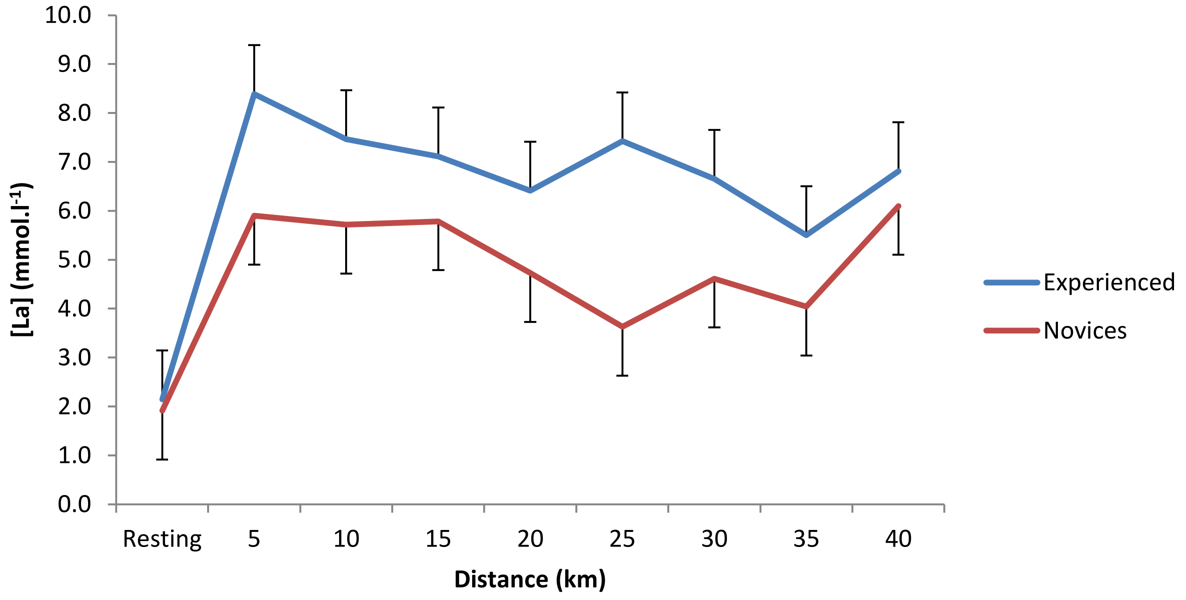


Figure 5.1 The changes in blood lactate concentration of the experienced and novice riders during the simulated time trial in the laboratory (means + SD).

Figure 5.2 illustrates the perceived exertion levels (RPE) of the two groups throughout the TT. Both novice and experienced groups reported the TT as hard (RPE between 14 and 16). Overall, there were no statistically significant difference in RPE response, despite the fact that the experienced group completed the distance at higher PO and higher blood lactate levels than the novice riders. Both groups showed an increase in RPE towards the end of the TT, which may by indicative of an end-spurt.

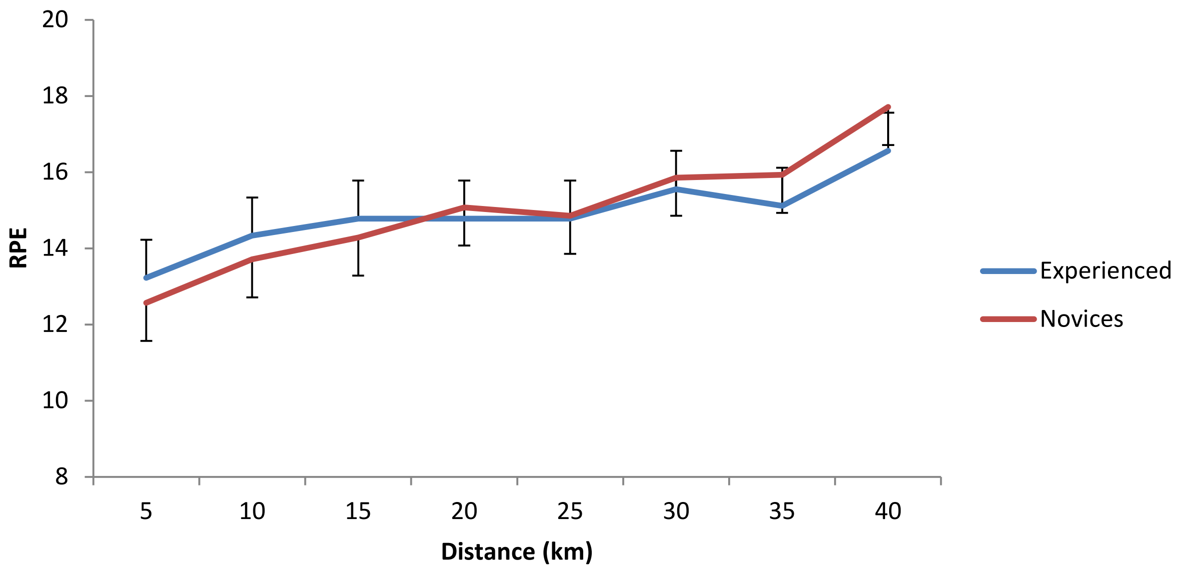


Figure 5.2 Rating of perceived exertion (RPE) for novice and experienced riders during the simulated time trial in the laboratory (means + SD).

D. THE PHYSIOLOGICAL RESPONSES AND PERFORMANCE OF THE CYCLISTS DURING THE 2014 ABSA CAPE EPIC

Two participants from the novice group withdrew from the event due to injury and their results were not included in this analysis. The cyclists' performance during the event are presented in Table 5.11, showing a statistically significant difference in the general classification ($P = 0.01$) and the total completion time of the event ($P = 0.004$) between the novice and experienced cyclists. The novice cyclists' general classification ranged from 77 – 500, while the experienced ranged from 37 – 330. The experienced riders completed the race in a statistically significantly shorter time (7:13:31) than the novice cyclists.

There was no significant difference in the average HR during the event between the groups, both expressed as percentage HR_{max} in the laboratory and in the field. The novice cyclists completed the race at 72 to 83% of maximal HR obtained in the laboratory and the experienced group at 68 to 83 % of laboratory based HR_{max}. According to ASCM this HR intensity is equal to 50 to 70 % of VO_{2max} (Otto, 2006). There was no statistically significant difference between the maximal HR obtained in the laboratory during the maximal aerobic capacity test (184 ±10 bpm, novices group and 181 ±9 bpm, experienced group) and the maximal HR obtained in the field during the event (189 ±8 bpm, novice group and 182 ±10 bpm, experienced group) for both groups.

Table 5.11 The physiological responses and performance of the cyclists during the race (means ± SD).

Variables	Novices (n = 12)	Experienced (n = 11)	P-value
HR_{ave} Field (bpm)	139 ±5	140 ±10	> 0.05
HR_{max} Lab (bpm)	184 ±10	181 ±9	> 0.05
HR_{max} Field (bpm)	189 ±8	182 ±10	> 0.05
% of HR_{max} (Lab)	75.3 ±2.8	78.2 ±4.5	> 0.05
% of HR_{max} (Field)	73.8 ±3.0	77.03 ±5.2	> 0.05
HR_{max} Field as % of HR_{max} (lab)	102 ±4	102 ±5	> 0.05
RPE_{ave} (W)	14 ±2	15 ±2	> 0.05
GC	327 ±139	166 ±113	0.01*
$Time_{AVE}$ (min:sec)	3002:12 ±356	2568:16 ±292:49	0.004*

HR_{ave}; average heart rate; RPE_{ave}, average rate of perceived exertions; GC, general classification position; $Time_{ave}$, average time for the whole duration of the event; HR_{max} (Lab), maximal heart rate obtained in the maximal aerobic test; HR_{max} (Field), maximal heart rate obtained during the event; % of HR_{max} (Lab), percentage of maximal heart rate obtained during the maximal aerobic test; % of HR_{max} (Field), percentage of maximal heart rate obtained during the event.

Figure 5.3 illustrate the RPE response for the novice and experienced cyclists for each stage of the event and shows that the two groups had similar perceived exertion levels throughout the race. Both groups' average RPE can be classified as hard on the RPE scale.

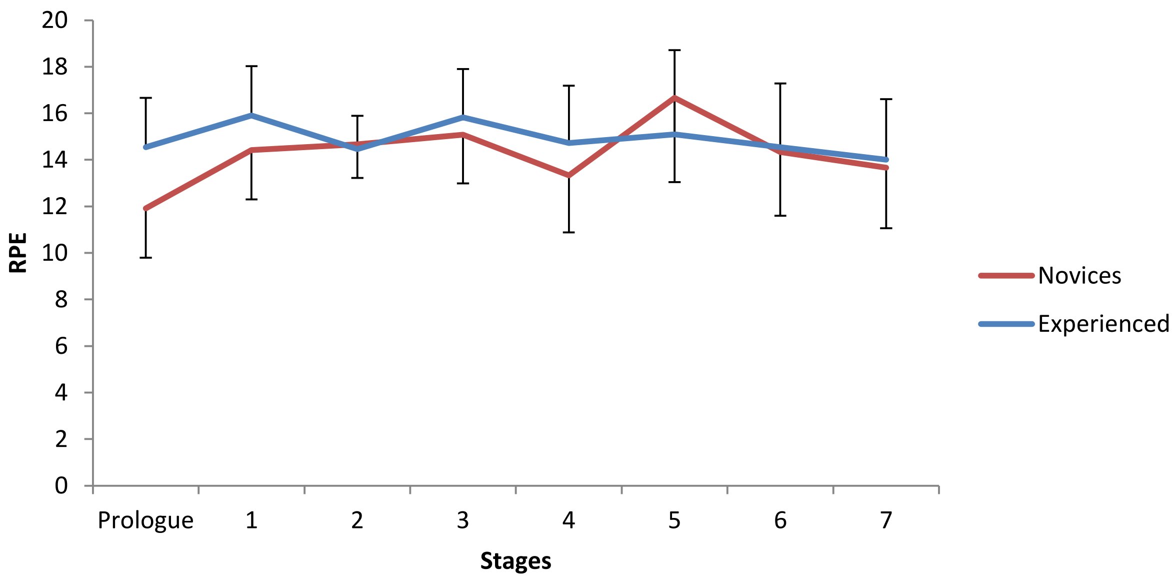


Figure 5.3 Rating of perceived exertion (RPE) during the race for novice and experienced riders (means + SD).

There were no statistically significant differences in the HR responses for each stage of the race between the two groups (Table 5.12). In both groups, the prologue resulted in the highest average HR, and the first stage the second highest average HR compared with the other stages. There was an overall decrease of 13.8% in maximal HR from the prologue to the last stage. The average maximal HR was higher for the novice group compared to the experienced group (189 ±9 bpm vs. 182 ±10 bpm), but this, together with the RPE responses, were not statistically significantly different between the two groups.

Table 5.12 Average HR during each stage of the event (means + SD).

Stages	Novices (n = 12)	Range	Experienced (n = 11)	Range	P-value
Prologue	162 ±8	145 – 175	164 ±10	149 – 187	> 0.05
1	149 ±9	141 – 167	149 ±10	128 – 163	> 0.05
2	136 ±6	128 – 148	139 ±10	116 – 153	> 0.05
3	136 ±4	129 – 144	138 ±10	117 – 151	> 0.05
4	132 ±6	117 – 142	133 ±12	109 – 148	> 0.05
5	132 ±6	123 – 145	133 ±11	114 – 149	> 0.05
6	131 ±7	120 – 143	133 ±12	110 – 150	> 0.05
7	134 ±9	119 – 146	132 ±11	109 – 148	> 0.05

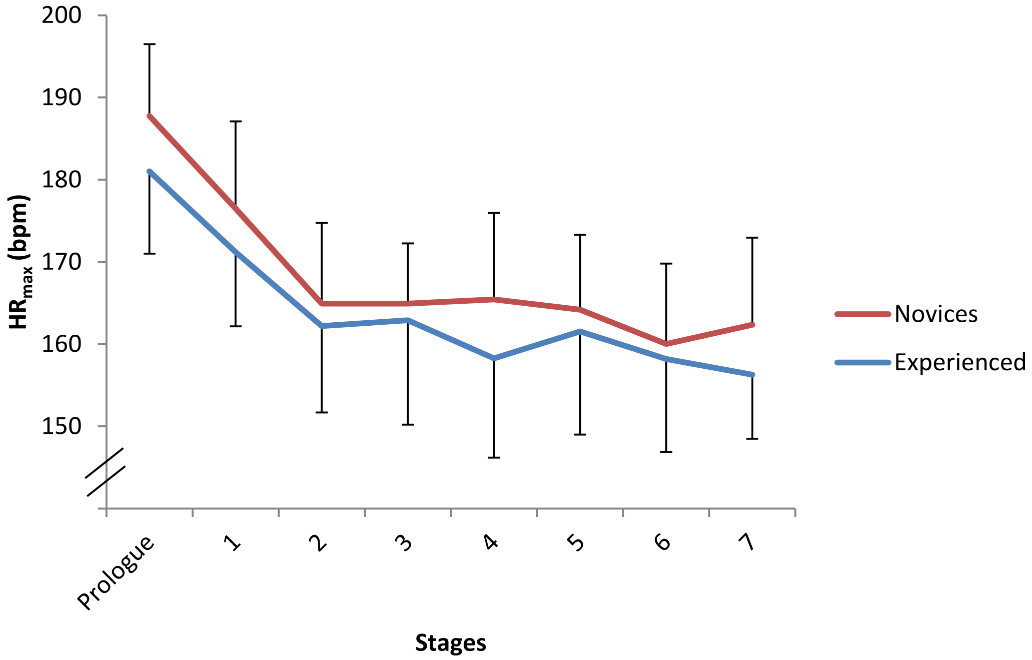


Figure 5.4 Maximal HR during each stage for novices and experienced cyclists.

Figure 5.5 depicts the percentage time spent in each HR zone (low, moderate and hard) for the total group during the laboratory TT and the event. The riders spent significantly more time in the low HR zone during the event than during the TT (**: P = 0.001), but significantly more time in the moderate (*: P < 0.001) and hard HR zone (#: P = 0.04) during the TT compared with the event.

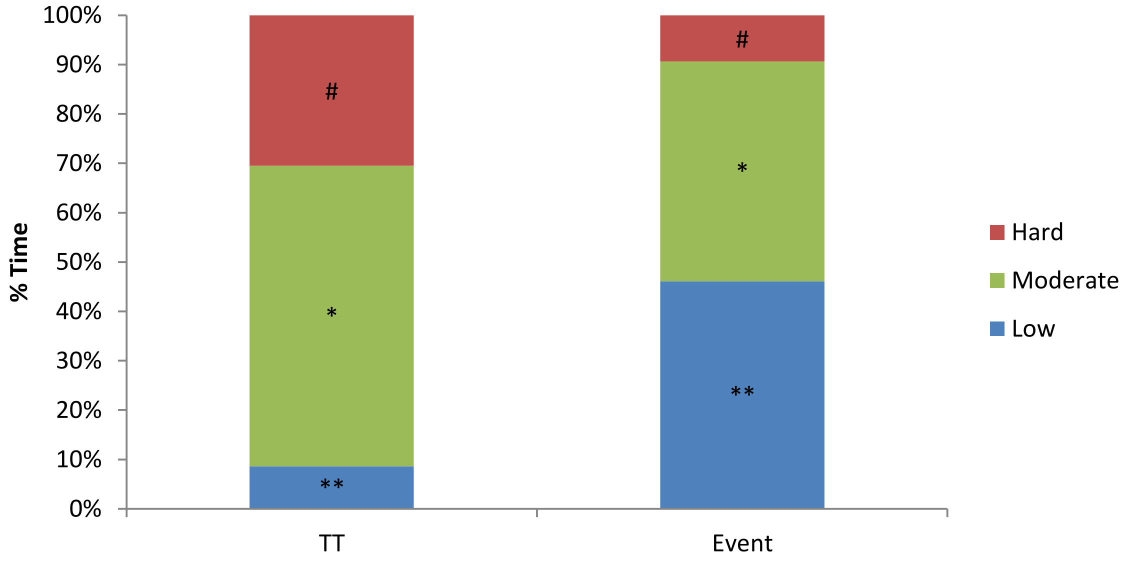


Figure 5.5 Percentage time spent in each HR zone during the laboratory TT and the event for the total group.

Figure 5.6 shows the percentage time spent in each HR zone (low, moderate and hard) during the laboratory TT and the event for the separate groups. The experienced group spent significantly more time in the moderate HR zone during the event than the novices (49.5 % vs. 35.4 %; *P = 0.001). The novice and experienced cyclists spent 58.5 % and 43.1 % in the low HR zone (P > 0.05) and 6.1 % and 7.4 % in the hard HR zone (P > 0.05), respectively. Similarly, there were no statistically significant differences between the two groups in the percentage time spent in each HR zone during the laboratory TT.

Compared to the TT, both groups spent significantly more time in the low HR zone during the event (^ P < 0.01, novices; ** P < 0.01, experienced). The novice group spent significantly less time in the moderate (+ P < 0.05) and hard HR zone (# P < 0.05).

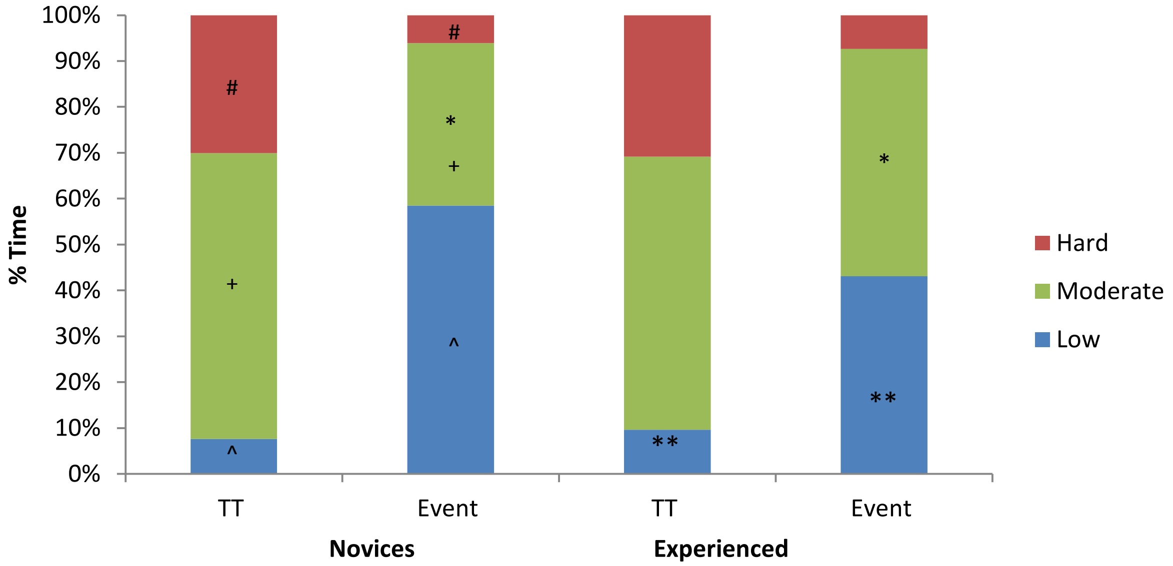


Figure 5.6 Percentage time spent in each HR zone during the TT in the laboratory and the event for novice and experienced cyclists.

Figure 5.7 illustrates the distribution of effort for the whole group during each stage of the event. The percentage time spent in the low HR zone increased from the prologue to stage 7 by 54 %, while the percentage time spent in the moderate and hard zones decreased by 13 % and 41 %, respectively.

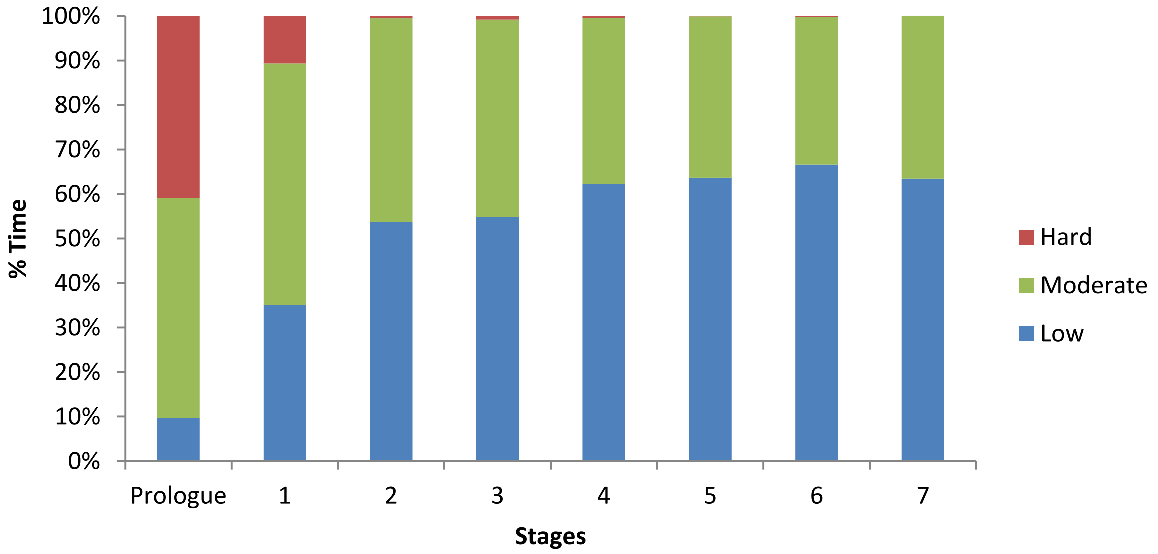


Figure 5.7 Percentage time spent in each HR zone during the event.

The distribution of effort for the novice and experienced group is presented in Figure 5.8 & 5.9, respectively. The experienced group spent statistically significant more time in the moderate HR zone during the first stage of the race than the novice group (66.2 % vs. 43.2 %; * P = 0.045). The exercise intensities for the remaining stages of the race were similar for the two groups.

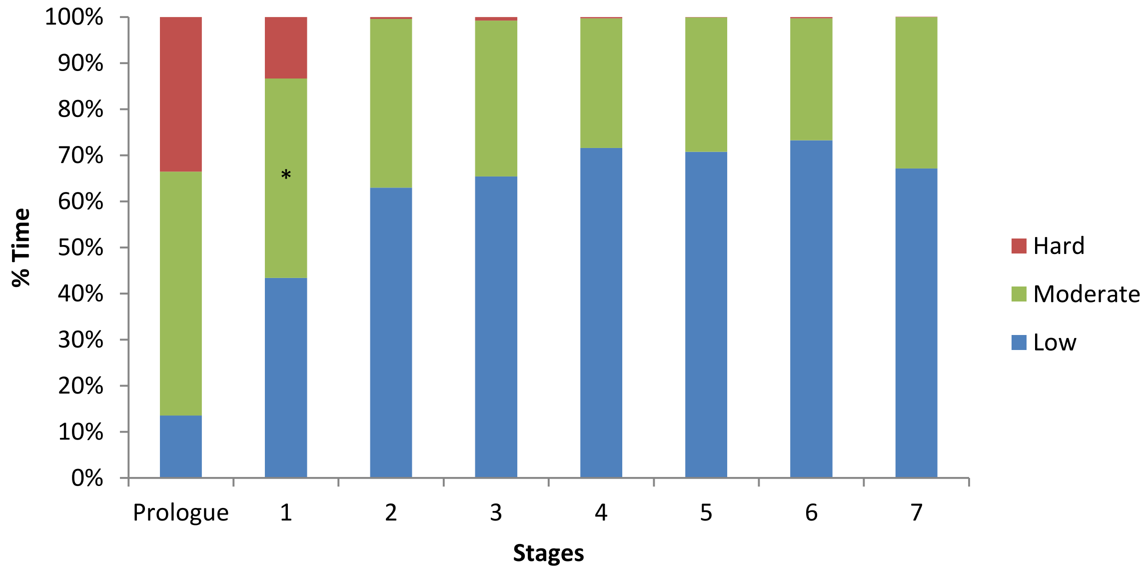


Figure 5.8 The distribution of effort during the event by the novice cyclists.

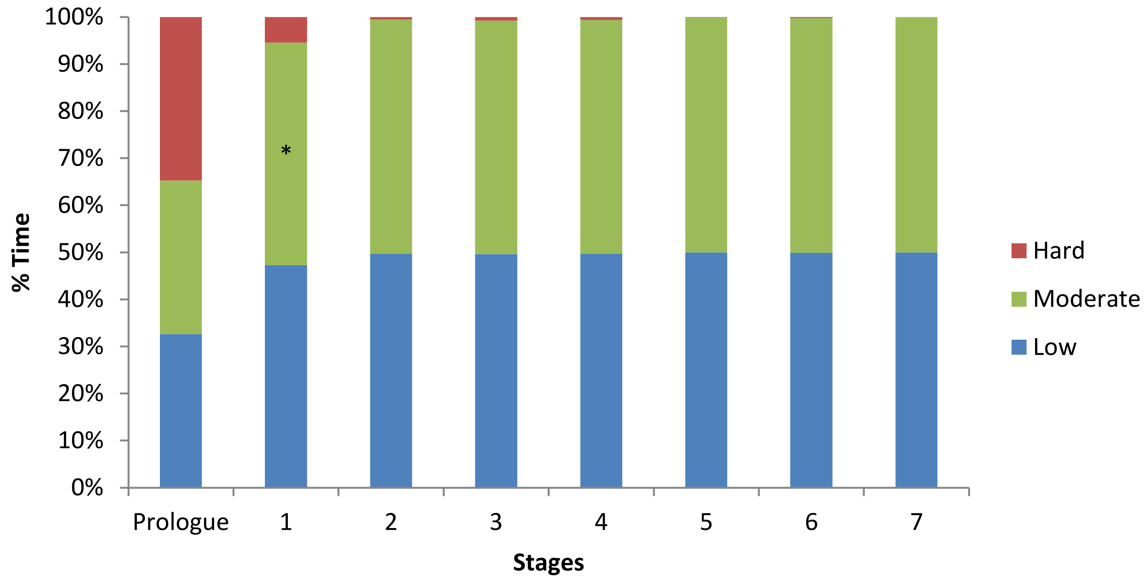


Figure 5.9 The distribution of effort during the event by the experienced cyclists.

1. Distribution of time spent in percentage maximal heart rate intervals during the TT and the event

Figure 5.10 illustrates the percentage time spent in each interval during the TT, performed in the laboratory, expressed as percentage of maximal HR obtained in the laboratory during the maximal aerobic test. During the TT and the prologue large percentage of time was spent in the 80-90 % and 90-100 % of HR_{max} zones.

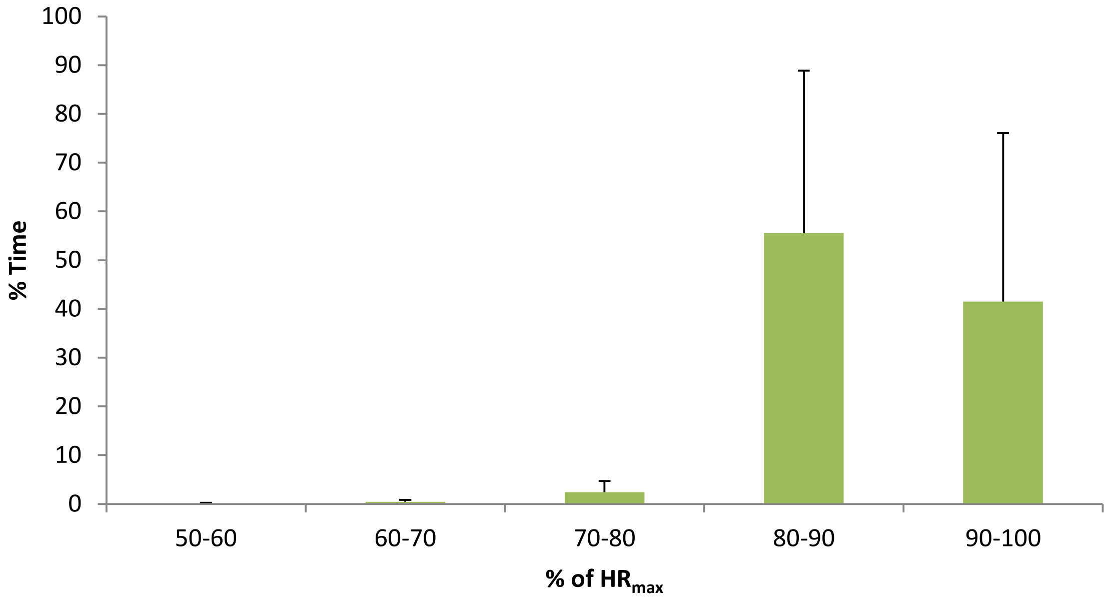


Figure 5.10 Percentage time spent during the TT in each interval expressed as percentage maximal HR obtained in the laboratory during the maximal aerobic test for the total group of cyclists.

Figure 5.11 (a-h) illustrates the percentage time spent in each HR interval, expressed as percentage of maximal HR obtained in the laboratory during the maximal aerobic test, during all eight stages (a - prologue, b - stage 1, etc.) of the event. The percentage time spent in the 90-100 % of HR_{max} decrease, showing that from stage 1-7 less time was spent in that zone. From stage 2 to stage 7 more time is spent in the lower percentages of HR_{max} and almost no time is spent in the 90-100 % of HR_{max} zone.

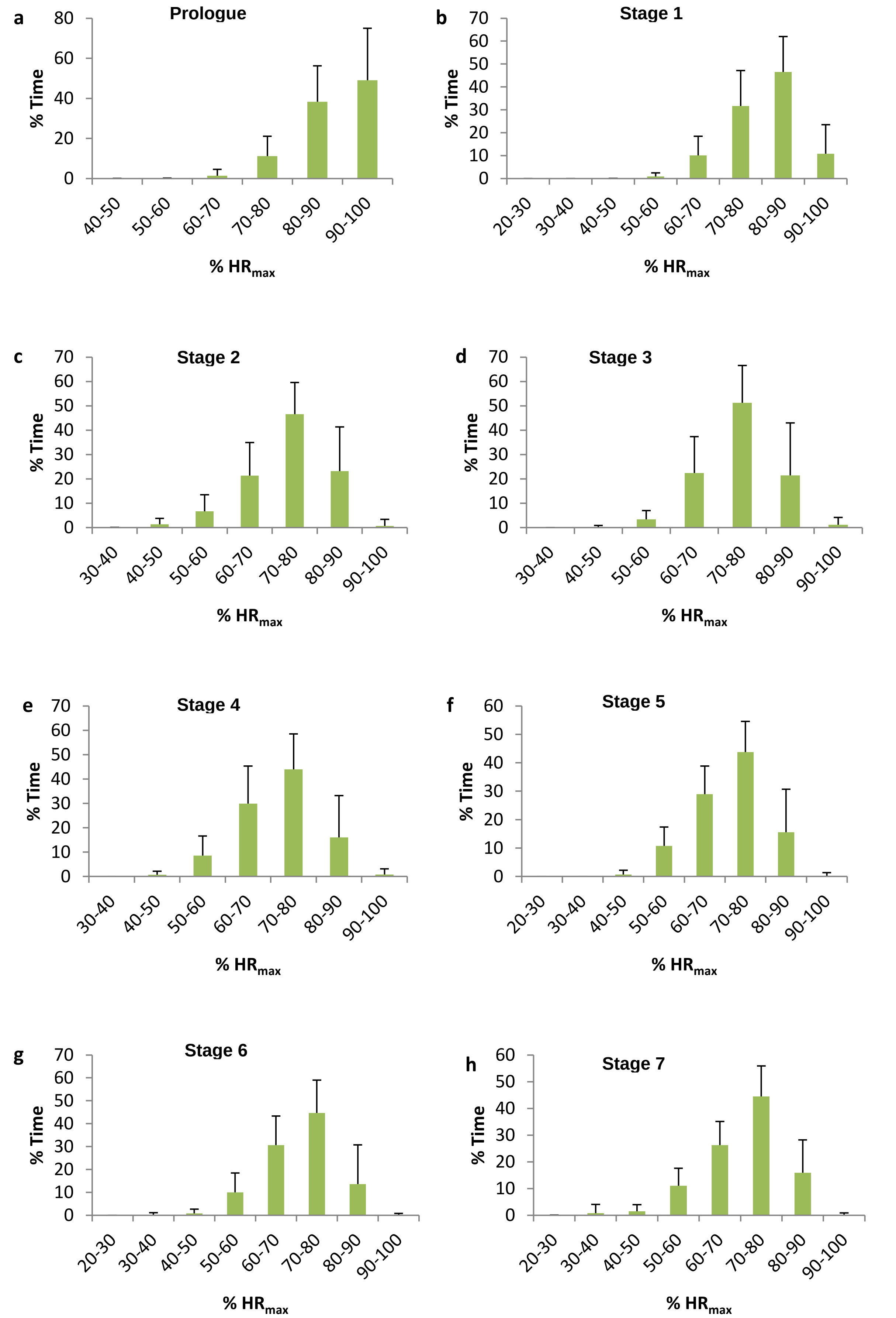


Figure 5.11 (a-h) Percentage time spent during each stage of the event expressed as percentage of maximal HR obtained in the laboratory during maximal aerobic test for the total group of cyclists.

2. Distribution of time spent in percentage maximal heart rate intervals during the TT and the event for the novices and experienced cyclists

Figure 5.12 illustrates the percentage time spent, during the 40 km TT in the laboratory, each HR interval is expressed as a percentage of maximal HR obtained during the maximal aerobic test in the laboratory for both novice and experienced cyclists. The percentage time spent in each interval is more or less the same for the two groups during the TT.

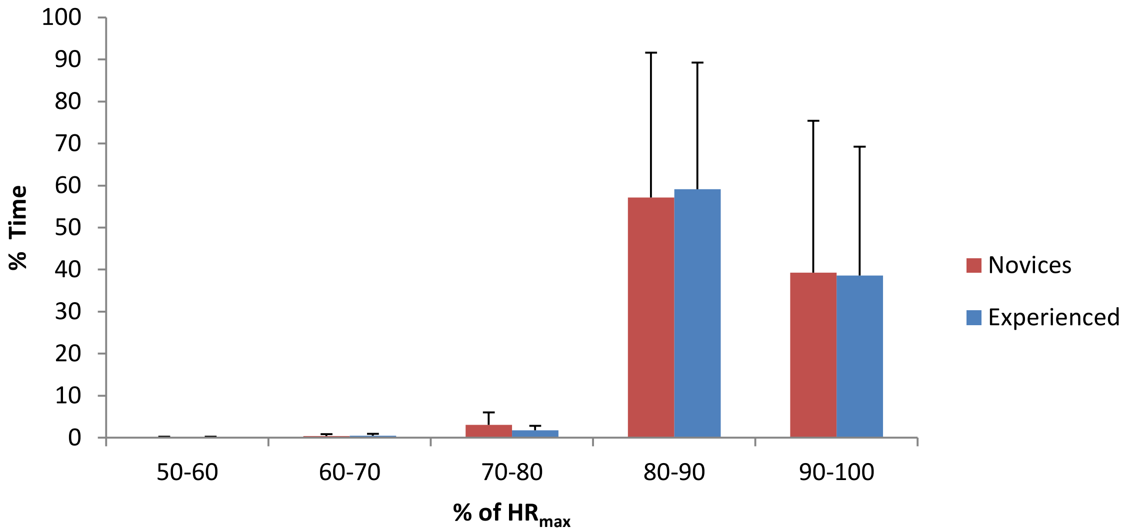


Figure 5.12 Percentage time spent during the TT in each interval expressed as percentage of maximal HR obtained in the laboratory during the maximal aerobic test for both novice and experienced cyclists.

Figure 5.13 (a-h) illustrates the percentage time spent in each HR interval, expressed as percentage of maximal HR obtained in the laboratory during the maximal aerobic test, during all eight stages (a - prologue, b - stage 1, etc.) of the event for both the novice and experienced group of cyclists. The experienced group spent more time in the higher maximal HR interval throughout the race, while the novice group spent predominately more time in the lower percentage maximal HR intervals. Only on the last stage of the race did the novice group spent slightly more time in the 80-90 % of maximal HR interval. This showed that the experienced group spent a greater percentage of time in the higher percentage intervals of maximal HR during the race compared to the novice group.

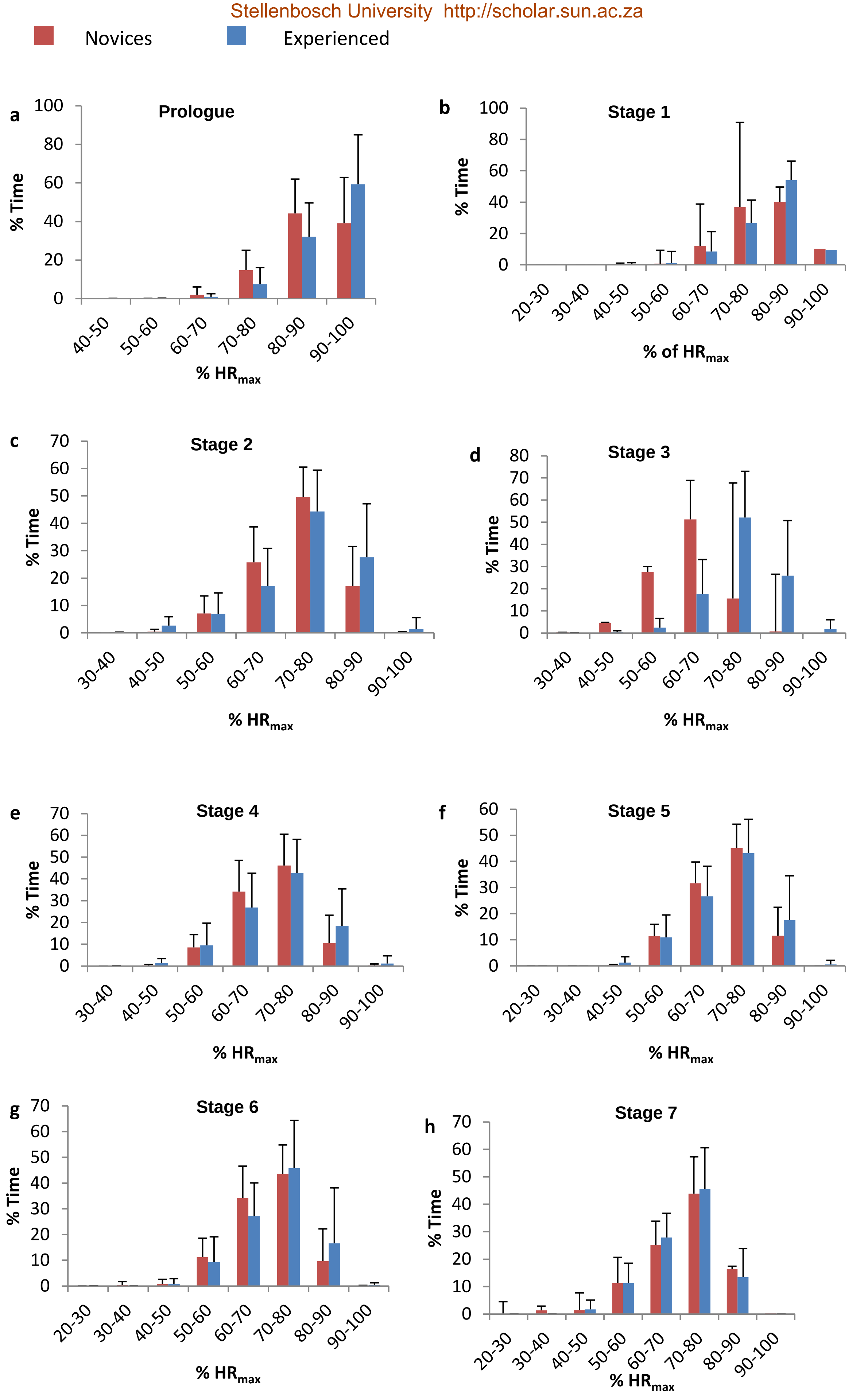


Figure 5.13 (a-h) Percentage time spent during each stage of the event expressed as percentage of maximal HR obtained in the laboratory during maximal aerobic test for both groups.

E. THE RELATIONSHIPS BETWEEN THE LABORATORY VARIABLES AND PERFORMANCE PARAMETERS DURING THE EVENT.

1. Maximal aerobic capacity test

Figure 5.14 illustrates the correlation coefficients and 95% confidence intervals between the maximal aerobic capacity measures and the cyclists' general classification in the event. There were moderately negative correlations between absolute peak power output (r = -0.68), relative peak power output (r = -0.57) and relative power output at OBLA (r = -0.68) and the cyclists' general classification at the end of the race. A high negative correlation between absolute power output at OBLA (r = -0.74) and the cyclists' general classification at the end of the race was observed. Low negative correlations were found between absolute and relative power output at lactate threshold (r = -0.36) and absolute maximal aerobic capacity (r = -0.35) and the general classification of cyclists. (The standard error of the estimate may be interpreted as the standard deviation of all the errors, or residuals, made when predicting Y from X)

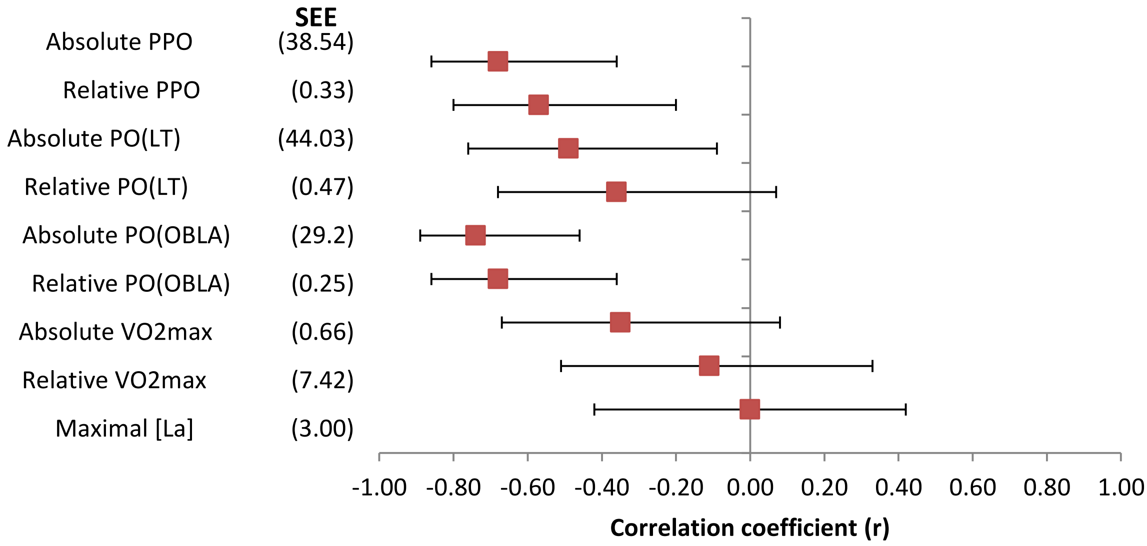


Figure 5.14 The relationship between VO_{2max} performance measures and the general classification of the cyclists at the end of the race. Values are indicated as r ± 95 confidence interval. The SEE values are presented next to the variable names. PPO, peak power output; PO_{LT}, power output at lactate threshold (the point where lactate concentration rise by 1 $mmol.l^{-1}$); PO_{OBLA}, power output at the onset of blood lactate accumulation (a lactate concentration of 4 $mmol.l^{-1}$); VO_{2max}, maximal aerobic capacity; [La], lactate concentration. SEE, standard error of the estimate is a measure of the accuracy of predictions.

The relationships between the parameters of the maximal aerobic capacity test and the average HR during the event were moderate to low (Figure 5.15). Of this subset of correlations, the strongest negative correlations were found between absolute peak power output (r = -0.28) and maximal lactate concentration (r = -0.32), while the strongest positive correlation was found for relative power output at lactate threshold and average heart rate during the event (r = 0.49).

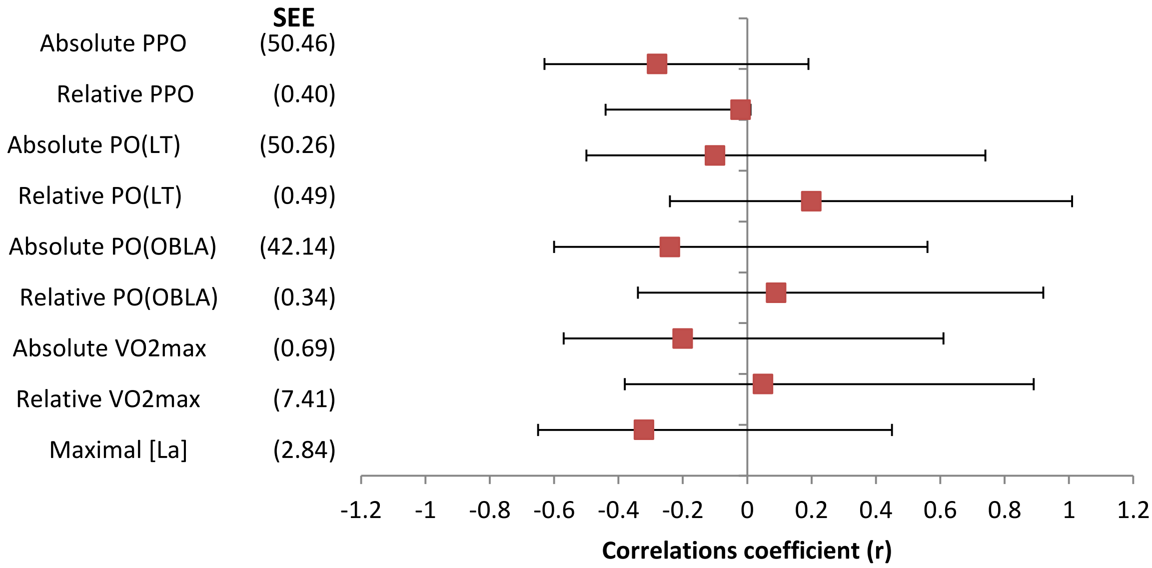


Figure 5.15 The relationship between the VO_{2max} performance measures and the average HR during the event. The SEE values are presented next to the variable names. PPO, peak power output; PO_{LT}, power output at lactate threshold (the point where lactate concentration rise by 1 mmol.l^{-1}); PO_{OBLA}, power output at the onset blood lactate accumulation (a lactate concentration of 4 mmol.l^{-1}); VO_{2max}, maximal aerobic capacity; [La], lactate concentration. SEE, standard error of the estimate is a measure of the accuracy of predictions.

Higher correlations were observed for the relationships between the parameters of the maximal aerobic capacity test and the total race time (Figure 5.16). The highest correlation was found for absolute power output at OBLA and the event time (r = -0.77), while moderate negative correlations were found for absolute and relative peak power output (r = -0.70 and r = -0.57, respectively), absolute power output at lactate threshold (r = -0.64) and for relative power output at OBLA (r = -0.68) and the event time.

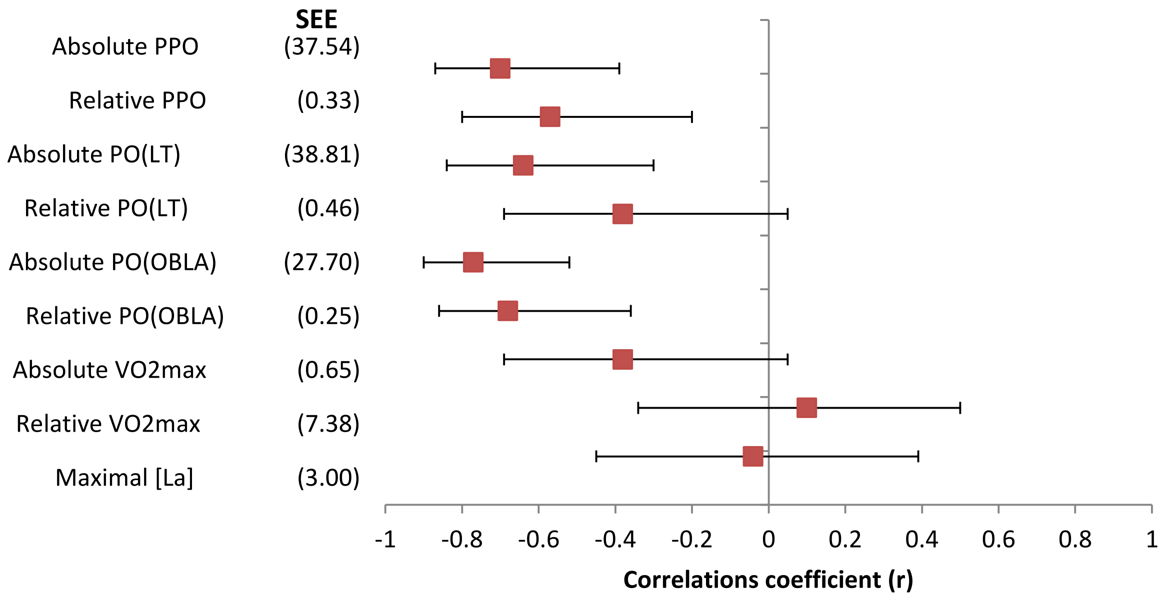


Figure 5.16 The relationship between the VO_{2max} performance measures and the cyclists' race times. The SEE values are presented next to the variable names. PPO, peak power output; PO_{LT}, power output at lactate threshold (the point where lactate concentration rise by 1 $mmol.l^{-1}$); PO_{OBLA}, power output at the onset blood lactate accumulation (a lactate concentration of 4 $mmol.l^{-1}$); VO_{2max}, maximal aerobic capacity; [La], lactate concentration. SEE, standard error of the estimate is a measure of the accuracy of predictions.

2. 40 km time trial

The correlations between the TT performance measures and the general classification in the event are illustrated in Figure 5.17. Low negative correlations were found between the absolute average power output (r = -0.45), relative average power output (r = -0.40), and average heart rate (r = -0.44) during the TT and the general classification. A low positive correlation was found between time trial time (r = 0.36) and the general classification of the cyclists at the conclusion of the event.

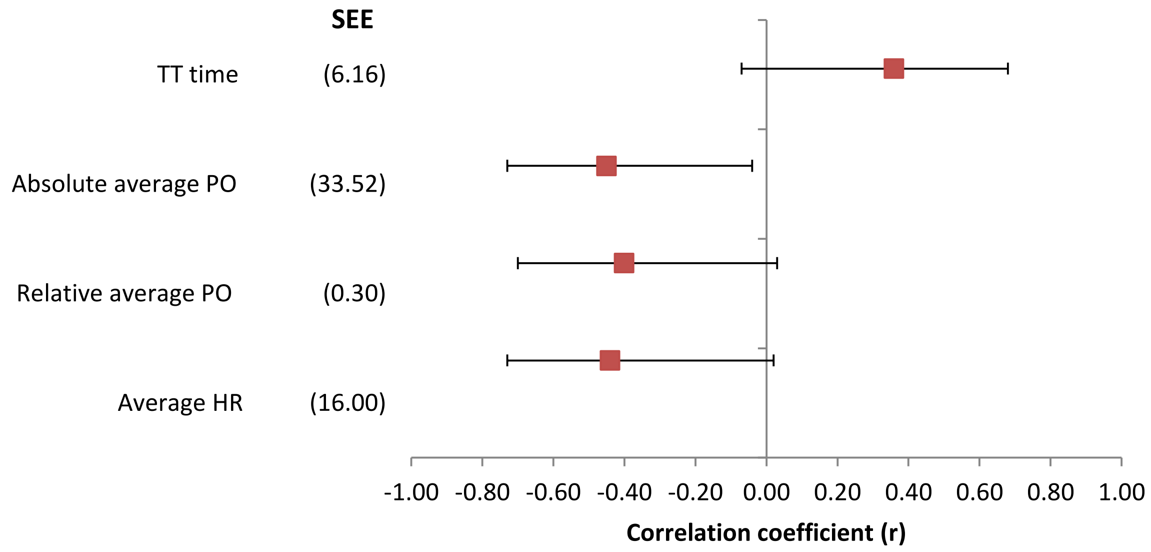


Figure 5.17 The relationship between the laboratory 40 km time trial and the general classification in the event. The SEE values are presented next to the variable names. PO, power output; TT, time trial; HR, heart rate. SEE, standard error of the estimate is a measure of the accuracy of predictions.

Figure 5.18 illustrates the correlations between the TT performance measures and the cyclists' exercise intensity during the event (average HR). There was a moderate relationship between the average HR during the TT and the average HR during the event (r = 0.58; SEE = 14.52). However, all other TT measures correlated poorly to the average exercise intensity of the cyclists during the event.

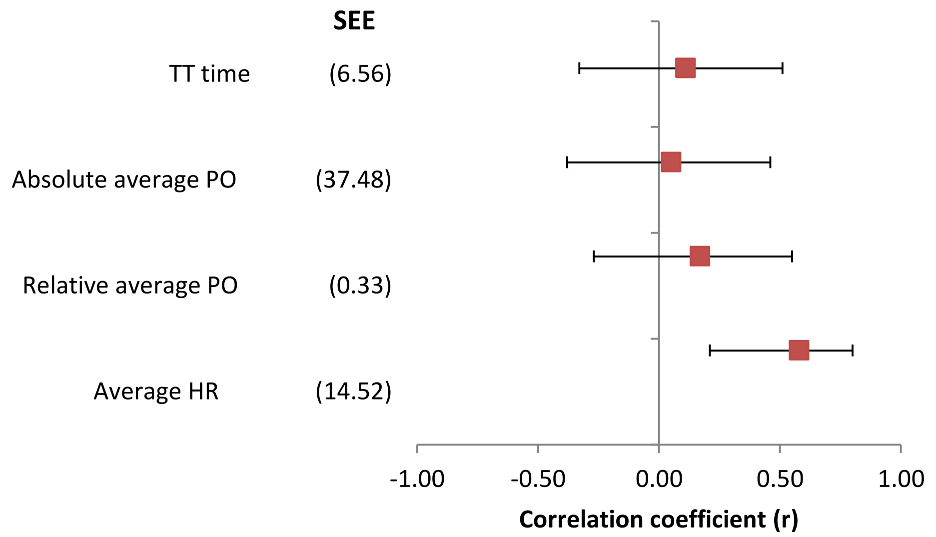


Figure 5.18 The relationship between the laboratory 40 km time trial and the average HR during the event. The SEE values are presented next to the variable names. PO, power output; TT, time trial; HR, heart rate. SEE, standard error of the estimate is a measure of the accuracy of predictions.

The correlation coefficients for the performance measures during the TT in the laboratory and the final race time are presented in Figure 5.19. A moderate positive correlation was found for time trial time (r = 0.61) when correlated with event time, while a moderate negative correlation was found between absolute average power output (r = -0.59) and event time.

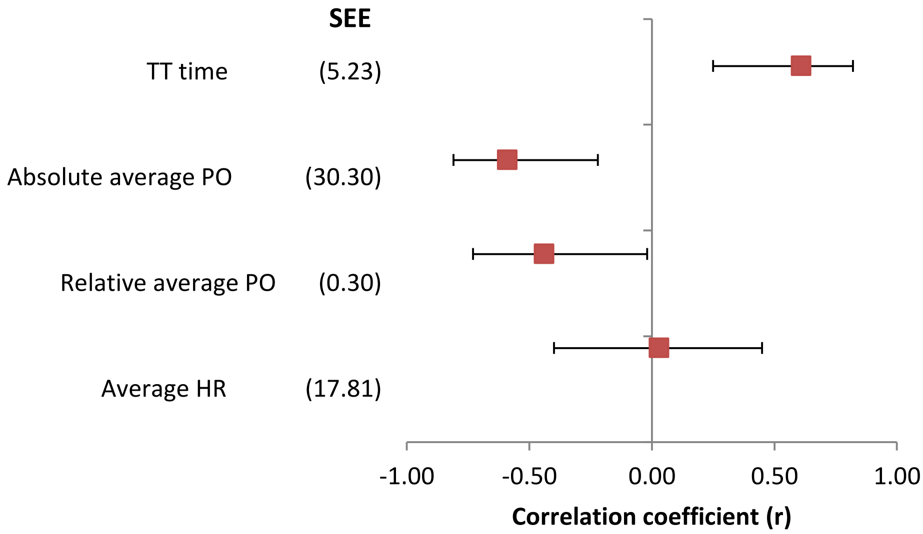


Figure 5.19 The relationship between the laboratory 40 km time trial and the event time. The SEE values are presented next to the variable names. PO, power output; TT, time trial; HR, heart rate. SEE, standard error of the estimate is a measure of the accuracy of predictions.

3. Predictors Cape Epic performance

3.1 Total event time

Significant predictors for total event time were absolute PO at OBLA (P = 0.01), relative PO at OBLA (P =0.02) and the maximal blood lactate concentration during the incremental exercise test (P =0.03). Although average HR during the 40 km TT and relative VO_{2max} during the incremental exercise test were identified in two and one model, respectively, as third best predictor, these variables did not contribute statistically significantly towards the individual regression models. These variables were therefore excluded as predictors of performance. The best subset models, according to R^2 values, were:

1. **Total event time = 5566.79 - 4.60 (PO_{OBLA}) - 562.74 (PO_{OBLA}: BM)** [R^2 = 0.71]

2. **Total event time = 5344.15 - 6.04 (PO_{OBLA}) - 3.18.27(PO_{OBLA}: BM) + 30.19 ([La_{max})** [R^2 = 0.70]

3. **Total event time = 3744.21 - 7.89 (PO_{OBLA})) + 49.26 ([La_{max}])** [R^2 = 0.66]

3.2 General classification

Although four independent variables were identified as important predictors of general classification, not all of these variables contributed statistically significantly to the model. In this case, significant predictors were relative peak power output (P = 0.01), average HR during the 40 km TT (P = 0.043) and relative maximal aerobic capacity (P = 0.048), whereas absolute peak power output (P = 0.28), absolute power output at OBLA (P = 0.27) and average PO during the 40 km TT (P = 0.13) were not statistically significant predictors. The best three subset models were:

1. **General classification = 1901.57 - 306.67(PPO: BM) + 10.56(VO_{2max}: BM) - 3.15(average TT HR)** [R^2 = 0.56]

2. **General classification = 1894.95 - 298.52(PPO: BM) - 3.21(average TT HR)** [R^2 = 0.53]

3. **General classification = 1864.76 - 296.71(PPO: BM)** [R^2 = 0.53]

3.3 Average event heart rate

Although four independent variables were identified as important predictors of general classification, not all of these variables contributed statistically significantly to the model. In this case, significant predictors were total time trial time (P = 0.03), average HR during the 40 km TT (P = 0.04) and absolute power output at OBLA (P = 0.03) and absolute peak power output (P = 0.03) whereas relative PO at OBLA (P = 0.08), were not statistically significant predictors. The best three subset models were:

1. **Average event HR = 87.23 – 0.14(PPO)** [R^2 = 0.40]

2. **Average event HR = 75.10 – 0.16(PO_{OBLA}) + 0.28(average TT HR)** [R^2 = 0.39]

3. **Average event HR = -29.98 + 0.95(total TT time)** [R^2 = 0.028]

Overall, the laboratory variables were better predictors of total race time than the general classification of the cyclists.

CHAPTER SIX

DISCUSSION

A. INTRODUCTION

In the present study cyclists were monitored during the 2014 Absa Cape Epic to assess their effort levels during the race and to establish predictors of performance for a multi-stage mountain bike (MTB) event. Exercise intensity profiling and predictors of performance are valuable information for cyclists, sport nutritionists and coaches to assist in program design and preparation for events and races. This study, the first of its kind on this particular MTB event, does not only contribute to the knowledge base of this field, but should also have important practical relevance for those involved in cycling.

B. DESCRIPTIVE CHARACTERISTICS OF THE STUDY SAMPLE

The popularity of mountain biking (MTBing) has rapidly increased over the last couple of years leading to a growing number of studies describing the physiological and physical characteristics of the sport (Wilber *et al.,* 1997; Baron, 2001; Lee *et al.,* 2002*;* Impellizzeri *et al.,* 2005, 2007).

1. Subject characteristics

The study sample included 25 well-trained, non-professional cyclists between the ages of 22 and 56 years. Some of the participants were experienced mountain bikers who completed a number of multi-stage MTB races, while others participated in their first multi-stage MTB event and also their first Absa Cape Epic. According to the information obtained from their training diaries, all the participants trained hard at least 6 days of the week in preparation of the event.

2. Body composition

It is always difficult to compare percentage body fat of athletes between published studies, because of different techniques, instruments and formulas that are used. Therefore any comparisons should be made with caution. Keeping this in mind, it has been previously reported that the percentage body fat of mountain bikers and road cyclists ranges from 5.8 to

6.4 % and 4.7 to 8.9 %, respectively (Wilber *et al.* 1997; Padilla *et al.,* 1999; Lucia *et al.,* 2000). Therefore it seems that mountain bikers are generally more concerned about maintaining a low body mass and percentage body fat than road cyclists, because of the perceived link between body mass and performance during hilly terrain. Padilla *et al*. (1999) found that PPO expressed relative to body mass is an appropriate predictor of hill climbing ability, which would support this notion.

Table 6.1 depicts the percentage body fat of the men in this study and data of off-road cyclists from other published studies. Only one study reported comparative data for women (Wilber *et al*., 1997).

Participants from this study had much higher percentage body fat than the national, international and sub-elite cyclists reported by four studies (MacRae *et al.,* 2000; Impellizzeri *et al.,* 2002; Lee *et al.,* 2002; Impellizzeri *et al.,* 2005). On the other hand the values from this study was more or less the same than the data from Warner *et al.* (2002) and Wingo *et al.* (2004) who tested elite and experienced cyclists, respectively. The physical characteristics of the men also differed from cyclists from the US National Off-Road Bicycle Association (NORBA) with regard to the total body mass (76.1 ± 8.1 vs. 71.5 ± 7.8; P > 0.05) and the percentage body fat (11.9 ± 2.1 vs. 5.8 ± 1.1; P = 0.0001) (Wilber *et al*., 1997). The women were also slightly heavier (59.1 ± 0.9 vs. 57.5 ± 4.7; P > 0.05) and had more body fat (19.0 ± 0.1 vs. 13.2 ± 2.0; P = 0.004) than the NORBA cyclists.

A lower body fat percentage, and therefore greater lean mass, is obviously an advantage in mountain biking (MTBing) and therefore the participants in this study could be made aware of the comparative data. A greater lean mass may contribute to better aerobic and power capacities and result in better laboratory performance measures.

Table 6.1 Percentage body fat values for male off-road cyclists.

Study	Cycle level	n	% Body fat
MacRae *et al.* (2000)	Sub-elite	6	8.5 ±0.9
Lee *et al.* (2002)	Int	7	6.1 ±1.0
Impellizzeri *et al.* (2002)	Int	5	5.1 ±1.6 (W)
			4.7 ±1.4 (S)
Warner *et al.* (2002)	Elite	16	11.5 ±2.7
Wingo *et al.* (2004)	Experienced	12	14.3 ±1.0
Impellizzeri *et al.* (2005)	NAT and Int	13	5.3 ±1.6
Present study	Club	23	11.9 ±2.1

W, winter season; S, summer season; Int, international; NAT, national

3. Physiological characteristics

The aim of the incremental test to exhaustion was twofold: (1) to classify the participants in terms of their endurance capacity and (2) to determine whether any of the physiological measures are significant predictors of performance in a multi-stage MTB event. The latter will be discussed in section D.

This incremental exercise test was indeed a maximal test, since all the participants reached at least 3 out of the 5 criteria for determination of a maximal test. All the participants had a familiarization session with the maximal aerobic capacity test before the pre-event testing session and this probably contributed to the maximal effort of the cyclists, as they knew what to expect.

According to Otto, (2006) the men in this study had excellent (90th percentile) aerobic capacities (VO_{2max}) and the women were classified as having good (85th percentile) aerobic capacity. As expected, the absolute maximal aerobic capacity and the absolute peak power output were statistically significantly greater in the men than in the women. There were no other statistically significant differences in the remaining physiological responses between the men and women.

The comparisons between the physiological measures of published studies in off-road women and men cyclists are presented in Table 6.2 and Table 6.3, respectively. These results show that the men and women in this study had lower maximal aerobic capacities than off-road cyclists from other studies, as well as lower maximal aerobic capacities compared with the US NORBA cyclists (Wilber *et al*., 1997). Both the absolute and relative PPO of the men in this study was statistically significantly lower than the PPO of the NORBA cyclists (Wilber *et al*., 1997). While the difference in VO_{2max} for the women was not significantly different, their absolute and relative PPO values were significantly lower than those of the NORBA cyclists.

Table 6.2 Physiological measures of women off- road cyclists in published studies.

Study	Cycling level	VO_{2max} (ml.kg^{-1}.min^{-1})	PPO (W)	PPO (W.kg^{-1})	PO_{OBLA} (W)	PO_{OBLA} (W.kg^{-1})	PO_{LT} (W)	PO_{LT} (W.kg^{-1})
Wilber *et al.* (1997) n=10	NORBA	58	313 ±2.4	5.4 ±0.4	-	-	204 ±20	3.6 ±0.3
Stapelfeldt *et al.* (2004) n=2	Elite	58	320	5.0	-	-	-	-
	Elite	61	28	4.5	-	-	-	-
Impellizzeri & Marcora (2007) n=10	NAT & INT	61	306 ±31	5.9 ±0.7	-	-	-	-
Wirnitzer & kornexl (2008) n= 2	Amateur	-	242 ±40	4.1 ±0.6	214 ±21	3.6 ±0.6	-	-
Present study n=2	Club	53	258 ±20	4.4 ±0.3	215 ±28	3.6 ±0.4	197 ±35	3.3 ±0.5

NORBA, National Off-Road Bicycle Association; Int, international level off road cyclist; NAT, national level off road cyclists; VO_{2max}, maximal aerobic capacity ; Abs. PPO, absolute peak power output; Rel. PPO, relative peak power output; LT, lactate threshold; OBLA, blood lactate accumulation

Table 6.3 Physiological measures of male off road cyclists in published studies.

Study	Cycling level	VO_{2max} (ml.kg^{-1}.min^{-1})	PPO (W)	PPO (W.kg^{-1})	PO_{OBLA} (W)	PO_{OBLA} (W.kg^{-1})	PO_{LT} (W)	PO_{LT} (W.kg^{-1})
Wilber *et al.* (1997) n= 10	Int	70.0 ±3.7	420 ±42	5.9 ±0.3	-	-	271 ±29	3.8 ±0.3
MacRae *et al.* (2000)	Amateur	58.4 ±2.3	-	-	-	-	-	-
Baron, (2001) n=25	NAT and Int	68.4 ±3.8	-	-	-	4.7 ±0.6	-	-
Lee *et al.* (2002) n=7	Int	78.3 ±4.4	413 ±36	6.3 ±0.5	-	-	-	-
Impellizzeri *et al.* (2002) n=5	Int	75.9 ±5.0	367 ±36	5.7 ±0.6	318 ±14	4.9 ±0.4	276 ±17	4.3 ±0.2
Warner *et al.* (2002) n=16	Elite	67.4 ±4.6	-	-	-	-	-	-
Stapelfeldt *et al.* (2004) n= 9	Int	66.5 ±2.6	368 ±25	5.3 ±0.3	-	-	-	-
Nishii *et al.* (2004) n=8	Elite	67.8 ±5.8	-	-	-	-	-	-
Cramp *et al.* (2004) n= 8	Amateur	60.0 ±3.7	-	-	-	-	-	-
Impellizzeri *et al.* (2005a) n=13	NAT and Int	72.1 ±7.4	392 ±35	-	340 ±38	-	286 ±32	-
Impellizzeri *et al.* (2005b) n=12	Elite, high level	76.9 ±5.3	426 ±40	6.4 ±0.6	-	-	-	-
Gregory *et al.* (2007) n=11	Elite	-	368 ±32	5.1 ±0.4	-	-	-	-
Impellizzeri & Marcora (2007) n= 12	Competitive	-	-	-	326 ±37	-	273 ±30	-
Prins *et al.* (2007) n=8	Competitive	63.6 ±5.7	372 ±37	5.1 ±0.4	289 ±60	4.0 ±0.7	-	-
Wirnitzer & Kornexl (2008)n= 5	Amateur	-	314± 43	4.8 ± 0.3	249 ±12	4.0 ±0.6	-	-
Present study n=23	Club	54.0 ±7.0	350 ±47	4.6 ±0.4	320 ±43	4.2 ±0.5	296 ±44	3.9 ±0.6

NORBA, National Off-Road Bicycle Association; Int, international level off road cyclist; NAT, national level off road cyclists; VO_{2max}, maximal aerobic capacity ; Abs. PPO, absolute peak power output; Rel. PPO, relative peak power output; LT, lactate threshold; OBLA, onset of blood lactate accumulation

The blood lactate thresholds and ventilatory thresholds (irrespective of definition and method of determination) are commonly used as indicators of endurance capacity (Lee *et al.,* 2002). Previous studies have shown that physiological parameters corresponding to the lactate thresholds (i.e. PO or HR) are better predictors of endurance performance than maximal aerobic capacity (Coyle *et al.,* 1988, 1991). In addition, these parameters can also be used to distinguish between cyclists of different standards. Lucia *et al.* (1998) found that in professional cyclists the ventilatory thresholds occur at a higher percentage of VO_{2max} when compared to that of elite road cyclists, while both groups had similar VO_{2max} values.

In this study the lactate threshold (LT) and onset of blood lactate accumulation (OBLA) was determined from the data obtained during the maximal aerobic capacity test. Similar data from other studies are depicted in Tables 6.2 and 6.3 for comparative purposes. The men in this study had a higher absolute PO at LT compared to cyclists in the other studies, but when expressed relative to body mass it was lower than some of the international cyclists. Their absolute and relative PO at OBLA was higher than that of the amateur and competitive cyclists (Wirnitzer & Kornexl 2008), but the relative value was lower than that for international cyclists, (Impellizzeri *et al.,* 2002). This can be explained by the higher body mass of the cyclists in this study. The women in this study had almost identical absolute and relative PO at OBLA compared to the amateur cyclists and slightly lower values than the NORBA cyclists. From these findings it can be concluded that the cyclists in this study had very good aerobic fitness levels which was similar to international amateur competitive cyclists.

It has been shown that uphill road cycling specialists are lighter and have higher maximal oxygen uptake relative to body mass than other road cyclists (Padilla *et al.,* 1999; Lucia *et al.,* 2000a). In particular, uphill specialists usually have exceptional power output relative to body mass that is higher than any other cyclists. The findings by Padilla *et al.* (1999) and Lucia *et al. (*2000a) were no surprise due to the importance of power-to-weight ratio for climbing ability (Swain, 1994). Mountain bike races take place over terrains involving a lot of hill climbing. The world cup MTB races places substantial emphasis on climbing and it is therefore expected that the smaller and lighter cyclists would have a performance advantage because of their higher power-to-weight ratio.

The absolute and relative PPO of the men and women in this study showed that in the majority of cases they were not as strong as those in previously published studies. They were, however, stronger and had more power than the amateur cyclists in the study by Wirnitzer & Kornexl (2008). Although their absolute PO at lactate thresholds was on par with others, their relative PO at LT and OBLA were lower due to their greater body mass. Since PPO and PO at OBLA are two of the strongest predictors of performance in the field, cyclists must strive to achieve high absolute and relative PPO values in order to perform better during competition. Therefore necessary training guidelines should be followed to improve these parameters in order to improve their ability to compete with elite cyclists.

When using data from laboratory tests to assess the fitness and potential of cyclists and also for comparative purposes. One has to take the day-to-day and week-to-week variation in maximal aerobic capacity and peak power output PPO into consideration (Kuipers *et al.,* 1985). Kuipers *et al.* (1985) reported an average coefficient of variance of 4.99 % for PPO and 7.89% for VO_{2max}. Although the reasons for this variability is not completed understood, there certainly is variance due to physiological reasons, such as changes in gross mechanical efficiency (Kuipers *et al.,* 1985). Other factors that can affect laboratory measures are different methods and protocols to determine these variables, the difference in stage duration of the test protocols (short stage increments tend to show higher PPO and VO_{2max} values compared to longer duration increments), the reliability and validity of the measurements, diurnal variations, the competitive level of the athletes (i.e. elite athletes are able to produce higher values with long stage increment protocols compared with untrained athletes), psychological factors (i.e. motivation) and also the specific period in the season when testing is done (pre-competitions phase, building phase or competitions phase). All these reasons can have an effect on the outcomes of the laboratory test and comparisons among different studies should thus be done with caution.

The majority of mountain bikers in this study only competed in regional mountain bike competitions and none of them were full time athletes. From the above findings it is concluded that the participants in this study can be considered above average amateur cyclists, rather than recreationally active cyclists.

4. 40 km time trial performance

In order to assess the performance ability of endurance athletes, laboratory-based tests must be reliable, valid, and sensitive to small changes in an athlete’s fitness level (Laursen et al., 2003). It has been reported previously that laboratory time trials, in general, has good reliability. Palmer (1996) reported high reproducibility for a simulated laboratory TT over 20 km and 40 km, both for time to completion (coefficient of variation 1.1 ± 0.9 % and 1.0 ± 0.5

%, respectively), as well as the mean power output for 20 km TT (CV= ±2.4%) and 40 km TT (CV=±3.3%). He also reported a significant correlation ($r = 0.98$, $p < 0.001$) between the 40 km TT in the laboratory and on the road, although the cyclists' times in the road race were, on average, ~ 8 % slower. This can probably be explained by the environmental factors that cyclists had to contend with on the road, which is obviously absent in the laboratory. Laursen (2003) investigated the reproducibility of the 40 km TT test in the laboratory on three different occasions. He reported a CV = 3.0 ± 2.9% for the total time between the first and third attempt, and CV = 0.9 ±0.7 between the second and third attempt. Smith (2001) reported no statistically significant difference in the mean power output of three indoor 40-km time-trials (CV= 2.01) when compared with the mean power output of three outdoor 40-km time-trial (CV= 2.55). These findings suggest that more than one familiarization test would lead to better reproducibility of the performance measure, but also that a laboratory TT is a good representation of outdoor performance.

In this study the 40 km TT was slightly modified from the traditional laboratory TT, in an attempt to simulate cross-country MTBing more closely. Cyclists had to contend with a few uphill and downhill sections over the course of the 40 km. During free range exercise (such as the simulated TT), cyclists can exercise over a broad range of workloads that are above and below their LT. Therefore, using a laboratory test with more ecological validity than fixed workload tests, the aim was to determine whether the workload distribution between the indoor test and the outdoor competition is similar, and also whether this test would provide high predictors of performance in the field.

The reliability (ICC and r-values) of the 40 km simulated TT used in this study showed moderate correlations for the average power output (PO) ($r = 0.72$) between the repeated trials and high correlations for both average HR ($r = 0.90$) and total TT time ($r = 0.86$). The interclass reliability coefficients for average power output, average HR and total TT time were also high ($R_1 > 0.90$). Bland-Altman plots of the difference in PO between TT1 and TT2 showed a bias ± random error of -13.43 ± 34.66 W, the average HR had a bias ± random error of 1 ± 16.97 bpm. To further improve the reproducibility of the TT performance, all the participants had a familiarisation session prior to the pre-event testing.

The average HR during the TT was almost identical for the men and women (159 ±20 bpm vs. 161 ±18 bpm), while the average PO and time to complete the distance were slightly better for the men than the women. None of these differences were statistically significant. This is not unusual findings; women normally have lower muscle mass, higher percentage body fat and lower maximal aerobic capacity than men and these physical differences would explain the slight differences in performance.

Lamberts (2014) reported the 40 km TT performance of 82 trained to elite male cyclists and 20 trained to elite women cyclists. His participants completed the distance in a significantly faster time than the cyclists in this study (men: 65:46 ±03:23 vs. 74:34 ±6:28; P < 0.0001; women: 73:46 ± 02:30 vs. 82:35 ± 5:59; P = 0.0003). Unfortunately Lamberts (2014) did not indicate whether his participants were road or MTB specialists. Nevertheless, the difference in performance times between the two studies can possibly be explained by the difference in the profiles of the time trials. The TT in the present study was hilly with a lot of climbing compared to a flat TT in the Lamberts (2014) study. The more difficult route would certainly lead to longer completion times.

C. DESCRIPTIVE CHARACTERISTICS OF THE NOVICES AND EXPERIENCED CYCLISTS

1. Subject characteristics

The experienced group participated on average in 11 ±4 3-day multi stage races in total, whereas the novices group had far less experience in 3-day multi stage races (2 ±1 races). The experienced group also had more competitive years in the sport compared to the novice group (11 ±8 years vs. 6 ±4 years). Despite these differences they reported similar amounts of training prior to the Cape Epic. Unfortunately the participants didn't complete their training diaries with adequate detail; therefore quality of training sessions between the two groups, if any, couldn't be compared.

2. Body composition

The experienced group had slightly higher percentage body fat compared with the novices. This may be attributed to the fact that the women were included in the experienced group and their body fat % were higher than those of the men (19.0 ±0.1% vs. 11.9 ±2.1%; P = 0.0001). The experienced group was also slightly taller and older, but the differences were not statistically significant (Table 5.3).

3. Incremental exercise test to exhaustion

There were only slight differences in the maximal exercise capacity of the experienced and novice riders, but none of these differences were statistically significant (Table 5.9).

4. 40 km time trial

There were no statistically significant differences in the performance variables measured during the 40 km simulated TT between the two groups, except that the experienced group had a higher average [lactate] than the novices (6.4 ±1.8 $mmol.l^{-1}$ vs. 4.7 ±1.4 $mmol.l^{-1}$) (Table 5.10). The average lactate concentration for the participants in this study during the TT ranged from 2.2 to 13.6 $mmol.l^{-1}$. All the cyclists in the experienced group had an average [lactate] higher than OBLA, while the values for four cyclists from the novices group were lower than OBLA. One must keep in mind that cyclists cannot "free" during downhill sections of the TT in the laboratory, therefore, despite a lower PO; they still had to produce a workload to go downhill. This is different to real life situations where the downhill sections give cyclists an opportunity to recover. For this reason the [lactate] remain high and even above OBLA.

The findings in this study are similar to that reported by Myburgh *et al.* (2001). They measured an average [lactate] of 7.6 ±2.1 $mmol.l^{-1}$ for a 1-h TT (range: 5.0 to 12.3 $mmol.l^{-1}$), suggesting that it is possible to sustain a high intensity of exercise despite considerable blood lactate accumulation (Myburgh *et al.,* 2001). Stapelfeldt *et al.* (2004) showed that endurance performances can be maintained at intensity levels above the individual anaerobic threshold measured during laboratory testing. These high intensities are associated with higher lactate levels (Coyle *et al.,* 1991). The fair amount of energy required to perform these power levels is gained through oxygen independent pathways and therefore causes lactic acid to accumulate in the muscles (Impellizzeri *et al.,* 2002). Terblanche, (1996) also found, in 4 trained and 4 untrained cyclists, that during a 40 km free range exercise test, the average work rate was higher than many of the thresholds determined during incremental exercise tests. Terblanche (1996) also found that the LT and dynamic parameters of blood lactate response during the incremental exercise test didn't predict the blood lactate response of the cyclists during the free range exercise test. Most of the subjects spent substantial amounts of time above the 2 and 4 $mmol.l^{-1}$ blood [lactate] thresholds.

The lactate-PO relationship during the maximal exercise capacity test suggests that the blood [lactate] is exponentially related to the intensity of exercise. It is further suggested that individuals would not be able to sustain a PO above OBLA, as the increase in the rate of lactate accumulation and the concomitant decrease in the rate of lactate removal will lead to muscle fatigue (Wasserman *et al.,* 1986). This relationship is, however, not true for exercise during a simulated TT. Therefore, parameters obtained from a maximal aerobic capacity test can not necessarily be used to extrapolate to a prolonged endurance test (laboratory TT) performed at or near maximal sustainable intensity. This point is illustrated by the findings in this study, as well as others (Myburgh *et al.,* 2001; Stapelfeldt *et al.,* 2004), that cyclists are able to maintain exercise intensities above OBLA during a test where they can free select their work rate.

There was no significant difference in the average RPE for the novices and experienced cyclists, suggesting that both groups experienced the TT to be "hard" (RPE = 15). Both groups also showed a gradual increase in RPE towards the end of the TT, which may be indicative of an end-spurt. Importantly, however, is that the experienced group maintained a higher average PO during the TT and recorded a faster TT time, with the same perception of effort, than the novices. Whether this is a reflection of differences in the aerobic and anaerobic fitness levels of the two groups, is not clear. Considering that the groups' physical and physiological characteristics and performance measures during the incremental exercise test were not statistically significantly different, two possible explanations are in order. Either the incremental exercise test to exhaustion is not sensitive enough to discriminate between cyclists that are more or less at the same level, in which case the performance on the TT may show differences, or the cyclists who had more experience in MTBing were able to pace themselves better during the TT.

A supplementary problem with the use of OBLA as a universal indicator for training exercise prescription is the inter-individual difference in the respiratory and metabolic responses during exercise (Boulay *et al.,* 1997). Boulay *et al.* (1997) found that the predicted [lactate] at VT varied by more than twofold. This observation provides evidence against the use of a constant [lactate] like OBLA as a training indicator.

The average HR for the TT in both groups was lower than the average HR at OBLA obtained from the maximal aerobic test. The average PO for the TT (expressed as percentage of PPO) was 68.6 ±4.1 % and 72.1 ±8.1 % for the novice and experienced group, respectively. The average PO during the TT was on average between 70 and 80 W (30% and 20% for novices and experienced riders, respectively) lower than the PO at OBLA (Table 5.9 & 5.10). The average HR during the TT, expressed as % of laboratory HR_{max}) was 85.9 ±10.6 % (novices group) and 88.9 ±3.5 % (experienced group). Therefore, both the HR and PO responses during the TT were lower than the HR and PO at OBLA. This is different from the lactate response, where most cyclists had [lactate] above OBLA throughout the TT. This may be indicative of the differences in the kinetics of HR, PO and lactate, i.e. HR and PO respond at a faster rate to changes in the route profile than [lactate].

The findings above do not support the notion that HR and PO values corresponding to OBLA should be used for training prescription. Boulay *et al.* (1997) are of the opinion that the HR response and the corresponding VO_2 obtained from a common incremental laboratory exercise test remains the most effective way for controlling exercise intensity during prolonged workouts.

From the above it can be concluded that parameters from the incremental exercise test to exhaustion are not good predictors of performance in a 40 km TT. Perhaps this is related to the specific incremental protocol that was used in this study, or perhaps the cyclists did not give a maximal effort during the TT test. The main reason for including the 40 km TT in this study was to see whether the cyclists' performance in the laboratory test predict what happens in the field. For this reason it was important that the cyclists' gave an all-out effort in the laboratory. Both groups experienced the TT as "hard" according to the Borg scale and considering that the RPE values at the end of the TT were 18 ± 2 and 17± 3, for the novices and experienced group, respectively, it is safe to say that the cyclists gave a very good effort, but that it probably cannot be regarded an all-out, maximal effort.

C. THE PHYSIOLOGICAL RESPONSES AND PERFORMANCES OF CYCLISTS DURING THE 2014 ABSA CAPE EPIC

The 2014 Absa Cape Epic was the 10th of its kind since the inaugural event in 2004. The race lasts 8 days and typically covers ± 700 km. The shortest route was in 2009 where cyclists had to cover 685 km and the longest route punished the riders on the 2008 Cape Epic with a total distance of 966 km. The original route was a point-to-point race, beginning in Knysna and ending in the winelands of the Western Cape. The format changed in 2009, where riders spent multiple days in each stage location. This year, 522 teams out of the 600 completed the race. In this study, the experienced group was representative of the top 35% of the cyclists that completed the 2014 Cape Epic, while the novices group was representative of the top 65%.

The cyclists' performances in the event were classified according to the total time to complete the race and overall general classification (overall position). The experienced riders completed the race in a statistically significantly shorter time and higher general classification than the novices. In fact, they spent on average 7 hours less time on the bike during the race. This lead to the large difference in general classification for the two groups (166 ±113 compared to the 327 ±139; P = 0.01). This was an interesting finding which was not reflected in the laboratory tests where no statistically significant differences were observed between the two groups The only real difference between the two groups was related to MTB experience. It therefore seems that multi-stage MTB experience is an important determinant of Cape Epic performance, as it accounted for 20% of the variance in final general classification of the event (r = - 0.45).

It can be speculated that the experienced group adapted to a more efficient pacing strategy over the years of competing in multi-stage MTB events and therefore recorded a better end result than the novices. Atkinson *et al.* (2007) and Swain *et al.* (1997) found that by varying power (increased PO during uphill of headwind sections and decreasing PO during downhill and tailwind sections) during time trials elicited significant time savings in comparison to an even pacing strategy. The time saving was achieved without any additional physiological distress. It seems that the experienced riders in this study may have adopted the same strategy, and they did so with similar physiological effort (RPE, maximal stage HR and average event HR) than the novices. The experienced group thus probably performed better by using a better pacing strategy and the latter is very much dependent on prior experience.

1. Profiling the exercise intensity of cyclists during the Cape Epic

The exercise intensity profile of the event can be useful to understand the physiological demands of these particular cycling competitions and from a practical point of view, the information could also help to design proper training programs (Impellizzeri *et al.,* 2002). The exercise-intensity profile could be useful to understand the training load imposed on athletes due to the fact that many coaches include races as part of their training season (Impellizzeri *et al.,* 2002).

HR has often been used in past studies to describe the exercise intensity during cycling competitions (Palmer *et al.,* 1994; Lucia *et al.,* 1999, 2000; Andez-Garcia *et al.,* 2000; Padilla *et al.,* 2001; Impellizzeri *et al.,* 2002; Lucia *et al.,* 2003a; Rodriguez-Marroyo *et al.,* 2003; Impellizzeri *et al.,* 2005a; Padilla *et al.,* 2008; Wirnitzer and Kornexl, 2008). In fact, HR is more often used than PO as it has been shown that the HR response of a specific type of exercise is more stable (i.e. less noise) than the PO response (Hurts and Atkins 2002; Stapelfeldt *et al.,* 2004; Hurts and Atkins, 2006). Jeukendrup and Van Diemen (1998) suggested that HR might be a good indicator of whole body stress, whereas power output might be a good indicator of exercise intensity. Padilla *et al.* (2008) contend that since there are no indicators of exercise intensity that is without limitations the use of HR to quantify the exercise intensity during cycling competitions are acceptable.

However, researchers are aware that HR monitoring, specifically during real-time events, is potentially limited by numerous factors. Duration of daily race, altitude, environmental conditions, terrain and type of bike (front suspension MTBs), cardiovascular drift and dehydration are some of the factors that could elevate the HR response and should be considered. Since these factors are to a great extent similar for all participants, it should be of limited influence on the differences in HR responses of cyclists. Moreover, the HR responses cannot be biased by race tactics (bunch building and/or drafting) as these tactics are not always easily accomplished and sometimes not even possible during MTBing. Considering all these factors, it is contended that the error margin in this study should be acceptable.

Another way of determining exercise intensity is by using the Borg rating of perceived exertion (RPE) scale. It was developed to enable athletes, sport scientists and coaches to obtain simple, reliable and valid estimations of exercise intensity (Day *et al.,* 2004). Borg based the RPE scale on the idea that a measure of perceived exertion is the level of physical strain and intenseness of the exercise performed by the individual and how the individual experiences the physical effort (Borg, 1982). The RPE scale is used primarily in exercise science (both in sport and clinical settings) and more specifically to quantify exercise intensities during aerobic training (Foster *et al.,* 2001). This method of monitoring exercise intensity has been shown to be an effective method to quantify exercise through a wide variety of exercise types (Foster *et al.,* 2001). Martin and Andersen (2000) used the HR-RPE relationship to monitor exercise intensity during training and tapering sessions and found that this relationship is useful to obtain a broader explanation of how the athlete really experiences a training session.

Since the experienced group had better performance outcomes than the novices, it does not necessarily mean that they worked harder. In fact, both groups described the event as hard according to the RPE scale (14 ± 2 for the novices group and 15 ± 2, for the experienced group) and their average HR during the event was almost identical. It can rather be concluded that the experienced group cycled smarter over the eight days, probably through better race tactics and pacing strategy. However, what is also interesting is that similar results were found during the laboratory TT; both groups described the TT as hard and had similar physiological responses, but the experienced group performed better. This may suggest that the 40 km TT is a good reflection of the performances of cyclists during the Cape Epic.

2. The heart rate response of the novices and experienced groups during the event.

Overall, there were no statistically significant differences in the heart responses of the novices and the experienced riders during the event. Both groups reached slightly higher maximal heart rates during the event in the field compared to the maximal HR reached in the laboratory during the maximal aerobic test. Both groups also showed a decrease in average HR from day one to the last day of the event, however, the differences were not statistically significant. The average HR of the cyclists during the event was almost identical for the two groups. The novices group maintained intensity between 72 – 83 % of laboratory HR_{max} and 70 – 80 % of field HR_{max} while the experienced group cycled at an intensity of 68 – 83% of laboratory HR_{max} and 66 - 83 % of field $HR_{max.}$.

The first day of the event was the prologue (distance = 23 km). The average HR on this day ranged from 145 – 175 bpm (novices group) and 149 – 187 bpm (experienced group). This was slightly lower than the average heart rate during the TT (157 ±22 bpm vs. 162 ±8 and 162 ±12 bpm vs. 164 ±10; novices and experienced, respectively), but the differences were not statistically significant. Expressed as % of HR_{max} obtained in the laboratory the intensity was slightly higher in the event than during the TT (novices: 88.0 ± 4.9 % vs. 85.9 ±10.6 % and experienced: 90.9 ± 3.7 % vs. 88.9 ±3.5. During the TT in the laboratory, the cyclists spent most of their time in the 80-90% and 90-100% of HR_{max} intervals (Fig. 5.10) and the same was found for the prologue (Fig 5.11a). The slight difference in average heart rate between the TT and the prologue can be explained by the fact that during the TT the cyclists was on a stationary bike in the laboratory with the temperature set between 18 - 21 °C. The higher HR values in the field can be attributed to differences in temperature, humidity and wind speed, as well as the fact that cyclists need to control and handle their own bike during the race. Furthermore, the cyclists' performances in the prologue are used to determine their starting group for the next stage. It can therefore be expected that the cyclists would give an all-out effort during this part of the race and this may also lead to higher heart rates than in the laboratory.

During multi-day MTB stage races and cross-country competitions the race will start in a form of a "starting loop" to spread out the riders in the initial part of the course. This allows the best cyclists to start in the front positions and to avoid a pile up behind less advanced cyclists when the course enters the more technical parts. Cyclists therefore try to start as far in front as possible to avoid slowing down when the road narrows. It is therefore noted that in MTB events, maximal HR is reached soon after the start, because of the fundamental importance of the individual's position at the start which can affect his/her race strategy. For this reason mountain bikers are used to start a competition at very high intensities (Impellizzeri *et al.,* 2002).

The results from the present study can also be compared to the 2004 TransAlp data (Wirnitzer and Kornexl, 2008) and this is done in Table 6.4. The cyclists in the two studies compared well with regards to the outcomes of the maximal exercise test in the laboratory. The average HR of the cyclists during the events was also similar and in both cases this was less than HR at OBLA in the laboratory. However, cyclists reached higher maximal values during the Cape Epic compared with the TransAlps.

Despite the differences in the profiles of the routes, it is remarkable that the cyclists had very similar HR responses. Both groups can also be classified as amateur cyclists and are probably representative of the majority of cyclists who participate in events like these.

Table 6.4 Comparison between the heart rate response during the 2014 Cape Epic and 2004 TransAlp Challenge.

Variable	2014 Cape Epic		2004 TransAlp	
	Men	**Women**	**Men**	**Women**
$HR_{max\ Lab}$ (bpm)	184 ±9	174 ±11	174 ±2	183 ±1
HR_{OBLA} (bpm)	167 ±11	164 ±15	157 ±4	168 ±3
HR_{OBLA} as % of HR_{max}	91.0 ±2.1	93.9 ±2.4	90.2 ±2.6	92.1 ±1.2
Variable	**Novices**	**Experienced**	**Grouped**	
Event RPE_{ave}	14 ±2	15 ±2	16.1 ±0.5	
$HR_{max\ Field}$ (bpm)	189 ±8	182 ±10	165 ±4	
HR_{max} Field as % of HR_{max} Lab (bpm)	102 ±4	102 ±5	93 ±2	
Event HR_{ave} (bpm)	139 ±5	140 ±10	141 ±5	
$HR_{ave\ Event}$ % of $HR_{max\ Field}$	74 ±3	77 ±5	85 ±2	
$HR_{ave\ Event}$ % of $HR_{max\ Lab}$	75 ±3	78 ±5	79 ±1	

$HR_{ave;}$ average heart rate; RPE_{ave}, average rate of perceived exertions; GC, general classification position; $Time_{ave,}$ average time for the whole duration of the event; HR_{max} (Lab), maximal heart rate obtained in the maximal aerobic test; HR_{max} (Field), maximal heart rate obtained during the event; % of HR_{max} (Lab), percentage of maximal heart rate obtained during the maximal aerobic test; % of HR_{max} (Field), percentage of maximal heart rate obtained during the event.

It has been reported that the exercise intensity of professional road cyclists during a stage race (6 days; 758 km) ranged between 140 – 144 bpm (Vogt *et al.*, 2006). Palmer *et al.* (1994) also reported that amateur road cyclists maintained intensities of 82 and 79%, respectively of HR_{max} in the field during the second (105 km) and fourth (110 km) stages of a 4 day road stage race. These figures are comparable to those in the present study and the 2004 TransAlp challenge, even though the road races were competed over 4 and 6 days, respectively. Thus in comparison to the 8 day stage races, one would initially expect to find higher effort levels than for the shorter races. However, it should be kept in mind that during the Cape Epic and TransAlps the cyclists have the opportunity to stop for food, water and rest, whereas in road cycling this doesn't normally happen. Thus the MTB bikers have short periods of recovery and can then continue to cycle at high intensities after they recovered.

3. A decrease in maximal heart rate during the event

In the current study, the cyclists' HR_{max} reached during the stages decreased after the first and the second stages of the race, but then remained stable till the end of the race. HR_{max} lowered by 13.8 % from the prologue to the last stage in both the novices and experienced cyclists. This same phenomenon was described by other researchers. Wirnitzer and Kornexl (2008) reported a decrease in HR_{max} after the first stage of the 2004 TransAlp Challenge and then it stabilized till the end. Similar declines in HR_{max} during stage races were reported by Lucia et al. (2003b) during the Vuelta a Espana (4.4 %) and the Tour de France (3.9 %). Lucia *et al.,* (2003b) reported a decline of 0.4 bpm a day in both the Tour de France and the Vuelta a Espana corresponding to an eight bpm decline after the 3 week stage races and about a three bpm decrease in HR_{max} after eight days of racing. The decline in the HR_{max} in the present study was more or less 10 bpm more than what was found by Wirnitzer and Kornexl (2008) and almost 10% more than what was found by Lucia *et al.* (2003b).

On the last day of the race the average HR for both groups decreased by almost 30 bpm from the average HR during the prologue and by almost 15 bpm from the first stage of the rage. The other stages were much longer in duration than the prologue, so the lower average HR is understandable. The decrease in average HR happened after the first two stages of the event and thereafter it stabilized at an average of 131-136 bpm for the novices and 132 – 139 bpm for the experienced group. The distribution of effort (expressed as time spent in percentage HR_{max} intervals) followed a similar pattern than HR_{max} during the event (Fig. 5.11 (a-h)).

One of the reasons for the lower HR during the latter stages of the race can probably be attributed to cumulative fatigue over the couple of days racing. Another explanation is catecholamine exhaustion and/or a reduction in the sympathetic nervous activity (Lucia *et al.,* 2003b). It can be expected that the cyclists would be extremely excited and nervous on the first day and during the first stage, but as the day's progress, this excitement would fade. One also has to consider the possibility of hypervolemia that occurs during acute high intensity exercise in already trained subjects (Richardson *et al.,* 1996; Wirnitzer and Faulhaber, 2007). An increase in blood volume is secondary to the decrease in plasma volume, leading to a decrease in average HR during exercise and also the maximal HR that can be achieved. Hypervolemia and sparing behavior (i.e. preventing the body from maintaining an exercise intensity that will lead to insufficient oxygen delivery to the brain; Noakes, 2007) during these particular stage races could also be a possible explanation for the decrease in HR_{max}. Although it can be assumed that participants completed each stage with the aim of reaching the best possible general position at the end of the event, a sparing behavior (i.e. pacing strategy) and race tactics cannot be excluded as factors which could explain the heart rate responses of the cyclists.

After stage 1 the cyclists spent very few minutes of their time in the “hard” HR interval and this was true for both the novices and experienced riders. Fig 5.8 & 5.9 show that the experienced group also spent more time in the “moderate” HR zones compared to the novices. A possible reason for this can be the range of self-chosen work rate explained by Mastroianni *et al.* (2000). It was reported that depending on the duration and intensity of the exercise, the range of self-chosen work rates may vary substantially among cyclists. For long exercise bouts lasting 2.5 to several hours the energy expenditures can vary from 35 to 45 % VO_{2max}. Another possible reason for the results could be the difference in pacing strategies. More experience in multi-stage MTB events may have come in handy when they had to attend to technical problems in the field. The novices group could also have spent more time at the water points to rest, leading to an increase in the time they spent in the “low” zone, rather than in the “moderate” zone.

4. Comparison to cross-country MTB events

During the 2014 Cape Epic the average event HR expressed as percentage of field HR_{max} was 75.3 ±2.8 % for the novices group and 78.2 ±4.5 % for the experienced group. Higher values was found by Impellzzeri *et al.* (2002) on four different cross-country events with an average HR of 90 ±3% maximal HR obtained in the field for these four events. The average HR for cross-country competitions lasting 147 ±15 min is similar to the exercise intensity of time trials lasting 10 ±3 min and 39 ±11 min (89 ±3% and 85 ± 5%, respectively) of maximal HR (Padilla *et al.,* 2001).

The average HR during the Cape Epic was higher than what was found for on-road cycling TT stages of longer duration. Padilla *et al.* (2001) found the average HR in professional cyclists during semi-and high-mountainous stages with a mean duration of 302 ±57 min and 355 ±67 min, respectively, to be 58 ±6% and 61 ±5% of maximal HR.

When comparing cross-country events lasting on average 147 ±15 min with a total distance of 34.3 ±3.9 km with stage races that is much longer in distance and duration, it is expected that the average HR expressed as a percentage of maximal HR would be lower for events that are longer in duration. In this study, the average HR expressed as a percentage of field

HR_{max} is lower than the results for cross-country MTBing, but higher than on-road cycling stages of longer duration.

It is evident form the results above that cross-country competition are conducted at higher intensities than road stage races. These types of events happen over shorter distances and lower relative speeds, over bad terrain conditions, including continuous climbs and descents and with larger tires. Thus off-road cyclists spent most of their time and effort against the force of gravity and presumably greater rolling resistance compared with on-road cycling (Padilla *et al.,* 1999). In addition, mountain bikers cannot use drafting (using the draft of other cyclists to ride in) to reduce energy expenditure. Drafting on flat roads can result in up to 26 – 39% energy saving (Hagberg and McCole, 1996). Unlike road cycling, MTBing does not often afford riders the opportunity to cycle in a group together at high speeds. This also increases the energy expenditure during MTBing. Another factor contributing to elevated HR during MTBing is the intense and repeated isometric contractions of arm and leg muscles that are required to absorb shock and vibrations caused by the terrain and for bike handling and stabilisation. Isometric muscle contraction significantly increases the HR during exercise and this may also contribute to the higher mean HR during off-road cycling compared to on-road cycling.

5. Comparison of the heart rate responses in specific heart rate zones.

Another method to profile exercise intensity in cycling competitions is by using the HR corresponding to certain lactate thresholds (i.e. LT and OBLA) determined with laboratory tests. In this study the following zones was used: LOW_{ZONE}, for intensity below HR corresponding to LT; $MODERATE_{ZONE}$, for intensity between HR corresponding to LT and OBLA; $HARD_{ZONE}$, for intensity above HR corresponding to OBLA. The same intensity zones were used by Impellizzeri *et al.* (2002) to report the exercise intensity during four different cross-country competitions. Similar intensity zones were used by Wirnitzer and Kornexl, (2008) to describe the exercise intensity of the 2004 TransAlp Challenge. The only difference is that they used a fixed [lactate] at 2 $mmol.l^{-1}$ as the first threshold.

Table 6.5 illustrates that the two MTB multistage events resulted in very similar HR responses. Large amounts of time were spent in the LOW and MODERATE intensity zones and only a small percentage of time in the HARD intensity zones above OBLA. This data indicates the importance of a well-developed aerobic energy system in order to succeed in events like this. The fact that small amounts of time are spent in the intensity zone above OBLA doesn't mean that the anaerobic energy system is not of importance for these types of events. The fact that cyclists stop for rest periods, at water points and for technical difficulties, would also contribute to the large amounts of time spent in the “low” zone. Vogt *et al.* (2006) used when SRM power meters to determine the exercise intensity during a 6 day road stage race. They found that the description of exercise intensity through HR tends to underestimate the time spent in Zones 1 (low) and 3 (hard), and to overestimate the time spent in Zone 2 (moderate). Vogt *et al.* (2006) explained that the regulation of the cardiovascular system is slower to adapt to the quick changes in high and low PO in decisive race simulations. During descents, for instance, HR can be in Zone 2 while PO is already in Zone 1. Or during intermittent sprints, PO is already in Zone 3 while HR is still in Zone 2. The cardiovascular drift can be another explanation for underestimation of the time spent in Zone 1, leading to more time spent in the “moderate” zone.

Table 6.5 Comparison of the percentage time spent in each intensity zone during the Cape Epic and TransAlp

Intensity zones	**2014 Cape Epic**		**2004 TransAlp**
	Novices	**Experienced**	
LOW (%)	58.5	43.1	36
MODERATE (%)	35.4	49.5	58
HARD (%)	6.1	7.4	5
VERY HARD (%)	-	-	2

During this study the participants progressively spent more time in the LOW intensity zone towards the end of the race. This finding corresponds to the decrease in average stage HR of the participants and also the decrease in maximal stage HR, previously discussed. When comparing the distribution of effort between the two groups during the race the experienced group spent statistically significantly more time in the “moderate” HR zone during the first stage of the race than the novice group (66.2 % vs. 43.2 %), meaning that they exerted more effort for longer periods of time. This could be the explanation for the significant difference in total race time and general classifications between the two groups.

Cross-country events of shorter duration and distance lead to different results than what was found in this study. Impellizzeri *et al.* (2002) found that, during four different cross-country competitions, riders spent 18 ±10 % of the time “low” zone, 51 ±9 % in the “moderate” zone and 31 ±16 % in the “hard” zone. This shows that in cross-country competitions more time is spent at HR corresponding to OBLA and above OBLA. This is possible due to the shorter durations of the event. Cross-country competitions only last on average a couple of hours, whereas events like the TransAlp and Cape Epic consists of eight days of consecutive racing where cyclists are very much aware of reserving energy for the next day.

Comparing the distribution of effort during the Cape Epic with the laboratory TT, it was observed that cyclists spent more time in the “moderate” and “hard” HR zones during the TT than during the event. Very little time was spent in the LOW HR zone during the TT. During the event the opposite happened. The cyclists spent predominately more time in the “low” and “moderate” HR zone and very little time in the “hard zone. This can be due to the fact that the TT was only 40 km in distance and was a once off event, while the Epic consisted of longer durations with stage distances ranging from 23km to 134 km and lasting eight consecutive days of racing. During the event the cyclists had to pace themselves to have the best opportunity to complete the race.

The HR values recorded during the 2014 Cape Epic showed that this multi-day cross-country marathon competition is physiologically very demanding. It also shows that both aerobic and anaerobic energy systems are involved in this event. These results can be useful to design appropriate training programs, based on real life race data. These data can also be used to design specific nutritional interventions to sustain the physical demands of this kind of MTB competition.

Our results can also assist coaches who use minor competitions as part of the training program to quantify the training load imposed on the athletes. Despite the increasingly popular use of power output to prescribe and describe exercise intensity in endurance sport, the knowledge gained by this study led the researcher to believe that HR monitoring remains the most practical and financially acceptable tool for coaches and athletes to use.

D. RELATIONSHIPS BETWEEN LABORATORY MEASURES AND PERFORMANCE IN THE CAPE EPIC

Laboratory tests are conducted to determine athletes’ aerobic and anaerobic fitness levels with the aim to assist the athlete in his/her training. Laboratory determined parameters can be used for training prescription and the assessment of training progress. If the aim is to use laboratory parameters to predict performance in the field, one also has to study the physical and physiological demands of the events. The information gathered from competitions and simulated race trails coupled with data from the laboratory- based tests can be used to gain better insight into the importance of physiological measures as predictors of MTB race performance (Gregory *et al.,* 2007).

The two most commonly used methods to predict cycling capacity are PPO and 40 km TT time (Lamberts, 2014). Both of these tests have been shown to be good indicators of a cyclist's training status (Lucia *et al.,* 2000; Jeukendrup *et al.,* 1996) and are able to detect meaningful changes in the training status of well-trained cyclists.

The performance outcomes of the Cape Epic that were considered included average heart rate during the event, total time to complete the race and general classification at the end of the race. The race outcomes were correlated to the cyclists' physiological and performance responses during the two laboratory tests, namely the maximal exercise test to exhaustion and the 40 km TT.

For the prediction of MTB performance in the field the physiological variables obtained from laboratory-based test were expressed in both absolute and relative terms, as body mass and frontal area greatly influence gravity-dependent or aerodynamic resistance (Padilla *et al.,* 1999). For this reason, all correlations are also reported relative to body mass.

1.1 Predictors of the time to complete the race

The final event time and the general classification of cyclists at the end of the race are less affected by moment-to-moment changes in the race and both were therefore considered as event performance outcomes.

From the maximal aerobic capacity tests only three parameters were highly correlated to the final event time. Absolute PPO ($r = -0.70$), absolute PO at OBLA ($r = -0.77$) and relative PO at OBLA ($r = -0.68$) showed the highest correlations to total event time. The other laboratory measures showed low correlations to final event time, especially absolute ($r = -0.38$) and relative ($r = 0.10$) maximal aerobic capacity. This means that high PPO and PO at OBLA values are necessary if the cyclists want to perform well during the event.

The time to complete the laboratory TT also correlated with the event time ($r = 0.61$; SEE = 5.23, although it was not a high correlation. None of the other TT variables resulted in worthwhile correlations with event time. This correlation can partially be explained by the relationship between the absolute average PO during the TT and total event time ($r = -0.59$; SEE = 30.30). Thus, the higher the rider's average PO during the event, the better the event performance. However, these correlations were not as high as the correlations between the laboratory variables from the maximal aerobic capacity test and the performance outcomes of the event.

The best subset regression model to predict the time to complete the race included absolute and relative PO at OBLA (P = 0.01 and P = 0.02, respectively). This model explained ~ 71 % of the variance in total Cape Epic time (R^2 = 0.71).

1.2 Predictors of final general classification

From the maximal aerobic capacity tests the same three parameters was highly correlated to final general classification for the event than for time to completion of the race. Absolute PPO (r = -0.68), absolute PO at OBLA (r = -0.74) and relative PO at OBLA (r = -0.68) showed the highest correlations to the final general classification of the cyclists. The other laboratory measures showed low correlations to final event time, especially for absolute (r = -0.35) and relative (r = 0.11) maximal aerobic capacity.

The physiological parameters obtained from the laboratory TT did not result in any high correlations with the general classification. The correlations ranged from r = 0.36 to -0.45. According to the best subset regression analysis, average HR during the TT was a statistically significant predictor (P = 0.043) of the general classification in the event. However, this parameter did not appear in the majority of subset model and therefore it is not included in the final model.

The best subset regression model indicated that relative PPO (P = 0.02) and relative maximal aerobic capacity (P = 0.048) were statically significant predictors of general race classification. This model explained 56% of the variance in general classification.

1.3 Predictors of the average exercise intensity during the event

The correlations between the various outcome variables during the maximal exercise test and the average HR during the event ranged from -0.02 to -0.32 (Fig. 5.15). At best, the maximal [lactate] at the end of the test to exhaustion would only predict ~ 10% of the cyclist's performance in the field.

The average HR obtained during the laboratory TT correlated with the average HR obtained during the event. This correlation was not very high (r = 0.58; SEE = 14.52). The possible reason for this could be that during the TT, high average HR values were reached; while during the event the cyclists could have paced themselves over the eight days, keeping the average HR lower than in that in the TT. Also during the event the cyclists had time intervals where they were not on the bike. They spent time at the water points to rest and also time with technical difficulties (like a flat tire) or when they had to wait for their partners. These factors influenced the consistency of the heart rate responses, creating fluctuations and resulting in a lower average event HR.

When using the best subset regression model, significant predictors were identified as total time trial time (P = 0.03), average HR during the 40 km TT (P = 0.04) and absolute power output at OBLA (P = 0.03) and absolute peak power output (P = 0.03). PPO explained 40% of the variance in average HR during the event. This model, however, was the weakest of all the models to predict Cape Epic outcome. The reason for this could be because of the many external factors that may affect HR (for example: cardiac drift, dehydration, heat stress, catecholamine exhaustion and hypervolemia).

Cristafulli *et al* (2006) also pointed out that the HR/VO_2 relationship assessed during incremental laboratory exercise testing appears to be stable and reliable, but when the athlete is in the field setting this relationship is affected by several potentially perturbing factors where HR may not reflect oxygen consumption accurately. These authors showed that the reliability coefficient (R^2), which is a measure of the strength of a relationship, was higher for the laboratory derived HR/VO_2 relation than for field data (R^2 = 0.87 in laboratory and R^2 = 0.69 in field). This finding is particularly important for an event such as the Cape Epic, as cyclists often have forced or unforced stops during a stage. Cyclists may spend significant amounts of time off their bikes due to technical difficulties, or one partner may have to wait for the other partner, or they may choose to take extended rest periods at water points and also periods. These situations cause huge fluctuations in HR and it is unfortunately impossible to exclude these fluctuations from the data.

Although HR is certainly one of the easiest variables to measure in the field, the use of heart rate monitoring to assess intensity of exercise in the field will be unreliable in some situations. Cristafulli *et al.,* (2006) also concluded that this method should be used with care.

1.4 Comparison between the laboratory predictors in this study to other published studies

The physiological parameters in absolute values and expressed relative to body mass were used to determine correlations. In Table 7.8 the correlations between race time and physiological variables expressed in absolute and relative terms of various published studies and the present study is presented.

The same physiological variables that showed high correlations with race time in this study were also reported in other studies. It can therefore be concluded that the physiological variables in Table 6.6 depict the variables that will best predict performance on the field. Of these, PPO and PO at submaximal lactate parameters are the best predictors of race time during events. The best correlations in this study were between absolute and relative PO at OBLA and race time.

Table 6.6 The correlations between race time and physiological variables expressed in absolute and relative terms

Study	Variables	Race time vs absolute values	Race time vs relative values
Impellizzeri *et al.* (2005a)	VO_{2max}	-0.66	-0.62
	PPO	-0.71	-0.76
	PO_{OBLA}	-0.71	-0.89
	PO_{LT}	-0.73	-0.86
Impellizzeri *et al.* (2005b)	VO_2 at RCT	-0.18	-0.66
	PO at RCT	-0.22	-0.63
Prins *et al.* (2007)	PPO	-0.65	-0.83
	PO_{OBLA}	-0.56	-0.64
Present study	PPO	-0.70	-0.57
	PO_{OBLA}	-0.77	-0.68
	PO_{LT}	-0.64	-0.38

VO_{2max}, maximal oxygen consumption; PPO, peak power output; PO_{OBLA}, power output at onset blood lactate accumulation; PO_{LT}, power output at lactate threshold; VO_2 at RCT, oxygen consumption at respiratory compensatory threshold; PO at RCT, power output at respiratory compensatory threshold

Correlations between the final rankings and physiological variables for this study and a study by Impellizzeri *et al.* (2005a) are presented in Table 6.7 to show the resemblance.

Impellizzeri *et al.* (2005a) Gregory *et al.* (2007) are the only two studies that found good correlations between maximal aerobic capacity and performance on the field. Although maximal aerobic capacity is traditionally regarded as an important determinant of endurance performance (Coyle *et al.,* 1988), neither absolute nor relative VO_{2max} (r = -0.35 and r = -0.11, respectively) in this study correlated well with the cyclists' general classification. Moderate to high correlations were found between PPO and PO at OBLA and the total race time (r = -0.70 and -0.77, respectively) and final rankings (r = -0.68 and -0.74, respectively).

Table 6.7 The correlations between final rankings at the end of the event and physiological variables expressed in absolute and relative terms

Study	Variables	Final rankings vs absolute values	Final rankings vs relative values
Impellizzeri *et al.* (2005a)	VO_{2max}	-0.72	-0.66
	PPO	-0.69	-0.81
	PO_{OBLA}	-0.65	-0.88
	PO_{LT}	-0.73	-0.92
Present study	VO_{2max}	-0.35	-0.11
	PPO	-0.68	-0.57
	PO_{OBLA}	-0.74	-0.68
	PO_{LT}	-0.49	-0.36

VO_{2max}, maximal oxygen consumption; PPO, peak power output; PO_{OBLA}, power output at onset of blood lactate accumulation; PO_{LT}, power output at lactate threshold

The correlation between the physiological variables obtained in the laboratory in absolute and relative terms, and outdoor time trial performance of other published studies are presented in Table 6.8.

The positive correlations found by Gregory *et al.* (2007) were between average TT speed and physiological variables. The other studies that used total TT time and showed negative correlations. High correlations was found between relative PPO and PO at OBLA and outdoor TT performance for studies by Prins *et al*. (2007) and Gregory *et al*. (2007).

Anton *et al.,* (2007) showed good correlations between relative PPO and uphill TT performance ($r = -0.66$), as well as with the relative workload values ($r = -0.55$ to -0.60; $P < 0.05$) corresponding to lactate parameters ($W_{+1.5}$, workload corresponding to an increase in lactate concentration of 1.5 $mmol.l^{-1}$ above baseline values, W_4, workload corresponding to a lactate concentration of 4 $mmol.l^{-1}$and W_5, workload corresponding to a lactate concentration of 5 $mmol.l^{-1}$). While the absolute PPO also correlate to flat TT performance ($r = -0.90$). This also indicated the importance of body mass during cycling event that consists of a lot of uphill sections.

Most of the studies showed higher correlations when the physiological values are expressed relative to body mass. The study by Hawley and Noakes (1992) and Balmer *et al.* (2001) showed higher correlations for absolute values.

Table 6.8 The correlations between outdoor TT performance and physiological variables expressed in absolute and relative terms

Study	Variables	Outdoor TT vs absolute values	Outdoor TT vs relative values
Prins *et al.* (2007)	PPO	-0.66	-0.83
	PO_{OBLA}	-0.67	-0.74
Hawley & Noakes (1992)	PPO	-0.91	-0.68
Gregory *et al.* (2007)	PPO	0.64	0.93
	VO_{2max}	0.66	0.80
	PO at IAT	0.50	0.78
Balmer *et al.* (2001)	PPO	-0.99	-

VO_{2max}, maximal oxygen consumption; PPO, peak power output; PO_{OBLA}, power output at onset of blood lactate accumulation; PO at IAT, power output at individual anaerobic threshold

The study by Hawley and Noakes (1992), found a decrease in correlation between PPO and 20 km TT time, when PPO was expressed relative to body mass. The same was observation was found in this study. Swain *et al.* (1987) explained that larger cyclists will have an advantage in terms of absolute oxygen consumption and power output over smaller cyclists on level roads, due to the reduction in wind resistance when they assume the racing position; however this advantage is lost when cycling uphill. This finding can be supported by the physical characteristics of the participants in the study, with high body mass and percentage body fat values.

The results from our study did not show that parameters from the simulated 40 km TT correlated better with outdoor performance than the parameters from the maximal aerobic capacity test. Therefore the standard maximal aerobic capacity test are sufficient for testing mountain bikers and sport scientists can continue using this test to prescribe exercise intensity zones for training and events.

The results of this study also support the widespread assessment of the conventional maximal workload, in this case PPO, and submaximal measures, in this case the lactate thresholds, as measures of aerobic fitness in off-road cyclists, rather than maximal aerobic capacity. As a result, cyclists with high maximal aerobic capacities should incorporate training strategies that will focus on improving the capacity to maintain high levels of submaximal aerobic work (OBLA intensity). However, significant correlations does not imply causality and therefore experimental studies are needed to determine whether training aimed at improving the PPO and lactate thresholds will result in enhanced off-road performance. Although the findings of this study do not explain the importance of technical skills and other physiological factors, they suggest that aerobic power and anaerobic capacity are important components of off-road performance.

The interesting finding from this study was that HR and PO corresponding to OBLA was not a good indicator for optimal exercise intensity for prolonged exercise, due the fact that the participants from this study could not maintain the exercise intensity corresponding to OBLA for the duration of the laboratory TT. Nevertheless absolute and relative PO at OBLA was the best laboratory predictors of performance during the Cape Epic and can therefore be used to evaluate if cyclists will be able to perform well during multi-stage MTB events. Finally despite the numerous factors influencing the performance during the Cape Epic, our laboratory predictors still agreed with other published studies.

E. SUMMARY OF MAIN FINDINGS

The main findings of this study were that the men and women in the study sample did not differ from each other in physiological characteristics or in performance outcomes in the laboratory. Therefore all the participants where pooled and divided into a novices and experienced group according to their MTB experience. The two groups didn’t differ in physical or physiological characteristics and performance outcomes in the laboratory. Except for the higher blood lactate response during the TT by the experienced group. The experienced group performed better during the event than the novice group in both the final event time and general classifications category. The experienced group spent statistically significantly more time in the “moderate” HR zone and a greater percentage of time in the “high” HR zones than the novices group. It was also found that there was a decrease in maximal HR obtained in the field from the first day of the event to the last. The same happened for the average stage HR and the percentage time spent in the hard HR zones (80-90% and 90-100% of maximal HR) for both groups. Absolute and relative PO at OBLA showed the strongest correlations to event performance. Low correlations were found between the laboratory variables and average HR during the event, showing that it is not possible to predict the HR response during an event from laboratory variables. Lastly, the correlations found between the laboratory TT variables and event performance was not high and therefore the use of the maximal aerobic test to determine predictors of performance is sufficient.

F. LIMITATIONS OF THE STUDY

During the event certain information was obtained from the cyclists through questionnaires. This information relied on their memory of the day's events and the participants could have forgotten important aspects of the day that may have influenced the interpretation of the results.

The study sample only consisted of two women participants, making a comparison between the men and women impossible. The study sample also did not include any professional or international cyclists and therefore the results of the study is only representative of good, amateur cyclists.

Cyclists compete in the Absa Cape Epic in teams of two. Therefor the stronger rider's HR and RPE values can be affected by the slower race pace adopted to accommodate his teammate.

The fact that the participants possibly did not perform an all-out effort during the laboratory TT could have been avoided if blood [La] measures were not taken at 5 km intervals and if the participants were blinded from feedback during the TT. This should be kept in mind for future studies.

G. FUTURE DIRECTIONS

Future studies should aim to include professional cyclists in the sample. This could provide interesting comparisons to the cyclists who probably make up the majority of the field, namely the good, amateur cyclists.

It is recommended that the anaerobic Wingate test is included in the test battery, as the parameters obtained from this test could be significant predictors off performance in the field.

The use of SRM power meters during the event would provide more direct assessment of the exercise intensity of cyclists during the event. It would also be useful to see how well laboratory variables correlate with PO during the field, especially because of the high correlation between PPO and PO at OBLA and performance during the event found in this study.

It would also be interesting to test the cycling efficiency of the cyclists to see if this variable is possibly a high predictor of performance in the field.

Appendix A: Informed consent form

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
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STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

PARTICIPANTS

Physiological demands and predictors of performance of the ABSA Cape Epic mountain bike race

You are asked to participate in a research study conducted by Marli Greeff (Honors in Sport Science) from the Sport Science Department at Stellenbosch University. The results will contribute to a Master's thesis. You were selected as a possible participant in this study because you intend to participate in the 2014 ABSA Cape Epic event.

PURPOSE OF THE STUDY

The primary aim of the study is to describe the physiological demands and predictors of performance of the ABSA Cape Epic 2014.

1. PROCEDURES

If you agree to participate in the study, we asked that you do the following: You will be required to visit the laboratory on two different occasions. On your first visit you will be asked to complete questionnaires (Appendix A, B and D) to ensure that they meet the inclusion criteria.

Thereafter your body composition will be measured using a BodyMetrix BX2000. This procedure will take 10 minutes to complete.

You will be asked to do a maximal exercise test on the cycle ergometer. The aim of this test is to determine your VO2 peak value (peak oxygen consumption). This will give us an indication of your functional capacity. Your capillary blood lactate concentration will be determined by a finger prick after each workload increment. The test will continue until exhaustion. The procedure will take around 40 minutes varying from person to person.

Your second visit will be at least 72 hours after visit one, but no more than one week later. You will be asked to complete a 40km time trial on the cycle ergometer in the shortest possible time. Your capillary blood lactate concentration will be determined by a finger prick during the test. The procedure will take around 90 minutes, varying from person to person.

All the procedures will take place in the physiology laboratory at the Department of Sport Science.

You will wear a heart rate monitor during the ABSA Cape Epic. Your official stage times and total race times will be obtained from the race office after each stage. You will be asked to keep a diary (Appendix C) of your daily food and fluid consumption, medicine or supplements used during the day, as well as smoking history during the day. At the end of each stage you must I also give a description of the stage. This will include information about any technical difficulties experienced with your bikes during the stage.

1. POTENTIAL RISKS AND DISCOMFORTS

There are no profound risks involved in this study. All the laboratory tests are standardized cycling tests with certain rules to ensure safety. You may experience dizziness and nausea during the tests on the cycle ergometer. If that is the case, exercise will be stopped immediately. You may also experience slight discomfort, such as muscle soreness and muscle stiffness, after the exercise test, but it won't be more than after a hard training session.

2. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

The results of all the tests and measurements will be made available to you, which may help you in your preparation for the Cape Epic.

The results of the study will help sport scientists to better understand the physical and physiological demands of mountain biking so that they can prepare and advise cyclists better for races.

3. PAYMENT FOR PARTICIPATION

You will receive no compensation for your participation in this study.

4. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

Confidentiality will be kept by storing the data on a computer with a confidential password. Only the researcher and the study leader will have access to the data. The data will be stored on the study leader's computer (with a password) for 3 years after the study. Only the study leader has access to the computer.

If the article is published there will be no mentioning of participants' names. Only group results will be made available.

5. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You can refuse to answer certain questions and still participate in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. The following circumstance will allow termination; if you: do not comply with the regulations preceding the laboratory tests, do not complete all the stages of the event, if they don't complete their training diaries or their race diaries, have any serious injuries that would affect your cycling ability, have any health problem or use any chronic medication that may affect your heart rates and/or lactate values

6. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact:

Marli Greeff
0825724601

Sport Physiology Laboratory
Department of Sport Science
University of Stellenbosch
Tel: 021 808 2818
http://www.sun.ac.za/exerciselab

Prof. Elmarie Terblanche

Chairperson
Department of Sport Science
Private Bag X1
MATIELAND
7602
+27 21 808 2742/4915
+27 21 808 4817
et2@sun.ac.za
http://www.sun.ac.za/education
http://www.sun.ac.za/exerciselab

7. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

Should you incur any research-related injury or incident during the laboratory exercise tests, all costs will be covered by the insurance of Stellenbosch University. To this end, you may contact Mr. van Kerwel (wvankerwel@sun.ac.za) for information on the issue of compensation and coverage of medical expenses in the event of a research-related injury.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

The information above was described to me ______________________________ (name) by ________________________ (researcher) in _________________ (language) and I am in command of this language or it was satisfactorily translated to me. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study. I have been given a copy of this form.

____

Name of Subject/Participant

____

Name of Legal Representative (if applicable)

____ _______________

Signature of Subject/Participant or Legal Representative **Date**

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to ___________________*]. [He/she*] was encouraged and given ample time to ask me any questions. This conversation was conducted in [*Afrikaans/*English*] and no translator was used.

____ _______________

Signature of Investigator

Appendix B: Ethical clearance

Approval Notice
New Application

13-Nov-2013
Greeff, Marli M

Proposal #: DESC_Greeff20123
Title: Physiological demands and predictors of performance of the ABSA Cape Epic mountain bike race

Dear Miss Marli Greeff,

Your DESC approved **New Application** received on **04-Oct-2013**, was reviewed by members of the **Research Ethics Committee: Human Research (Humanities)** via Expedited review procedures on **12-Nov-2013** and was approved.

Please note the following information about your approved research proposal:

Proposal Approval Period: **12-Nov-2013 - 11-Nov-2014**

Please take note of the general Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

Please remember to use your **proposal number** **(DESC_Greeff20123)** on any documents or correspondence with the REC concerning your research proposal.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

Also note that a progress report should be submitted to the Committee before the approval period has expired if a continuation is required. The Committee will then consider the continuation of the project for a further year (if necessary).

This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the Guidelines for Ethical Research: Principles Structure and Processes 2004 (Department of Health). Annually a number of projects may be selected randomly for an external audit.

National Health Research Ethics Committee (NHREC) registration number REC-050411-032.

We wish you the best as you conduct your research.

If you have any questions or need further help, please contact the REC office at 0218839027.

Included Documents:

Questionnaire
REC Application
Consent forms
Research proposal
DESC form

Sincerely,

Susara Oberholzer
REC Coordinator
Research Ethics Committee: Human Research (Humanities)

Appendix C: Health Questionnaire

Researcher contact info:
Marli Greeff
15767981@sun.ac.za
021 808 2818

Name:
Email address:
Tel:
Participant number (official use):

HEALTH HISTORY

Please complete the following questions.

Name and Contact number of general physician/ doctor	
Has your doctor ever said that you may not do any physical activity?	No ☐ Yes ☐
Do you feel pain in your chest when you do physical exercise?	No ☐ Yes ☐
Do you smoke?	No ☐ Yes ☐
Have you had any chest pains in the past month?	No ☐ Yes ☐
Do you lose your balance because of dizziness?	No ☐ Yes ☐
Do you experience the loss of consciousness?	No ☐ Yes ☐
Do you have a bone or joint problem that could be aggravated with exercise?	No ☐ Yes ☐
If yes, please specify:	
Are you using any medication?	No ☐ Yes ☐
If yes, please specify: *Name and indicate if chronic*	
Do you know of any reason why you should not participate in this study?	No ☐ Yes ☐
Have you recently had an injury which limited your activity levels?	No ☐ Yes ☐

Do you suffer from any of the following conditions? Please specify if necessary.		
Musculo- skeletal problems	No ☐ Yes ☐	
Metabolic- and endocrine disorders	No ☐ Yes ☐	
Immune deficiencies	No ☐ Yes ☐	
Cardiorespiratory disorders	No ☐ Yes ☐	
Cardiovascular disorders	No ☐ Yes ☐	
Haematological problems	No ☐ Yes ☐	
Previous performance		
Partake in competition during the past 3 months?	No ☐ Yes ☐	
Last best performance		
How many times per week do you train?		
For how many years have you been competing?		

Appendix D: Pre- event questionnaire

<table>
<tr><td>Questions:</td><td colspan="2">Answers:</td></tr>
<tr><td>Age:</td><td colspan="2"></td></tr>
<tr><td>Do you have proof of an ABSA Cape Epic 2014 entry?</td><td>YES</td><td>NO</td></tr>
<tr><td>Do you have your own downloadable Heart Rate monitor?
If yes, Specify type and model:</td><td>YES</td><td>NO</td></tr>
<tr><td rowspan="2">Are you using any medication or do you have any medical condition that may influence on your heart rate or lactate values?</td><td>YES</td><td>NO</td></tr>
<tr><td colspan="2">Please Specify:</td></tr>
<tr><td rowspan="2">Have you participated in an ABSA Cape Epic Before?</td><td>YES</td><td>NO</td></tr>
<tr><td colspan="2">Number of Cape Epic events?

Date of the previous ABSA Cape Epic:</td></tr>
</table>

Appendix E: Mountain biking experience

Names:	Completed Y/N?	How many times?	Year
Ride2Nowhere – McGregor MTB 2013			
Glacier by Sanlam Storms River Traverse			
RE:CM 200 Knysna			
Grindrod Bank Umngazi Pondo Pedal			
Nedbank sani2c			
The Old Mutual joBerg2c 3 days (first 3 days of Old Mutual joBerg2c)			
The Old Mutual joBerg2c (full 9 days)			
Rovos Rail Ride: Pretoria to Livingstone			
Star Gazer 3 Night Stage Race			
Cape Outback 4-day MTB stage expedition			
Nashua Grape Escape (3-day and 2-day options)			
The Rocky Mountain Garden Route 300			
The Bridgestone Route 66 MTB Experience			
Tankwa Trek			
Ride the Rock 3 Day MTB Multi Stage Race			
Cape Pioneer			
Other:			

Appendix F: Training History

In what training phase are you at the moment?	Base☐ Build ☐ Race ☐
How many times per week do you train?	
How many hours per week do you train?	
Describe the last 3 months of training:	Times per week:
	Hours per week:
	Training phase:

Appendix G: Event questionnaire

Example of one stage

Categories	Please fill in:	
How did you feel after and during the stage: (6-20)		
Official stage time:		
Caffeine intake during the day and in the evenings:	Coffee: Number of Cups:	Energy drinks: Name: Amount:
If you smoke, please indicate brand and number of cigarettes per day.		
Food and supplement intake: before stage (please list)		
Fluid intake during the day: List and amount		
Food and supplement intake: during Stage (please list)		
Food and supplement intake: after stage until the end of the day (please list)		
Average Heart Rate: During stage		
Did you take any medication today? If so, please list.		
Please list all the events during the stage when you were off your bike for more than 1 minute.		
File name for storage of data for this stage:		

Appendix H: Borg Scale

Borg Rating of Perceived Exertion

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

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