UNIVERSITY OF TARTU
Institute of Sports Pedagogy and Coaching

Karmen Reinpõld

Predictors and characteristics of an ultra-distance mountain bike race performance

Master Thesis

Physical Education and Sport

Supervisor: Assistant Professor, J. Mäestu

Tartu, 2017

TABLE OF CONTENTS

ABSTRACT

Aim: The aim of the present thesis was to investigate markers that predict and characterize performance of an ultra-distance mountain bike race and to investigate the dynamics of heart rate and power output.

Methods: 6 highly trained male mountain bikers (age 38.5 ± 6.5 years) participated in the study. The study period lasted for 6 months and ended with Cape Epic 8 –day race. During the preparatory period, the athletes took part in three tests (incremental exercise test, Functional Threshold Power test, DXA screening). Testing protocol started with an initial load of 100 W and step power was increased by 50 W per every 2.5 minute until exhaustion. Individual aerobic and anaerobic threshold intensities and heart rate were determined and maximal oxygen uptake parameters were identified. Body composition was measured using dual-energy X-ray absorptiometry. Within three days after incremental exercise test all participants completed Functional Threshold Power test. The mean maximal power during 20-minutes was reduced by 5 % to define subject's Functional Threshold Power. During training period and racing heart rate and power output was measured and divided into 7 intensity zones.

Results: Aerobic and anaerobic threshold were increased during the preparatory period from 228 to 253 and from 348 to 368 watts, respectively ($p < 0.05$). There were significant differences ($p < 0.05$) when compared during training period and during racing. Relative anaerobic threshold power (W/kg) was the best single predictor of Prologue performance (r^2 = 0.797), while for the first stage race the best performance predictor was body mass (r^2 = 0.683).

Conclusions: Heart rate and power analyze yield to different patterns in training zone distribution during preparatory period and during racing. Relative anaerobic threshold power and body mass can be used to characterize the performance of a mountain biker on shorter and longer distances, respectively.

Keywords: mountain biking; ultra-distance; stage race, heart rate, power output; physiological capabilities.

1 LITERATURE REVIEW

Mountain biking (MTB) is an endurance sport but it has its specific demands on cyclist to perform at the highest level of cycling sport. There are four main disciplines in the field according to UCI rules (*Union Cycliste Internationale*) – cross-country, downhill, four cross, enduro. This study focuses on cross-country discipline: mainly cross-country stage race which is the mix of cross-country Olympic and cross-country marathon. The first one is carried out in circuits, usually 5-6 highly technical laps, with total elapsed time of approximately one and a half hours (for elite men). Marathon race however, is held on a one long loop – not so technical as cross-country Olympic, but lasts at least three hours and more.

As road cycling has its own long tours (most famous being Tour de France), mountain biking has different stage races also, with most famous being Cape Epic, held on the Republic of South Africa. Even though the pattern of movement is the same, there are considerable differences between road and mountain biking such as minimal drafting behind another rider during MTB race (Wilson et al., 2004).

1.1 Physiological demands of mountain bike performance

It has been found that mountain biking is highly versatile and demands several capabilities such as high maximal oxygen consumption (VO_{2max}) and anaerobic threshold power (Smekal et al., 2015; Novak and Dascombe, 2014; Zapico et al., 2007; Impellizzeri et al., 2005). Smekal et al. (2015) using portable spirometry, leg-power output, heart rate (HR) and blood lactate concentration, investigated the demands of mountain biking on 24 male competitive level cyclists in simulated mountain bike competition as well as laboratory condition. HR and blood lactate measures were not sufficiently sensitive to ascertain the load profiles of competition. They concluded that the best predictor of performance and useful way to design an off-road specific workout is the data originating from competitions due to the limitations of simulating the race conditions in laboratory. Other studies have come to similar conclusions (Adams, 2012; Padilla et al., 2008).

Even though it has been found (Ahrend et al., 2016; Novak and Dascombe, 2014; Impellizzeri and Marcora, 2007; Impellizzeri et al., 2005; Lee et al., 2002) that power output and VO_{2max} at anaerobic lactate threshold intensity are more relevant predictors of mountain bike performance than maximal power output and maximum oxygen uptake, those parameters may explain only about 40 % of the competition performance variance. Additionally, the body mass or power-to-body mass ratio is highly important for the mountain bike performance (Prins et al., 2007; Costa and De-Oliveira, 2005; Lee et al., 2002). However, there must be other factors – physiological and technical – which contribute to the success of a mountain biker. One aspect would be 1 and 5-minute (Ahrend et al., 2016), 3-minute (Miller and Macdermid, 2015) and 4-minute (Nimmerichter et al., 2010) mean maximal power output during a cycling test (as critical power) which has been found to be significant predictor of the performance of the mountain bikers. In contrast, even though critical power and maximal lactate steady state power are highly correlated with each other, it has been found that the latter represents the upper limit of the heavy exercise domain (Dekerle et al., 2003; Pringle and Jones, 2002). Adams (2012) in his research concluded that no single testing protocol can define an athletes' ability to perform but different tests will give athletes and coaches information about the strengths and weaknesses of the athlete and combining this information with course profile the one knows what abilities to focus on.

1.2 The use of different methods for measuring intensities during mountain bike training and racing

During mountain biking the aerobic energy system is highly stressed (Impellizzeri and Marcora, 2007), while on the climbs and while spurting significant proportion of anaerobic energy is used. Therefore, it is crucial to test and train both, aerobic (Macdermid and Stannard, 2012) and also anaerobic (Macdermid and Stannard, 2012; Inoue et al., 2011) fitness of the athlete. To be able to gain optimal training effect it is essential to monitor training intensities (Baron, 2001). Nowadays it is relatively easy to monitor both the heart rate and the power output. The latter measures the exercise intensity *per se* and former is considering also a whole-body stress (Jeukendrup and VanDiemen, 1998).

1.2.1 Intensities measured by heart rate

Heart rate monitors have been used for more than 20 years by now in everyday training. Heart rate monitor is relatively low-cost and accurate device. At the same time, it has its limitations because heart rate reacts to other outside stimuli similarly to training intensities. Those main other variables are: cardiovascular drift, hydration status, temperature (cold, heat), altitude (Achten and Jeukendrup, 2003) but also increased training load has a negative effect on heart rate (Borresen and Lambert, 2007; Neumayr et al., 2003).

Exercise intensities during an 8-day mountain bike marathon race were described in a study by Wirnitzer and Kornexl (2008). Seven MTB-amateurs completed a maximal incremental cycling test to determine four intensity zones. Mean HR during the competition was 85.4 % of maximal HR during the race or 79.2 % of laboratory determined maximum. It was found that 36 % of total race time was spent in the high and very-high intensity zones (above lactate level 4 mmol/L and more). These data indicate mountain bike marathons to be highly demanding disciplines and challenge the racers to be fit in every intensity zone.

MTB events, in contrast to the road races conduct very high intensity especially in the beginning of the race (Impellizzeri et al., 2002) and therefore, heart rate is high from the early stages of the race. Padilla et al. (2008) investigated three major 3-week long road cycling stage races (Tour de France, Giro d'Italia, and Vuelta a Espana) in terms of exercise intensity and load during uphill cycling. They divided the hills as no-category, first and second category passes and whether the hill appeared in the beginning, middle part or at the end of the stage. The study found that first and second category passes were physiologically highly demanding but if they appeared in the end section of the stage, the heart rate was significantly lower. Similar trend was found for power output. This effect is probably also seen in MTB stage races. Therefore, the more we know about the race profile, the greater the options for planning training strategies before the race.

1.2.2 Intensities measured by power output

The intensity of the MTB-race is relatively high but very variable – during the descents considerable amount of time is spent in recovery zone according to individual power output or coasting whilst the power generated during ascents is above critical power (Macdermid and Stannard, 2012). The same pattern occurred during the mountain bike stage race but the heart rate does not react similarly (Vogt et al., 2006). Because the heart rate is too slow to react adequately to the changes of variable intensities, it is advantageous to couple it up with power output measures and also cadence (Mazzoleni et al., 2016). The study of Nimmerichter et al. (2011) monitored the power output and heart rate data for 11 months in one female (VO_{2max}: 71.5 $ml \cdot kg^{-1} \cdot min^{-1}$) and ten male ($VO_{2max}$: 66.5 ± 7.1 $ml \cdot kg^{-1} \cdot min^{-1}$) MTB, road and track cyclists. They found both power output and heart rate were valid measures to assess the exercise intensity distribution of low-intensities i.e. aerobic workouts. For high-intensity intermittent workouts or races, the application of heart rate was limited, since it did not accurately reflect the instantaneous changes of power output and muscle workload. Heart rate probably underestimates the time spent at low and high intensities and overestimates the time spent in between aforementioned zones (Vogt et al., 2006). To date there is lack of data about the relationship between power output and heart rate during the ultra-endurance mountain bike races.

Heart rate limitations also occur during ultra-endurance cycling events when HR response decreases considerably due to the general cardiovascular feature of the over-all duration (Borresen and Lambert, 2007), suggesting that anaerobic threshold might occur at lower intensities than measured in laboratory (Neumayr et al., 2004).

To interpret power intensity accurately compared to cyclist performance, one must be able to assess the anaerobic threshold power of the cyclist (Smekal et al., 2015). In everyday practice, it is common to estimate athlete's current anaerobic threshold power with a 20-minute highest mean power output test, which is called Functional Threshold Power (FTP). Power output measured during 20-minute test (minus 5 %) has been found to be in an agreement with power output at the respiratory compensation point and the second lactate turn point and has acceptable accuracy to determine these markers as of anaerobic threshold power (Nimmerichter et al., 2010).

1.3 Performance assessment of mountain bikers

To achieve the highest mean power output during 20-minute test it is advisable to maintain as constant and as high power output as possible (Foster et al., 1993; Gordon, 2005). However, it has been concluded (Smekal et al., 2015), that the physiological demands of mountain bikers are high both in relations of aerobic and anaerobic capabilities. FTP test is the best predictor of steady state time trial cycling (Nimmerichter et al., 2010) but may not be in the context of mountain biking. Therefore, research (Miller et al., 2014) has validated the use of functional threshold power and intermittent power (IP) to predict cross-country mountain bike race outcome. They performed FTP test as 20-minute maximal effort (minus 5 %) and an intermittent power test of 45 seconds' work and 15 seconds' recovery or coasting. In addition, they completed simulated 30 km MTB race in the field. Both tests significantly predicted ($p < 0.001$) the race performance. Another aspect with intermittent (variable) power output (aerobic and anaerobic) to be considered is the neuromuscular fatigue which occurs on such cases (Theurel and Lepers, 2008) but highly performing mountain biker has to possess both type of abilities.

To decide how many different tests should be necessary during the preparatory phase to analyze the changes in heart rate and power threshold there has been found (Manunzio et al., 2016; Zapico et al., 2007) that one to three tests are sufficient because no changes in HR occurred during relatively short time period but threshold power change was significant ($p < 0.05$) when compared 1st and 3rd test results.

In conclusion, to better understand what are the performance predicting characteristics and what kind of power and heart rate dynamics occur during training period and racing in MTB discipline, we aimed to investigate the relationships of the physiological parameters to mountain bike marathon performance.

2 THE AIM OF THE STUDY AND PURPOSES

The general aim of the present thesis was to investigate performance predicting and characterizing markers of an ultra-distance mountain bike race.

The specific aims of the thesis were:

- To identify athletes' functional capabilities and main training characteristics during the preparatory period for the ultra-distance mountain bike stage race;
- To investigate the differences of heart rate and power output intensity zones dynamics during preparatory training period;
- To investigate the differences of heart rate and power output intensity zones dynamics during racing in ultra-distance mountain bike stage race;
- To determine parameters which would best predict the performance of an athlete on short (Prologue) and ultra-distance (Stage 1) mountain bike race.

3 METHODS

3.1 Participants

The study sample consisted of 6 highly trained male mountain bikers, with one of them being an elite level cyclist (characteristics of the subjects are listed in Table 1) who participated in an 8-days mountain bike stage race in March 2016, in the Republic of South Africa – in total 651 km and 15 100 m of vertical gain. The subjects were healthy and did not have severe medical problems during the study period nor they were taking any medicines.

The author of this study leaded the whole process as a coach and all functional tests were done according to the preparatory plan as described by the coach. The study was conducted in accordance of the Ethical Committee of the University of Tartu (232/T-12).

Table 1. Main characteristics of the subjects (n = 6) at the beginning of the study period, (mean ± standard deviation).

Age	**Height**	**Body mass**	**Percentage body fat**	**Fat free body mass**	**VO2max, relative**	**VO2max, absolute**
38.5 ± 6.5	180.8 ± 2.5	80.4 ± 8.1	16.0 ± 2.7	63.0 ± 4.8	61 ± 12	4819 ± 608
[years]	[cm]	[kg]	[%]	[kg]	[mL/kg/min]	[mL/min]

The study period lasted for 5 months and ended with Cape Epic race on 13 – 20 of March 2016. The preparatory period for racing started in the beginning of November 2015. The competition season for the subjects had ended in the end of September and after that subjects took 1 – 2 weeks of inactive break and 2 - 3 weeks of active break.

3.2 Testing protocols

During the preparatory period, all the athletes took part in the following tests (Figure 1) for three different times in October (to define the base level), January and March. The final testing in March was done 12 days before the race:

- Incremental exercise test until exhaustion

- Functional Threshold Power test
- DXA screening

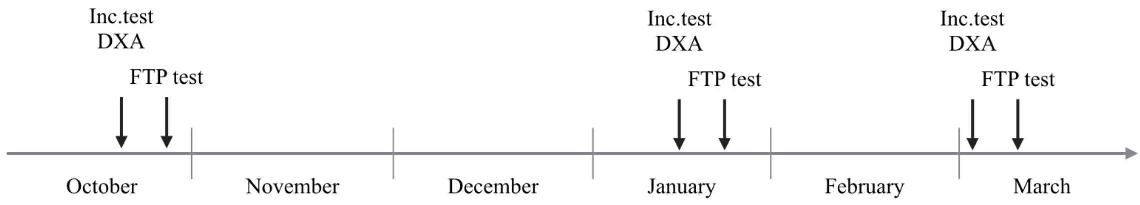

Figure 1. The timeline and the tests of current study.

Before each testing athletes were advised to avoid strenuous training 24 hours before testing and were advised to keep their energy and fluid levels high for the testing day. They did not consume tobacco, alcohol nor caffeinated drinks during the testing day.

3.2.1 Incremental exercise

Three times (in October 2015, in January and March 2016) athletes had to complete incremental exercise until exhaustion on a Cyclus 2 ergometer (Avantronic, Leipzig, Germany) using their own road racing bicycles (Figure 2). Respiratory gas exchange variables were measured throughout the tests using a breath-by-breath mode with data being stored in 10-s intervals. During tests, subjects breathed through a facemask. Oxygen uptake, carbon dioxide output, minute ventilation, breathing rate were continuously measured using a portable open-air spirometry system (MetaMax 3B, Cortex, Leipzig, Germany). The analyzer was calibrated with Cortex calibration gases of known concentration before each test and a 3-L standard syringe was used to calibrate the turbine volume transducer (Hans Rudolph, Kansas City, MO) according to the manufacturer’s guidelines. All data were calculated by means of computer analysis using standard software (MetaMax–Analysis 3.21, Cortex, Leipzig, Germany). To calculate anaerobic threshold the second ventilatory turnpoint concept, that occurs at about 90% of maximal intensity, was used (Seiler and Kjerland, 2006).

Testing protocol started with an initial load of 100 W and step power was increased by 50 W per every 2.5 minute until voluntary exhaustion or when the subjects could not maintain pedaling frequency above 60 rpm.

Figure 2. Incremental exercise test on subject's own bike. (With a permission of the subject. K. Reinpõld)

3.2.2 Functional Threshold Power testing

Within three days after incremental exercise all participants completed Functional Threshold Power test on Cyclus 2 ergometer using subjects' own road bikes. The aim of this testing was to maintain as high mean maximal power throughout 20 minutes as possible (Nimmerichter et al., 2010). The power output was self-determined by every individual. Before the test started, during warm-up, all athletes did 5-minute all-out effort to minimize anaerobic capabilities. Heart rate and power output were continuously measured during the test and stored for later analysis. Subjects were aware of all the characteristics (time, power output, heart rate) during the test. The mean maximal power during 20-minute was reduced by 5 % to define subject's Functional Threshold Power. FTP Aerobic Threshold power (FTP AeT) was calculated as 75 % of FTP (Allen and Coggan, 2010).

3.2.3 DXA screening

During every incremental exercise testing day, the subjects underwent dual-energy x-ray absorptiometry (DXA) scan, which is considered the most accurate approximate method for estimating body fat, lean mass and bone mineral density (Wang et al., 2011). Body composition (fat mass and lean body mass) were measured using dual-energy X-ray absorptiometry (DXA; DPX-IQ densitometer, Hologic Discovery, Marlborough, MA, USA) equipped with proprietary software (version 3.6). Subjects were scanned in a supine position wearing light clothing. The medium scan mode and the standard subject positioning was used for total body measurements, which were analyzed using the extended analysis option. The precision of measurement expressed as coefficient of variation was < 2 % for all bone mineral and body composition measurements for the apparatus.

3.3 Training schedule and training diaries

All the athletes had several years of mountain biking experiences but only few had been working with personal coach before this project. Individual day-by-day training-plan was prescribed to athletes taking into account their previous experiences and level of performance. The main purpose was to achieve the highest possible athletic performance for every individual. Training-plan was adjusted during the process daily if necessary.

General training plan (Figure 3) followed the concept of 3 weeks increasing training volume and 1 week of recovery and if necessary, testing was planned at the end of the recovery week. Due to the climatic conditions trainings throughout November and December were largely done on a stationary bike stand on subjects' personal bike and the main aim was to increase anaerobic threshold power. In January, the subjects participated in a cycling camp in warm climate to accumulate long hours in cycling, simulating partially the stage race, therefore the intensity was not completely low. In February, some high VO_{2max}, anaerobic and neuromuscular power intervals were included to training plan, but not exceeding more than 1 – 2 % of training volume.

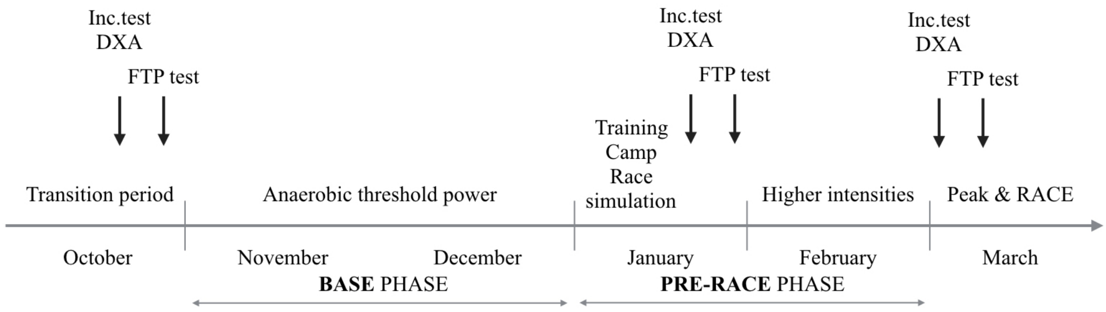

Figure 3. The structure of the general training plan and racing

During each training session subjects' bikes were equipped with portable power meters (In-Power, Rotor Componentes Tecnológicos, S.L., Madrid, Spain) and Garmin heart rate belts. Using ANT+ protocol all the data were sent to the cloud based Garmin training diary (Garmin, USA) and transferred to TrainingPeaks software (Boulder, CO, USA) afterwards and for later analysis.

3.3.1 The use of power zones in prescribing training intensities

Training intensities were prescribed preferably according to power zones. In practice the power zones were used as described earlier (Allen and Coggan, 2010):

- Z1 – 56 % or less of FTP
- Z2 – 56 % - 76 % of FTP – aerobic threshold
- Z3 – 76 % - 88 % of FTP
- Z4 – 88 % - 95 % of FTP
- Z5 – 95 % - 105 % of FTP – anaerobic threshold
- Z6 – 105 % - 120 % of FTP
- Z7 – 120 % or more of FTP

3.3.2 The use of heart rate zones in prescribing training intensities

If there was a mechanical (1-2 incidents) or data transfer problem (1-2 % of total data) using portable power meters then training intensities were used according to Friel (2012) based on the incremental test results as follows:

- Z1 – 82 % or less of AnT HR*
- Z2 – 82 % - 89 % of AnT HR
- Z3 – 89 % - 94 % of AnT HR
- Z4 – 94 % - 100 % of AnT HR
- Z5 – 100 % - 103 % of AnT HR
- Z6 – 103 % - 106 % of AnT HR
- Z7 – 106 % or more of AnT HR

The 100 % level is considered as anaerobic threshold level.

3.4 Racing

Cape Epic 8-day stage race consisted of first day prologue and 7 stages (race characteristics are shown in Table 2). Athletes were divided to pairs by their performance capabilities and had to ride together at all times with the maximal time cap in any point of the race not exceeding two minutes. During each stage athletes' bikes were equipped with portable power meters and heart rate chest belts. Using ANT+ protocol all the data was sent to the cloud based Garmin training diary (Garmin, USA).

All data from trainings and three stages of the race were used to conduct statistical analysis – Prologue, Stage 1 and Stage 5. First day prologue was maximal effort (time 90 ± 13 min) and the result would represent the highest performance capabilities of the athlete. Stage 1 and Stage 5 were similar but one occurred in the first part of the stage race week and latter one in the last third part to represent the fatigue accumulation. Unfortunately, two riders from different teams had to quit the race due to severe crashes during the race, therefore no later stages were used in analysis.

Table 2. Characteristics of the course profile of Cape Epic 2016

	UNIT	Pro-logue	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	MEAN ± SD
Temperature	[C]	23	28	26	31	24	24	24	23	25 ± 3
Humidity	[%]	61	58	65	61	76	78	64	58	65 ± 8
Stage distance	[km]	26	108	93	104	75	93	69	86	82 ± 26
Stage climbing	[m]	700	2300	2200	2150	1850	2500	2100	1200	1875 ± 614
Stage time	[min]	90.7	391.3	381.0	388.7	253.3	336.7	283.3	252.0	297.1 ± 101.9
Stage speed	[km/h]	17.5	17.0	15.2	16.6	18.2	17.0	15.3	21.0	17.2 ± 1.8

3.5 Statistical analysis

To statistically analyze the data Microsoft Excel Data Analyst (Microsoft, USA) and IBM SPSS (IBM, Armonk, NY, USA) software were used.

Means and standard deviations of the variables were calculated. Power and heart rate data from training and racing was saved to the head unit from there on the data was transferred to TrainingPeaks', WKO4 software (Boulder, CO, USA) and Golden Cheetah (open-source program) to analyze heart rate and power zones data and to divide raw data to specific training intensity zones. A paired t-test was used to calculate differences in variables across time. Independent t-test was used for comparing different power and heart rate zone data. To predict performance on Prologue and the first Stage of the race, a linear mixed model with time effect was conducted using physiological parameters as independent variables, race time as dependent variable. We used only first two stages for linear regression analysis, because the accumulation of the fatigue from previous days would have too much impact of the performance. The statistical significance was set to $p < 0.05$ for all the analysis.

4 RESULTS

4.1 Training volume, incremental exercise test and Functional Threshold Power testing

From November 2015 until the race in March 13, 2016 the subjects trained according to the training plan, incorporating bike and gym workouts as presented in Table 3. Even though cyclists' training volume is usually characterized by total distance, in current case it was not informative because riding on a stationary bike stand the speed and therefore distance were not either measured or were inadequate compared to riding outside. However, total distance was approximately 3500 – 4500 km.

Table 3. Characteristics of the main training parameters during the preparatory period (mean ± standard deviation)

Total time (training)	**Total time (cycling)**	**Total time (gym)**
225 ± 21	193 ± 28	33 ± 22
[hours]	[hours]	[hours]

Total cycling time spent in different heart rate and power zones are presented in Figure 4. Lower (Z1, Z2) intensities were significantly ($p < 0.05$) overestimated by heart rate and higher intensities were underestimated by heart rate ($p < 0.05$) when compared with power intensity zones.

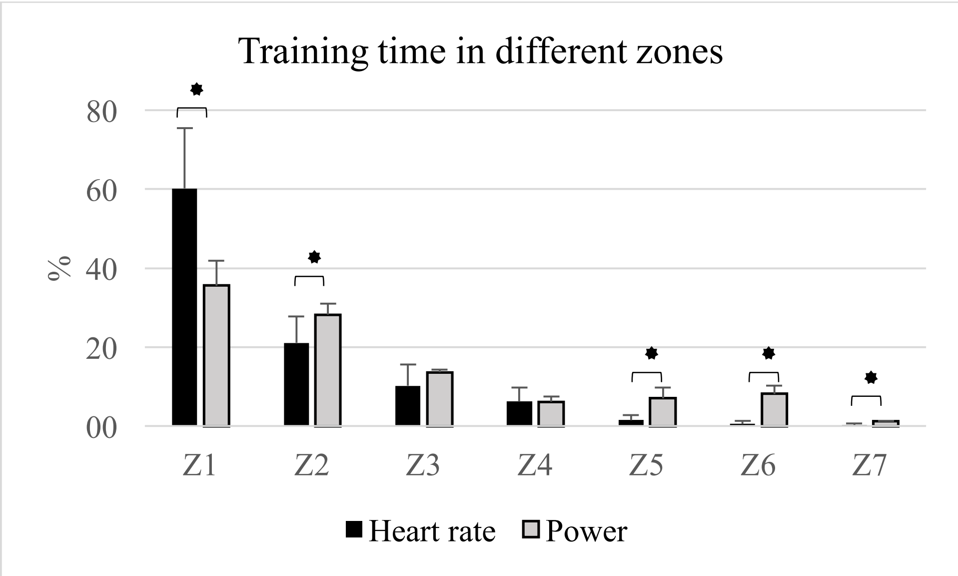

Figure 4. Total cycling time in different heart rate and power zones during the preparatory period. * $p < 0.05$

Different physiological parameters at aerobic and anaerobic threshold and at VO_{2max} intensity throughout the study period are presented in Table 4. Significant difference ($p < 0.05$) was found between October's and January's FTP AnT power and incremental exercise AnT power. In every aspect except AeT (a trend to increase was seen ($p = 0.06$)), the difference between October and March parameters was significant ($p < 0.05$).

Table 4.Values for (relative) FTP, anaerobic and aerobic threshold powers and VO_{2max}. Values are means ± standard deviations.

		October testing	**January testing**	**March testing**
	UNIT	Mean ± SD	Mean ± SD	Mean ± SD
FTP AeT, power	[W]	224 ± 30[3]	221 ± 26	251 ± 44[1]
AeT, power	[W]	228 ± 27	240 ± 15	253 ± 16
FTP AeT	[W/kg]	2,83 ± 0,59[3]	2,77 ± 0,56	3,18 ± 0,80[1]
AeT	[W/kg]	2,88 ± 0,56[3]	3,00 ± 0,42	3,18 ± 0,39[1]
FTP AnT, power	[W]	298 ± 40[*,3]	295 ± 35[*,1]	335 ± 59[1, 2]
AnT, power	[W]	348 ± 32[3]	357 ± 24	368 ± 25[1]
FTP AnT	[W/kg]	3,76 ± 0,78[3]	3,70 ± 0,74	4,24 ± 1,07[1]
AnT	[W/kg]	4,39 ± 0,72[3]	4,47 ± 0,65	4,64 ± 0,69[1]

VO_{2max}	[mL/kg/min]	63 ± 14[3]	59 ± 11	60 ± 11[1]
VO_{2max}	[mL/min]	4947 ± 761[3]	4714 ± 548	4797 ± 515[1]

Note: * - $p < 0.05$ significant difference from the corresponding type and time testing; [1] – $p < 0.05$ significant difference from October; [2] – $p < 0.05$ significant difference from January; [3] – $p < 0.05$ significant difference from March. FTP – Functional Threshold Power; AeT – aerobic threshold calculated at incremental exercise test; AnT – anaerobic threshold calculated at incremental exercise test; VO_{2max} – maximal oxygen consumption.

4.2 The difference of heart rate and power output during racing

Significant ($p < 0.05$) difference between the time spent in different heart rate zones in different Stages (Figure 5) was found between every stage in Z1 and Z4. In Zone 2 the only difference was found between the prologue and Stage 1 ($p < 0.05$). No more significant differences were found in heart rate distribution in different zones.

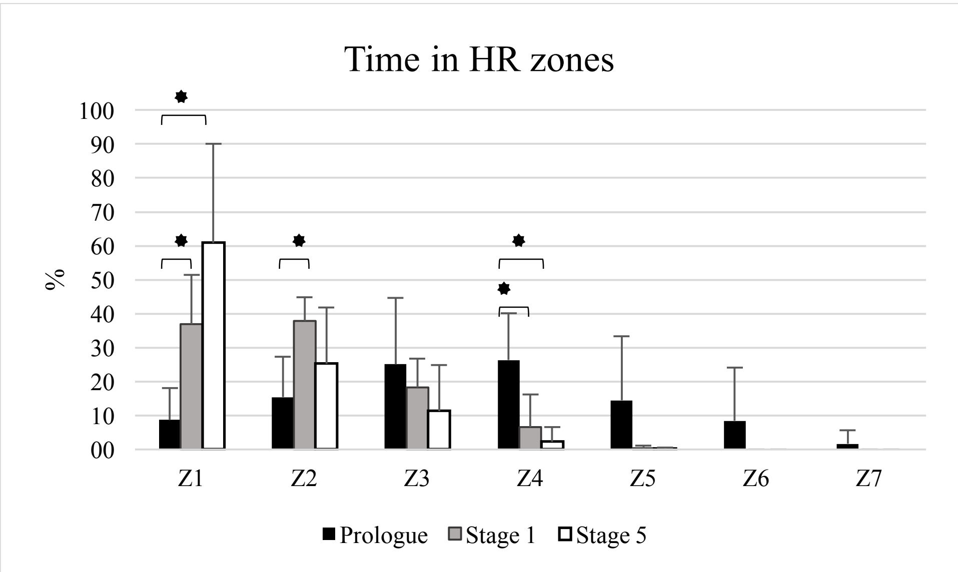

Figure 5. Time in different heart rate zones during prologue, stage 1 and stage 5. * $p < 0.05$

The same analysis for power zones (Figure 6) indicated that all intensity zones were with different power zone distribution ($p < 0.05$), except the difference between the Z1 for prologue and Stage 1 and no differences between Z4 for all three stages ($p > 0.05$).

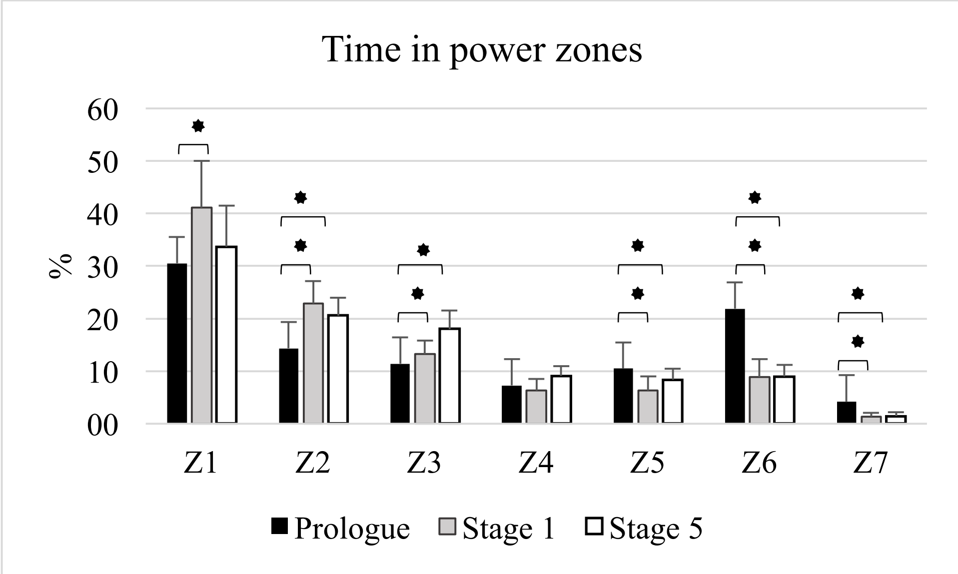

Figure 6. Time in different power zones during prologue, Stage 1 and Stage 5. * $p < 0.05$

If comparing heart rate and power intensity zones there were significant ($p < 0.05$) differences between the heart rate and the power in Z1 and Z4 for Prologue (Figure 7). During Stage 1 there were significant ($p < 0.05$) differences between the heart rate and the power intensities in Z2, Z5, Z6 and Z7 (Figure 8). During Stage 5 there were significant ($p < 0.05$) difference between the heart rate and the power output data in Z4, Z5, Z6 and Z7 (Figure 9).

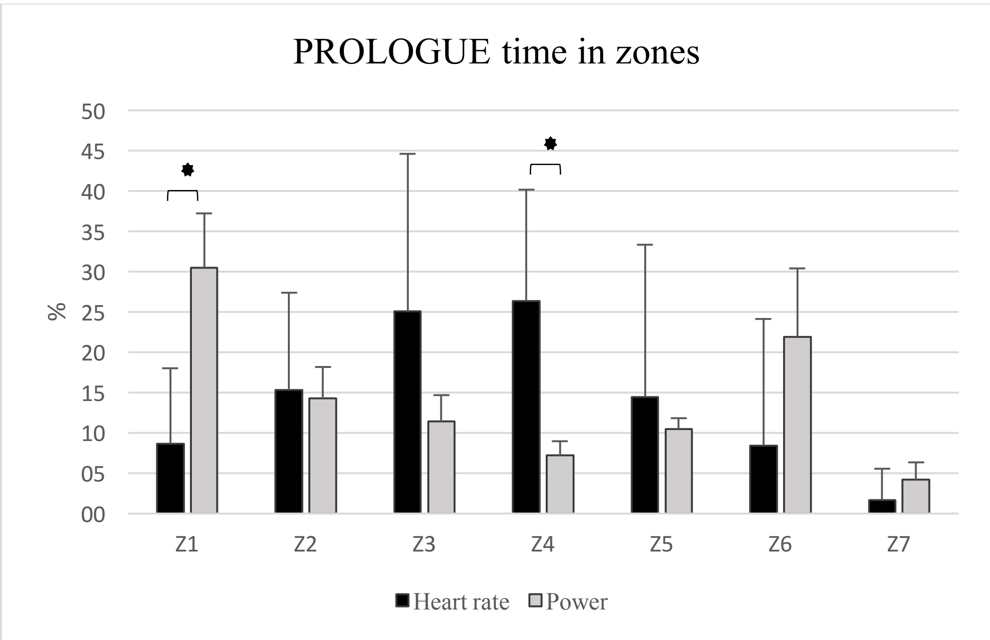

Figure 7. Prologue, time spent in heart rate and power zones

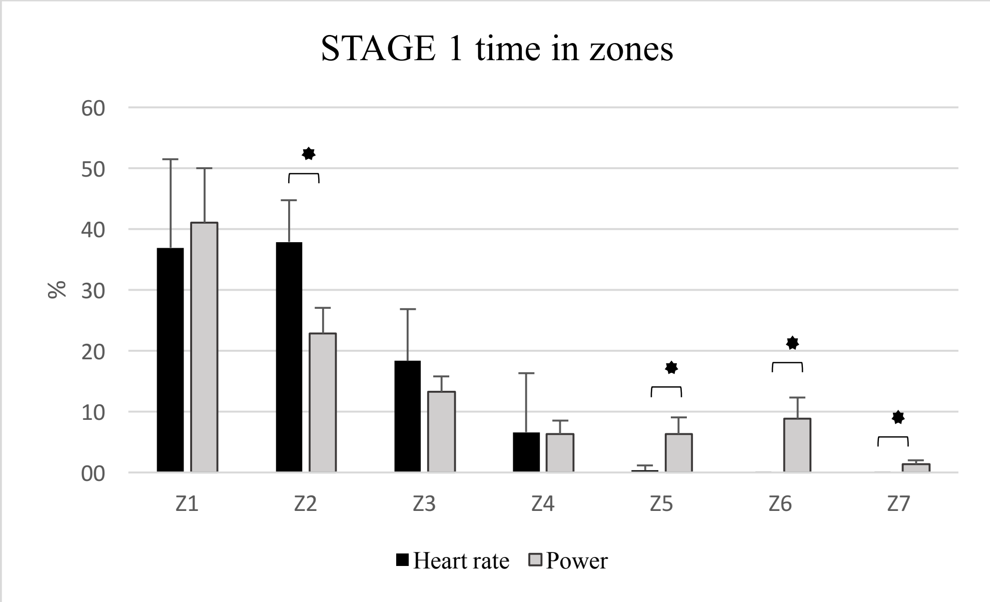

Figure 8. Stage 1, time spent in heart rate and power zones

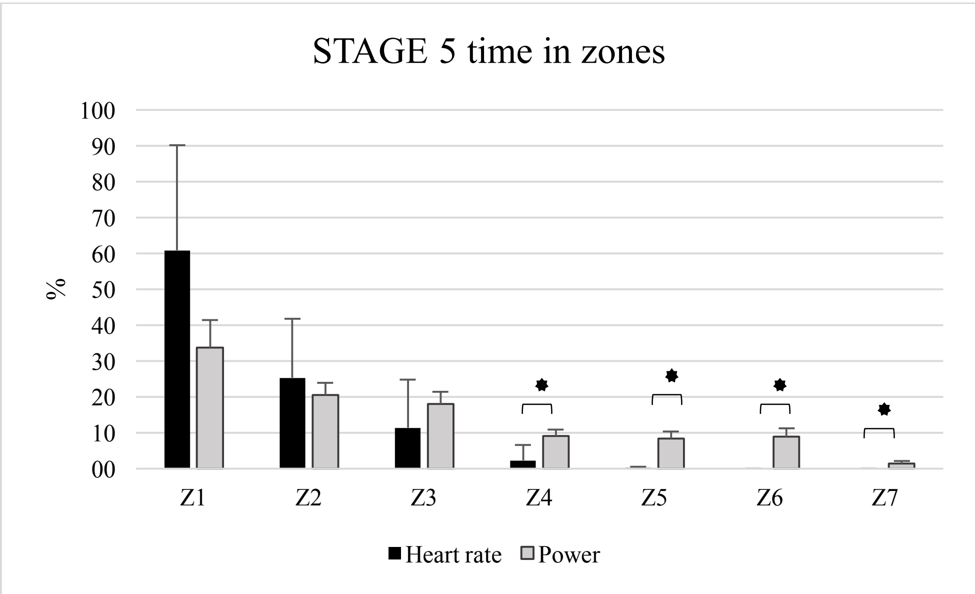

Figure 9. Stage 5, time spent in heart rate and power zones

Linear regression analysis indicated that relative anaerobic threshold power (W/kg) was the best single predictor of Prologue performance (r^2 = 0.797; b= -16.2 ± 2.3; $p < 0.05$), while for the first stage race the best performance predictor was body mass (r^2 = 0.683; b = 7.4 ± 0.8; $p < 0.05$).

5 DISCUSSION

The current study investigated 6 athletes' five months long training period and racing data to understand what parameters influence the ability to race in one of the world's hardest MTB 8-day stage race Cape Epic. This study found the best single predictor of Prologue performance was relative anaerobic threshold power (W/kg), while for the first Stage race the best performance predictor was body mass. Unfortunately, after severe crashes which eliminated two athletes from the competition, we did not perform any further analysis for the final stages due to limited number of finishers.

In sport, it is more and more essential to understand what kind of requirements different competitions have on the athlete to be able to prescribe the right training characteristics and intensities. At the same time, there must be an understanding how to test and measure athletes' functional capabilities that predict racing performance, because those target abilities should also be under focused during the training process.

During the training period, all the athletes' aerobic and anaerobic thresholds (except absolute aerobic threshold power) levels were elevated from October to March indicating a positive shift of performance. At the same time, maximal oxygen consumption slightly decreased which has been shown earlier for junior cyclists (Zapico et al., 2007) if approaching for competition period. However, in the latter study this effect was rather considered as a negative consequence as the junior cyclists were entering to the competition season not for a single race, while in the current study the age of the subjects also limits increases of maximal oxygen consumption.

We investigated the relationship of HR and power output during training and racing. The HR and power training data were stored into 7 different heart rate and power output zones. Nimmerichter et al. (2011) found when comparing the time spent either in HR or power zones during total cycling training time, heart rate could underestimate the time spent in higher zones. This was also the case in our study, with a clear underestimation of higher intensity zones by heart rate. In addition, as of Vogt et al. (2006) in his study, we also found that heart rate overestimated the recovery zone (Z1) and underestimated endurance zone (Z2). This may be explained by the fact that aerobic threshold was calculated mathematically and was not individualized in the current study. This finding is important in terms of practice, as further studies are needed to investigate, whether individual determination of cycling specific zones could lead to better match between heart rate and power in endurance zone (Wolpern et al., 2015).

During Prologue, it occurred that HR largely underestimated the time spent in Z1 but in zone 4 HR overestimated the effort. One explanation for this may be the athlete's heart rate is not able to recover fast enough during descents and in other terrains which does not require high power output. Visual representation of heart rate and power output in zones during Prologue revealed that the area under curve being the converse version of the characteristics. This probably refers to the conditions of riders being forced to ride in pairs and one of the team member being slightly stronger than the other, hence the high variability within the group.

If monitoring heart rate and power output in different zones during Stage 1 and Stage 5 there were no significant differences when comparing data between stages. However, heart rate limitations do occur during Stage 1 and 5 when HR response decreases considerably due to the general cardiovascular feature of the over-all duration (Borresen and Lambert, 2007), suggesting that the heart rate's anaerobic threshold intensity might be lower than measured in laboratory (Neumayr et al., 2004). In contrast, this may also occur because of the nervous system reactions to other stimulus (Achten and Jeukendrup, 2003) as hot weather, dehydration etc., which were also cases in our study as for first 5 stages the average temperature was 26 ± 3 degrees. However, power output remains largely unchanged which would indicate that even though HR does not respond to the changes of intensity when accumulated fatigue is severe, the muscles ability to generate power persist.

Until mobile power meters had not been introduced to wider audience, the only way to measure athletes' functional capabilities was laboratory testing. It remains one of the most accurate method for that purpose, as the data of the current study supports for the anaerobic threshold intensity relative to body mass to be the best predictor of relatively short MTB distance (Prologue) performance i.e. power to body mass. Similar results have been found by Lee et al. (2002), who investigated mountain and road bikers physiological characteristics and found that high power-to-body mass characteristics are important for success in mountain biking. However, laboratory testing is in most cases rather expensive and time consuming, and therefore it is hardly possible to monitor key elements in laboratory throughout the whole season. That is why coaches are looking for the ways to predict performance in field-testing or interpreting competition data.

For that purpose, Functional Threshold Power test was used to identify athletes' current performance and to describe their training intensities. Previous studies (Miller et al., 2014;

Nimmerichter et al., 2010) have revealed this method being a good indicator for anaerobic threshold power. However, in our study, there were no significant association between FTP and racing performance. It might be explained by the fact that FTP test was influenced by the ability to ride steadily on maximal effort for 20-minutes. If athlete starts the test at too high intensity, the power drop is considerable and the result might not be accurate. Moreover – there are individuals who are poor at exerting themselves outside of the race or unable to hold constant high power on stationary bike stand. Even though the result of FTP test is considered roughly equal to maximal mean power that athlete can maintain for an hour, this concept has indicated still high individual variability, varying from 35 – 60 minutes. Although FTP test, as simple field test to determine anaerobic threshold was considered to be a good predictor for MTB performance (Miller et al., 2014), in our study the laboratory measured anaerobic threshold was selected by regression model as the best parameter to describe 90 minute MTB performance ($r^2 = 0.797$; $p < 0.05$) (Prologue). The current study had also small number of subjects which would result in higher variability of the test results and therefore, the observed differences between FTP test and race performance ability.

The only characteristic which correlated with ultra-distance mountain biking race performance (measured as Stage 1) was body mass. As this race contained 15 100 meters of vertical gain, lasted long hours and days the burden of extra body mass becomes more and more important – power to body mass ratio and relative maximal oxygen consumption are both dependent on athlete's body mass and therefore performance ability. Somewhat similar results have been found for marathon runners, were body fat, a parameter that is significantly related to body mass, was the best predictor for marathon performance (Knechtle et al., 2014). While our study found correlation to body mass, not body fat, might be explained by the fact that body mass is supported by the bike while that is not the case in running, therefore the importance of low fat mass in overall body mass is not so important. Those results indicate that in such a long and hard races the performance may be predicted by relatively simple measure as body mass. However, there must be a previous assumption that the subjects have relatively high endurance performance. Athletes with similar endurance performance usually have different physiological parameters and those that are somewhat limited, might be compensated by other factors. However, if performance is related to high absolute energy consumption, it is considerably more efficient to transport lower body mass and which finally corresponds to higher economy, that has indeed characterized as one of the most important parameters of long endurance performances (Knechtle et al., 2014) as it makes an accumulated effect on economy.

The limitation of our study is the small cohort and high individual variability, that also have influence on the conclusions that were made. Furthermore, the nature of the Cape Epic includes racing in pairs, which might result in slightly lower effort for the stronger rider in the pair. However, the pairs were made based on the rider's performance in order to make the pairs as equal as possible.

This study provides also practical knowledge for coaches and athletes for understanding how heart rate and power output relate with each other and what might be the consequences of the feedback from training or racing if relying only one parameter. Even though heart rate may decrease in time with accumulated fatigue, it does not necessarily indicate that the muscles are not able to produce higher power any more. If preparing for ultra-distance race athletes should take into consideration that beside sport's performance the other variables such as body mass are contributing to the final results as well.

6 CONCLUSIONS

The following conclusions were made based on the current study:

- Different physiological characteristics like aerobic and anaerobic threshold intensities were increased throughout the training period, while maximal oxygen consumption decreased.

- During preparatory period heart rate underestimated the total time spent in higher intensity zones and overestimated the time spent in lower intensity zones compared with power intensity zones, while

- During Prologue heart rate underestimated, the time spent in recovery zone and overestimated the time spent in anaerobic threshold intensity zone.

- During ultra-distance Stages 1 and 5 heart rate response to intensity shifted towards lower intensity zones, while power output remained largely unchanged indicating that even with accumulated fatigue, the muscles' ability to generate power persist.

- Relative anaerobic threshold power (W/kg) was the best single predictor of Prologue performance, while for the first Stage race the best performance predictor was body mass.

REFRENCES

Achten, J., and Jeukendrup, A.E. (2003). Heart rate monitoring: Applications and limitations. Sport. Med. *33*, 517–538.

Adams, J. (2012). Laboratory and Field-based correlates of Off-Road Cycling Performance. Thesis. Boise: Boise State University.

Ahrend, M., Schneeweiss, P., Theobald, U., and Niess, A.M. (2016). Comparison of laboratory parameters of a mountain bike specific performance test and a simulated race performance in the field. J. Sci. Cycl. *5*, 3–9.

Allen, H., and Coggan, A. (2010). Training and racing with a power meter. 2nd ed. Boulder: VeloPress.

Baron, R. (2001). Aerobic and anaerobic power characteristics of off-road cyclists. Med. Sci. Sports Exerc. *33*, 1387–1393.

Borresen, J., and Lambert, M.I. (2007). Changes in heart rate recovery in response to acute changes in training load. Eur. J. Appl. Physiol. *101*, 503–511.

Costa, V., and De-Oliveira, F. (2005). Physiological variables to predict performance in cross-country mountain bike races. J. Exerc. Physiol. Online *11*, 14–24.

Dekerle, J., Baron, B., Dupont, L., Vanvelcenaher, J., and Pelayo, P. (2003). Maximal lactate steady state, respiratory compensation threshold and critical power. Eur. J. Appl. Physiol. *89*, 281–288.

Foster, C., Snyder, a C., Thompson, N.N., Green, M. a, Foley, M., and Schrager, M. (1993). Effect of pacing strategy on cycle time trial performance. Med. Sci. Sports Exerc. *25*, 383–388.

Friel, J. (2012). The power meter handbook : a user’s guide for cyclists and triathletes Boulder: VeloPress.

Golden Cheetah http://www.goldencheetah.org/ 17.01.2017

Gordon, S. (2005). Optimising distribution of power during a cycling time trial. Sport. Eng. *8*, 81–90.

Impellizzeri, F., and Marcora, S. (2007). The Physiology of Mountain Biking. Sport. Med. *37*, 59–71.

Impellizzeri, F., Sassi, A., Rodriguez-Alonso, M., Mognoni, P., and Marcira, S. (2002). Exercise intensity during off-road cycling competitions. Med. Sci. Sport. Exerc. *34*, 1808–1813.

Impellizzeri, F., Marcora, M., Rampinini, E., Mognoni, P., and Sassi, A. (2005). Correlations between physiological variables and performance in high level cross country off road cyclists. Br. J. Sports Med. *39*, 747–751.

Inoue, A., Sá Filho, A.S., Mello, F.C.M., and Santos, T.M. (2011). Relationship Between Anaerobic Cycling Tests and Mountain Bike Cross-Country Performance. J. Strength Cond. Res. *26*, 1589–1593.

Jeukendrup, A., and VanDiemen, A. (1998). Heart rate monitoring during training and competition in cyclists. J. Sports Sci. *16*, 91–99.

Knechtle, B., Barandun, U., Knechtle, P., Zingg, M.A., Rosemann, T., and Rüst, C.A. (2014). Prediction of half-marathon race time in recreational female and male runners. Springerplus *3*, 248.

Lee, H., Martin, D.T., Anson, J.M., Grundy, D., and Hahn, A.G. (2002). Physiological characteristics of successful mountain bikers and professional road cyclists. J. Sports Sci. *20*, 1001–1008.

Macdermid, P.W., and Stannard, S. (2012). Mechanical work and physiological responses to simulated cross country mountain bike racing. J. Sports Sci. *30*, 1491–1501.

Manunzio, C., Mester, J., Kaiser, W., and Wahl, P. (2016). Training Intensity Distribution and Changes in Performance and Physiology of a 2nd Place Finisher Team of the Race across America Over a 6 Month Preparation Period. Front. Physiol. *7*, 1–12.

Mazzoleni, M.J., Battaglini, C.L., Martin, K.J., Coffman, E.M., and Mann, B.P. (2016). Modeling and predicting heart rate dynamics across a broad range of transient exercise intensities during cycling. Sport. Eng. *19*, 117–127.

Miller, M.C., and Macdermid, P.W. (2015). Predictive Validity of Critical Power, The Onset of Blood Lactate and Anaerobic Capacity for Cross-Country Mountain Bike Race Performance. Sport. Exerc. Med. Open J. *1*, 105–110.

Miller, M.C., Moir, G.L., and Stannard, S.R. (2014). Validity of using functional threshold power and intermittent power to predict cross- country mountain bike race outcome. J. Sci. Cycl. *3*, 16–20.

Neumayr, G., Pfister, R., Mitterbauer, G., Gaenzer, H., Sturm, W., and Hoertnagl, H. (2003). Heart rate response to ultraendurance cycling. Br. J. Sports Med. *37*, 89–90.

Neumayr, G., Pfister, R., Mitterbauer, G., Maurer, A., and Hoertnagl, H. (2004). Effect of ultramarathon cycling on the heart rate in elite cyclists. Br. J. Sports Med. *38*, 55–59.

Nimmerichter, A., Williams, C., Bachl, N., Eston, R., Sciences, H., Kingdom, U., and Kingdom, U. (2010). Evaluation of a Field Test to Assess Performance in Elite Cyclists. Int J Sport. Med *31*, 160–166.

Nimmerichter, A., Eston, R., Bachl, N., and Williams, C. (2011). Longitudinal monitoring of power output and heart rate profiles in elite cyclists. J. Sports Sci. *29*, 831–840.

Novak, A.R., and Dascombe, B.J. (2014). Physiological and performance characteristics of road, mountain bike and BMX cyclists. J. Sci. Cycl. *3*, 9–16.

Padilla, S., Mujika, I., Santisteban, J., Impellizzeri, F.M., and Goiriena, J.J. (2008). Exercise intensity and load during uphill cycling in professional 3-week races. Eur. J. Appl. Physiol. *102*, 431–438.

Pringle, J.S.M., and Jones, A.M. (2002). Maximal lactate steady state, critical power and EMG during cycling. Eur. J. Appl. Physiol. *88*, 214–226.

Prins, L., Terblanche, E., and Myburgh, K.H. (2007). Field and laboratory correlates of performance in competitive cross-country mountain bikers. J. Sports Sci. *25*, 927–935.

Seiler, K.S., and Kjerland, G.Ø. (2006). Quantifying training intensity distribution in elite endurance athletes: Is there evidence for an “optimal” distribution? Scand. J. Med. Sci. Sport. *16*, 49–56.

Smekal, G., von Duvillard SP, Hörmandinger M, Moll R, Heller M, Pokan R, Bacharach DW, LeMura LM, and P, A. (2015). Physiological Demands of Simulated Off-Road Cycling Competition. J Sport. Sci Med *14*, 799–810.

TrainingPeaks, WKO4 http://www.trainingpeaks.com/wko4.html 17.01.2017

Theurel, J., and Lepers, R. (2008). Neuromuscular fatigue is greater following highly variable versus constant intensity endurance cycling. Eur. J. Appl. Physiol. *103*, 461–468.

UCI, Union Cycliste Internationale. Part 4 Mountain Bike. http://www.uci.ch/mm/Document/News/Rulesandregulation/17/29/73/4MTB-E-1.01.2017_English.pdf 17.01.2017

Vogt, S., Heinrich, L., Schumacher, Y.O., Blum, A., Roecker, K., Dickhuth, H.H., and Schmid, A. (2006). Power output during stage racing in professional road cycling. Med. Sci. Sports Exerc. *38*, 147–151.

Wang, Z., Heymsfield, S.B., Chen, Z., Zhu, S., and Pierson, R.N. (2011). Estimation of percentage body fat by dual-energy x-ray absorptiometry: evaluation by in vivo human elemental composition. Phys. Med. Biol. *55*, 2619–2635.

Wilson, D.G., Papadopoulos, J., and Whitt, F.R. (2004). Bicycling science. 3rd ed. Massachussets: MIT Press.

Wirnitzer, K.C., and Kornexl, E. (2008). Exercise intensity during an 8-day mountain bike marathon race. Eur. J. Appl. Physiol. *104*, 999–1005.

Wolpern, A.E., Ciulla, F., Janot, J.M., and Dalleck, L.C. (2015). Is a threshold-based model a superior method to the relative percent concept for establishing individual exercise intensity? a randomized controlled trial. BMC Sports Sci. Med. Rehabil. *7*, 1–9.

Zapico, A.G., Calderon, F.J., Benito, P.J., Gonzales, C.B., Parisi, A., Pigozzi, F., and Di Salvo, V. (2007). With Training Load in Elite Male Road Cyclists : a Longitudinal Study. J. Sports Med. Phys. Fitness *47*, 191–196.

SUMMARY IN ESTONIAN

Ultrapika maastikurattamaratoni tulemust ennustavad ja iseloomustavad näitajad.

Sissejuhatus ja töö eesmärk: Kuigi maastikurattasõit on eelkõige vastupidavusala, seab see kõrged nõudmised sportlase organismile lisaks aeroobsetele, ka anaeroobsete protsesside võimekusele. Optimaalse treeningkoormuse määramise eelduseks on intensiivsuste defineerimine nii südamelöögisageduse (SLS), kui võimsuse järgi. Kui SLS on muuhulgas mõjutatud ka erinevatest välistest stiimulitest, samal ajal reageerides suhteliselt aeglaselt väga järskudele treeningintensiivsuste muutustele, siis võimsuse kõikumine väga lühikeses ajahetkes on ülimalt kõrge. Kuigi intensiivsustsoonide määramine laboratoorsete testide andmete põhjal on laialt levinud ja adekvaatne, vajavad treenerid muutuste hindamiseks ka võimalust viia teste läbi laboriväliselt, efektiivselt ja madala kuluga. Seega, oli antud töö eesmärgiks, uurida millised näitajad ennustavad võistlusvõimekust kõige paremini ja vaadelda SLS- ja võimsustsoonide erinevusi nii treeningperioodil, kui võistlusel.

Meetodid: Uuringus osales 6 hästi treenitud meessoost maastikuratturit (vanus 38.5 ± 6.5 aastat). Uuring kestis 6 kuud ja lõppes 8-etapilise maastikuratta võistlusega. Ettevalmistusperioodil läbisid sportlased kolmel korral koormustesti (alates 100 W, sammuga 25 W 2,5 minuti tagant), funktsionaalse võimsuse testi (FTP test) ja DXA skriiningu. Gaasianalüsaatori abiga määrati iga sportlase individuaalsed aeroobsed (AeL), anaeroobsed (AnL) SLS ja võimsuse läved ning maksimaalse hapnikutarbimisvõime (VO_{2max}) parameetrid. Keha kompositsioon mõõdeti DXA aparatuuriga. Kolme päeva jooksul peale eelpool kirjeldatud test, sooritasid sportlased FTP testi, püüdes hoida 20 minuti jooksul maksimaalselt kõrget keskmist võimsust. Lahutades saadud tulemusest 5 %, saadi funktsionaalne läve võimsus, mille põhjal arvutati individuaalsed võimsustsoonid, mida kasutati treeningintensiivsuste määramiseks. SLS-tsoonid saadi koormustestil määratud anaeroobse läve SLS järgi. Treeningperioodil ja võistlusel (proloog, etapp 1 ja etapp 5) mõõdeti nii SLS, kui võimsusandmeid ja analüüsiti neid statistiliselt.

Tulemused ja järeldused:

- Erinevad füsioloogilised parameetrite näitajad nagu aeroobne ja anaesroobne lävi paranesid treeningperioodi lõikes, välja arvatud maksimaalne hapniku tarbimise võime, mis langes.

- SLS alahindas kõrgetes intensiivsustsoonides veedetud koguaeg ning ülehindas madalates tsoonides veedetud aega ettevalmistusperioodil võrreldes võimsustsoonidega, samal ajal, kui

- Võistluse proloogil SLS alahindas taastavas tsoonis veedetud koguaega, samas ülehindas aega, mis veedeti anaeroobse läve intensiivsuse tsoonis võimsuse järgi.

- SLS reaktsioonid intensiivsusele jäid madalamatesse tsoonidesse ülipikkadel distantsidel (Etapp 1 ja 5), samal ajal võimsuse puhul sarnast tendetsi ei olnud, mis osundab sellele, et ka väsimuse kuhjudes ja madala SLS korral, säilitab lihas võime kõrget võimsust genereerida.

- Parimaks proloogi võistlusvõimekuse ennustajaks oli suhteline anaeroobse läve võimsus (W/kg), samal ajal kui esimese ultrapika etapi tulemust võis seostada keha mass.

LIHTLITSENTS

Lihtlitsents lõputöö reprodutseerimiseks ja lõputöö üldsusele kättesaadavaks tegemiseks

Mina, Karmen Reinpõld, sünnikuupäev: 17.05.1981,

1. annan Tartu Ülikoolile tasuta loa (lihtlitsentsi) enda loodud teose

   "Predictors and characteristics of an ultra-distance mountain bike race performance", mille juhendaja on Jarek Mäestu,

   1.1. reprodutseerimiseks säilitamise ja üldsusele kättesaadavaks tegemise eesmärgil, sealhulgas digitaalarhiivi DSpace-is lisamise eesmärgil kuni autoriõiguse kehtivuse tähtaja lõppemiseni;

   1.2. üldsusele kättesaadavaks tegemiseks Tartu Ülikooli veebikeskkonna kaudu, sealhulgas digitaalarhiivi DSpace´i kaudu kuni autoriõiguse kehtivuse tähtaja lõppemiseni.

2. olen teadlik, et punktis 1 nimetatud õigused jäävad alles ka autorile.

3. kinnitan, et lihtlitsentsi andmisega ei rikuta teiste isikute intellektuaalomandi ega isikuandmete kaitse seadusest tulenevaid õigusi.

Tartus, 05.05.2017