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RESEARCH ARTICLE

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Physiological characteristics and performance in elite vs non-elite enduro mountain biking.

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Abstract

Enduro mountain bike racing is composed of several timed predominantly downhill race stages linked by time restricted, non-competitive transition stages. This study aimed to 1) detail and compare the laboratory assessed physiological characteristics of elite and non-elite enduro mountain bike riders, and 2) evaluate the use of 10Hz global positioning systems (GPS) unit including a 100Hz triaxial accelerometer to define the demands of enduro mountain bike racing and identify components of successful performance. Eleven male enduro mountain bike riders completed laboratory protocols for peak aerobic capacity (VO_{2peak}), fixed blood lactate concentrations (FBLC: 2 and 4 mmol.L^{-1}) enduro specific test (EST), and anthropometry measures. Participants were divided into elite (*n*=5) and non-elite (*n*=6) groups for analysis. Nine (*n*=9) elite enduro mountain bike athletes participated in field data collection at an international enduro mountain bike race. Two race stages were used for analysis of velocity, accumulated load, heart rate and time to complete specific sections of track calculated from GPS units placed on the bicycle seat mast and the rider's torso. Elite athletes produced greater power during the EST (475± 15W vs 390 ± 31W) and at VO_{2peak} (417 ± 29W vs 363 5 ± 30W), FBLC 2mmol.L^{-1} (267 ± 39W vs 198 ± 36W), FBLC 4mmol.L^{-1} (318 ± 31W vs 263 ± 25W) when compared to non-elite riders (all p<0.05) with no significant differences in anthropometry (p>0.05). Accumulated load was significantly greater on the bicycle than the rider on both stages (p<0.05) and load in both locations was significantly higher during technical terrain compared to non-technical terrain (p<0.05). GPS analysis allowed detailed analysis of performance showing winning performances were characterised by reduced time to complete both technical downhill and non-technical climbing sections during race stages. In conclusion, successful performance in enduro mountain bike racing requires ability to sustain high velocities over technical and non-technical terrain coupled with large aerobic and anaerobic capacities.

Keywords: Mountain biking, enduro, performance, physiology.

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Introduction

Enduro racing compromises of timed downhill sections of trail and non-competitive transition sections that must be completed within the provided time limit but do not contribute to overall race result. Enduro World Series (EWS) races feature a minimum of two race stages per day with a minimum of four stages per event, a maximum elevation gain of 2000m for a single day event and 3200m for a two-day event. Athletes ascend by pedalling or use of mechanical uplift to meet their time checks at the start of each race stage and overall time spent riding is between 3 and 9 hours per day. According to EWS guidelines race stages should comprise of a maximum of 20% ascending terrain. The remaining 80% will feature terrain similar to that of downhill (DH) racing designed to test the riders' technical ability. The winner of the general classification (GC) is the rider with the lowest combined time to complete all race stages. GC time must exceed 20 minutes per day of competition for the fastest rider overall, averaging 40 minutes for each round for the winner in 2017 with a mean total ride time of approximately 6h 40min per day of competition (Enduro World Series 2017).

Previously, research has concentrated on cross country (XC) and DH disciplines and demonstrated that elite athletes have specific characteristics suited to the demands of their chosen discipline. For example, XC athletes have larger aerobic capacity and produce greater power across bouts ≥15s when compared to DH athletes who produce greater power over durations <15s reflecting the longer duration of XC (~1.5hrs) compared to that of DH (~4mins) (Baron 2001; Novak & Dascombe 2014; Stapelfeldt et al. 2004). The rapid evolution of enduro has led to a large expansion in the number of professional enduro athletes resulting in a gap in knowledge concerning the demands of enduro racing and the physiological characteristics of successful enduro athletes. The prolonged total duration of enduro (3-9hrs), the time constrained uphill transitions (up to 2.5hrs alone) and average heart rate (HR) of >90% maximum (Hassenfratz et al. 2012) for up to 20 minutes per race stage suggests a considerable demand is placed on the aerobic system and thus provides rationale to assess aerobic exercise capacity. Additionally, (Hassenfratz et al. 2012) showed that blood lactate concentration in a case study of a world-class enduro rider rose from a mean of 3.0 mmol.L^{-1} at the start of a race stage to 15.2 mmol.L^{-1}immediately post stage thus providing rationale to assess blood lactate response to increasing workload. Hassenfratz et al. (2012) also reported that one elite rider produced <50W for 37-56% of the duration of timed stages though average HR was maintained at around 90% of maximum throughout. This discrepancy between power and HR may be due to the workload associated with damping accelerations transferred to the rider from the bicycle as a result of rough terrain (Macdermid et al 2014). Upper body muscular contractions are shown to contribute to this damping effect with greater magnitude of activity on rough terrain when compared with smooth terrain (Hurst et al. 2012). Magnitude and frequency of accelerations experienced by the rider are also influenced by suspension (Levy & Smith, 2005), wheel size (Macdermid et al., 2014), tire size and tire pressure (Macdermid et al. 2015) thus it is feasible these factors also influence physiological workload. Interestingly, when compared to a hardtail bike a full suspension bike reduced vibrations on the downhill section of a cross country course but did not improve performance or reduce physiological workload (Macdermid et al 2016). This suggests that further research is required to include the specific, likely more technical terrain and specialist equipment used by professionals (e.g. 160-200mm travel bikes vs hardtail) associated with other off road cycling disciplines such as downhill and enduro.

GPS devices incorporating accelerometers have been used to create a GPS activity profile in DH mountain biking, though to the best of the authors knowledge the components of successful performance have not yet been fully detailed (Florida-James et al. 2010; Hurst et al. 2013). The validity and reliability of GPS systems to assess activity profile of outdoor sports has been reported extensively (e.g. Aughey, 2011). Further, the validity of GPS units incorporating triaxial accelerometers for measuring physical activity has also been reported (Boyd et al. 2011) and been deemed suitable for use in sports similar to enduro such as DH (Hurst et al. 2013). Rider load was introduced as a term to describe accelerations and accumulated accelerations experienced by the bike rider, detailed previously (Hurst et al. 2013). Abbiss et al. (2013) showed that faster riders overall spent significantly less time in the technical uphill section when compared to slower riders overall at a World Cup XC race. The potential influence of terrain (Hurst et al. 2013) and time to complete designated sections (Abbiss et al. 2013) provides rationale to assess differences in GPS activity profile in relation to performance in elite enduro mountain bike racing.

The aims of this study were therefore to:

1) detail and compare the laboratory assessed physiological characteristics of elite and non-elite enduro mountain bike riders
2) Evaluate the field use of GPS/accelerometer units to define the demands of different terrain in enduro mountain bike racing and identify components of successful elite performance

Methodology

Laboratory data collection

Participants

Eleven (*n*=11) male enduro mountain bike riders (age= 24 ± 5 years, height=181 ± 5cm, mass=72 ± 6kg) participated in the laboratory testing. Participants were divided into elite (*n*=5; Top 40 EWS result) and non-elite (*n*=6; national level rider) groups for analysis. Ethical approval for the study was granted from the ethics committee of [name deleted to uphold integrity of review process], adhering to the ethical standard of this journal (Harriss & Atkinson, 2013). Subsequently, both oral and written consent was obtained from all participants.

Laboratory protocols

Participants were required to visit the human performance laboratories on two occasions, with at least 48hrs between visits. During the first visit, power at fixed blood lactate concentration of 2mmol.L^{-1} and 4 mmol.L^{-1} (FBLC 2 and 4 mmol.L^{-1} respectively) and peak oxygen uptake (VO_{2peak}) were assessed. On the second visit body composition and power output was measured. Participants were fully informed of the details of all protocols prior to each test. FBLC, VO_{2peak} and power were all assessed on a cycle ergometer (Racer Mate Pro, Velotron, USA) fitted with the participant's own clip-in pedals.

Lactate threshold protocol

FBLC was assessed using an incremental exercise test on cycle ergometer (Racer Mate Pro, Velotron, USA). Blood samples taken from the ear lobe were analysed for blood lactate concentration using the Lactate Pro Meter (Arkray LT-1710, Japan). The initial workload was set at 110W increasing 40W every 3 minutes. Samples were taken within the last 30s of workload until lactate concentration exceeded 4mmol.L^{-1} at which point the test was terminated. Lactate concentration was then plotted against power output in order to determine power output at 2 and 4mmol.L^{-1}.

VO_2peak protocol

Fifteen minutes of active recovery at a self-selected intensity (HR<120bpm) followed the lactate threshold test. VO_{2peak} was assessed by a ramp test to exhaustion where online gas analysis was used to determine oxygen uptake (Jaeger Masterscreen CPX, Germany; Hans Rudolph V2, Germany). The initial workload was set at 160W and increased 20Wmin^{-1} until volitional exhaustion or when cadence dropped below 60rpm. VO_{2peak} was taken as the highest 8-breath average from raw breath-by-breath data. Rating of perceived exertion (RPE) (Borg 1970) was assessed at every stage and HR (Polar, Finland) was recorded at 5s intervals throughout the two tests.

Anthropometry

The ISAK (International Society for the Advancement of Kinanthropometry, 2010) restricted profile was used to collect anthropometric data on the second visit to the laboratory. In addition, corrected measurements of calf, thigh, and upper arm girth were used to calculate estimated muscle mass (Martin et al. 1990). Body mass was measured using scales (Seca 761, Germany) and height was measured using a stadiometer (Holtain Limited Harpenden Portable, UK).

Enduro Specific Test protocol

The Enduro Specific Test (EST) is designed to test power with respect to enduro racing and is based on the Downhill Specific Test (DST; Florida-James, 2010). The cycle ergometer used for the test (Racer Mate Pro, Velotron, USA) was fitted with a Wingate specific chainring (85-tooth chain ring, Velotron, USA) and torque factor applied was 0.05 kilogram-force per kilogram body weight (kgf/kg). Resistance was constant for the duration of both stages and power data was recorded using Velotron Wingate software (Wingate Software, Computrainer, USA, 2012) at 10Hz. The EST was designed to replicate two competitive enduro stages separated by a pedal powered transition. Participants continued to pedal in the transition at low cadence. The first stage was followed by 150s active rest at self-selected intensity. Participants then completed 15mins fixed workload set at 80% of the individual power output at FBLC 4mmol.L^{-1} recorded in the previous laboratory visit. This was in an effort to replicate the physiological demand of a transition stage in enduro racing, which normally involves a climb back up a hill/mountain to the start of next stage. Stage 2 of the EST followed after a second period of 150s active rest at a self-selected intensity. See figure 1 below for further detail on the EST structure and specific sprint durations. Sprint and rest durations for the EST were informed by the power data of an elite athlete collected using a power meter at a national race presented by Hassenfratz et al. (2012).

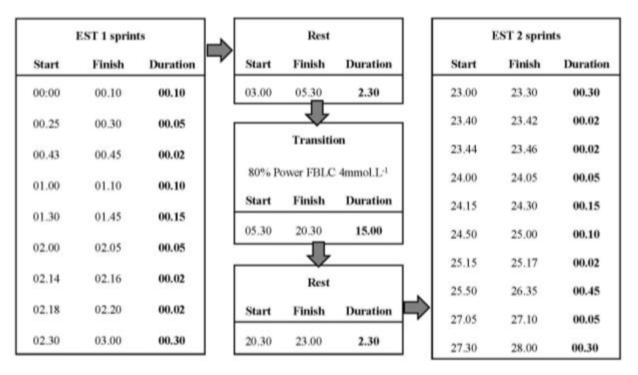
Field data collection

Participants

Nine (n=9) elite enduro mountain bike athletes were recruited for field data collection. All nine participants had finished an Enduro Worlds Series (EWS) race in the top 40 positions. Complete field data sets were obtained for four (n=4) riders as a result of issues with compatibility of GPS/Accelerometer units (see results section for more information).

Race event

A two-day international enduro race in the United Kingdom was chosen for the race analysis. The race day consisted of four timed stages of which two were used for analysis. The course was 48km in total length with a total ascent of 1094m. For details of stage, stage sections, distance, elevation and terrain please refer to figure 2 below.



EST 1 sprints

Start	Finish	Duration
00:00	00.10	**00.10**
00.25	00.30	**00.05**
00.43	00.45	**00.02**
01.00	01.10	**00.10**
01.30	01.45	**00.15**
02.00	02.05	**00.05**
02.14	02.16	**00.02**
02.18	02.20	**00.02**
02.30	03.00	**00.30**

Rest

Start	Finish	Duration
03.00	05.30	**2.30**

Transition

80% Power FBLC 4mmol.L^{-1}

Start	Finish	Duration
05.30	20.30	**15.00**

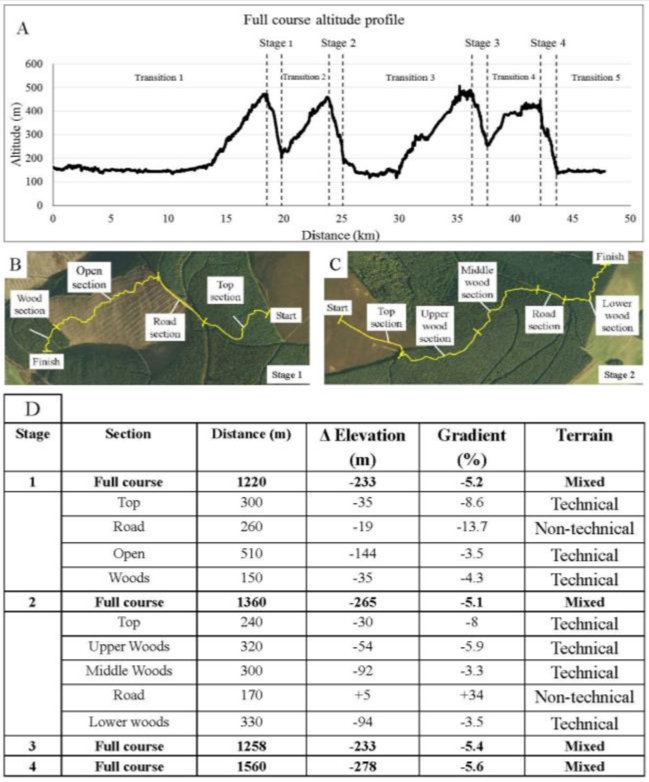
Rest

Start	Finish	Duration
20.30	23.00	**2.30**

EST 2 sprints

Start	Finish	Duration
23.00	23.30	**00.30**
23.40	23.42	**00.02**
23.44	23.46	**00.02**
24.00	24.05	**00.05**
24.15	24.30	**00.15**
24.50	25.00	**00.10**
25.15	25.17	**00.02**
25.50	26.35	**00.45**
27.05	27.10	**00.05**
27.30	28.00	**00.30**

Figure 1: EST protocol including duration of sprints in EST 1 and EST 2. Time presented as min.s; FBLC 4mmol.L^{-1} = power at fixed blood lactate concentration of 4mmol.L^{-1}. 'Start' indicates start of sprint effort and 'finish' indicates end of sprint effort.



Stage	Section	Distance (m)	Δ Elevation (m)	Gradient (%)	Terrain
1	**Full course**	**1220**	**-233**	**-5.2**	**Mixed**
	Top	300	-35	-8.6	Technical
	Road	260	-19	-13.7	Non-technical
	Open	510	-144	-3.5	Technical
	Woods	150	-35	-4.3	Technical
2	**Full course**	**1360**	**-265**	**-5.1**	**Mixed**
	Top	240	-30	-8	Technical
	Upper Woods	320	-54	-5.9	Technical
	Middle Woods	300	-92	-3.3	Technical
	Road	170	+5	+34	Non-technical
	Lower woods	330	-94	-3.5	Technical
3	**Full course**	**1258**	**-233**	**-5.4**	**Mixed**
4	**Full course**	**1560**	**-278**	**-5.6**	**Mixed**

Figure 2: Full course profile of altitude and distance for all stages and transitions (A) and GPS trace of stage 1 and 2 (B & C respectively) overlaid on Google Earth including separate sections created for detailed analysis. Details of length (m), elevation change (m), gradient and terrain type for full course stage and stage sections are also detailed here (D).

GPS and accelerometer methodology

A GPS device featuring 100Hz triaxial accelerometer (Catapult MinimaxX S4 or Catapult Optimeye S5, Catapult Innovations, Melbourne, Australia) was fixed to the seat mast of each participants bicycle in the orientation specified by the manufacturer. A second GPS device was placed in a specifically designed neoprene harness (Catapult Innovations, Melbourne, Australia) as described previously (Hurst et al. 2013). Three (n=3) participants used two MinimaxX S4 units, five (n=5) participants used two Optimeye S5 units and one (n=1) used an Optimeye S5 in the neoprene harness and a MinimaxX S4 attached to the bicycle. All participants wore a wireless HR monitor strap (Wearlink, Polar, Finland) encoded to their individual GPS units recording HR at 1Hz. The Catapult MinimaxxX S4 and Optimeye S5 use GPS signal to record position and subsequently velocity and altitude at sample rate of 10Hz however the Catapult Optimeye S5 also recognises Global Navigation Satellite System (GLONASS) signals. Both devices incorporate a 100Hz triaxial accelerometer which is used to calculate rider load and accumulated rider load, the validity and reliability of these parameters have been reported elsewhere (Boyd et al. 2011; Van Iterson et al. 2016). The GPS devices were switched on and checked for sufficient GPS signal 10minutes prior to leaving the race headquarters and the race start (Catapult Innovations, Melbourne, Australia). Upon return to the event headquarters the GPS unit was connected to a laptop and the data downloaded for later analyses.

Figure 3. Percentage time spent in velocity zones in technical and non-technical terrain. Data presented as mean ± SD. * denotes significant difference between technical and non-technical terrain (p<0.05).

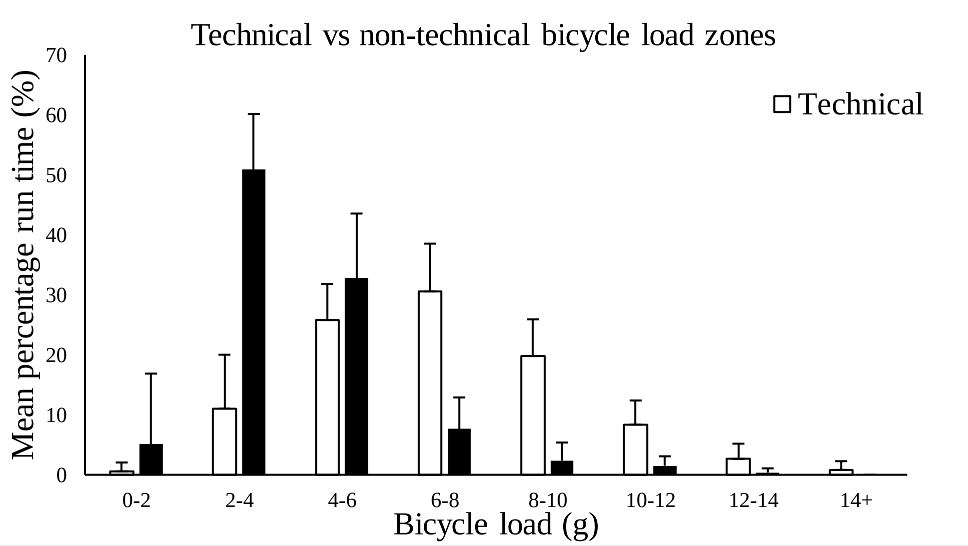
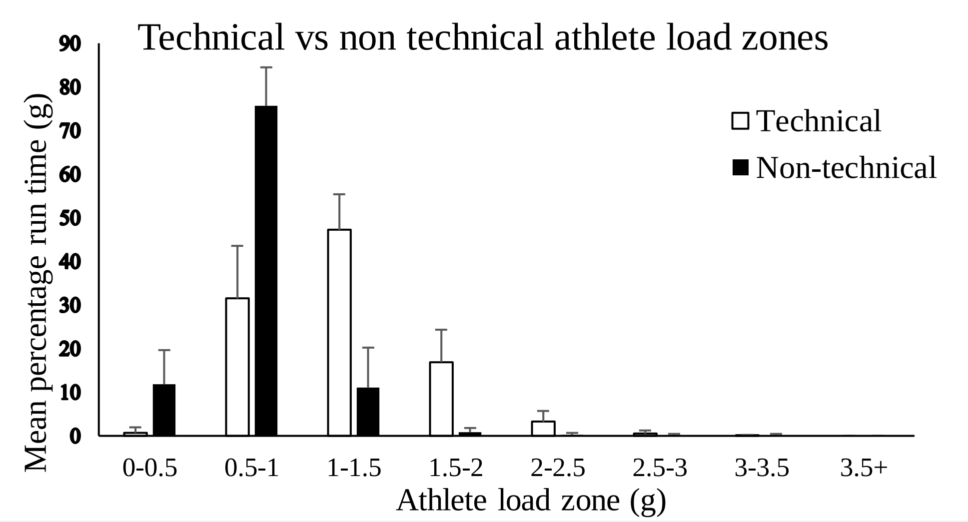


Figure 4. Percentage time spent in velocity zones in technical and non-technical terrain. Data presented as mean ± SD. * denotes significant difference between technical and non-technical terrain (p<0.05).



GPS analysis

GPS data was analysed on Catapult Sprint 5.1 software (Catapult Innovations, Melbourne, Australia). Race stages were identified where velocity moved above 0ms^{-1} at the stage start and back to 0ms^{-1} at the stage finish in conjunction with the map feature. Mean and peak HR data is displayed for each race stage. Stages were divided into sections detailed in figure 2 above. Terrain was either technical (single track with rocks and roots) or non-technical (gravel road) as noted below.

GPS data (10Hz sample rate) was used to calculate overall run time (s) in agreement with event organiser's time, section time (s) and percentage time spent in velocity zones (0-10, 10-20, 20-30, 30-35, 35-40, 40-45, 45-60 (km.h^{-1})). Rider load has been previously defined by Hurst et al., 2013 and is calculated using the formula available in the Catapult Sprint software manual (Catapult Innovations, 2013, page 80). Rider load for the Catapult unit placed on the athlete will be referred to as athlete load whilst rider load for the Catapult unit on the bicycle will be referred to as bicycle load from here on. Accelerometer data (100Hz sample rate) was used to calculate percentage time spent in bicycle load zones (0-2, 2-4, 4-6, 6-8, 8-10, 10-12, 12-14, >14 (g)), athlete load zones (0-0.5,0.5-1,1-1.5, 1.5-2, 2-2.5, 2.5-3, 3-3.5, >3.5(g)), and accumulated rider load (bicycle and athlete) for each track and terrain type (technical and non-technical) as defined in figure 2.

Statistical analysis

Laboratory

All data analysis was performed using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). Difference between physiology data of the elite and non-elite groups was assessed using an independent sample T-test. Significance was accepted at the 95% confidence interval (p=0.05). All data presented as mean ± standard deviation (SD). For ramp test data, power is presented as relative (watts/kilogram body weight, W/kg) and absolute (watts, W).

Field

Mean differences for stage time, accumulated rider load, accumulated bicycle load, mean heart rate and peak heart rate between stages 1 and 2 were analysed by paired sample T-tests. Between terrain differences for velocity, athlete load and bicycle load data were assessed using two-way repeated measures analysis of variance (ANOVA). Greenhouse Geisser correction was used to adjust the degrees of freedom if the assumption of homogeneity was violated. In the case of a significant main effect, significant simple main effects were also calculated and reported. All data presented as mean ± standard deviation (SD). Relationship between run time and mean bicycle load were investigated using Pearson's correlation coefficient. The magnitude of correlation coefficients was considered as trivial (r<0.1), small (0.1<r<0.3), moderate(0.3<r<0.5), large (0.5<r0.7), very large (0.7<r<0.9), almost perfect (r>0.9) or perfect (r=1; Hopkins, 2002). Significance was accepted at the 95% confidence interval (p=0.05) throughout.

Results

Laboratory testing

The physiological data obtained during the laboratory tests indicated that elite riders produced greater power output at VO_{2peak}, at an RER of 1, FBLC 2mmol.L^{-1} and FBLC 4mmol.L^{-1} (see Table 1).

The results of the Enduro Specific Test (EST) shown in table 1 demonstrated that the elite athletes are capable of producing greater power in seven out of the eight power indices measured in this specific test. Overall relative peak power (W/kg) was the only power parameter which elites did not produce more power than non-elite riders, suggesting that maintaining near maximal power across repeated sprints efforts is more important than the magnitude of maximal power produced in a single sprint effort. No significant differences were found in body mass (kg), skeletal muscle mass (kg), sum of 6 skinfolds, sum of 8 skinfolds, percentage muscle mass or thigh girth 1cm distal of the gluteal fold between groups (p>0.05) shown below in table 1.

Field results

All participants completed the race successfully. GPS data for one participant did not log and hence his data were removed from further analysis. The GPS system on the Catapult MinimaxX S4 unit failed to record complete files in the dense woodland surrounding the race tracks and thus could not be used for analysis. Thus only four (n = 4) sets of Catapult MinimaxX S5 data is presented. Mean time to complete stage 2 was significantly longer than stage 1 and bicycle load was substantially reduced in comparison to athlete load on both stages. Respective values of both athlete load and bicycle load were significantly greater on stage 2 than stage 1 (see table 2) though mean HR was similar for both stages.

Table 1. Results of laboratory tests. All data presented as mean ± SD for each group.*denotes significant difference between elite and non-elite groups (p<0.05).

Parameter (unit)	Non-Elite	Elite
VO_{2peak} (ml.kg.min^{-1})	63.6 ± 6.1	65.8 ± 3.7
Power VO_{2peak} (W)	363 5 ± 30	417 ± 29*
Relative Power VO_{2peak} (W/kg)	5.2 ± 0.4	5.6 ± 0.3
Power RER = 1 (W)	282 ± 27	343 ± 25*
Power FBLC 4mmol.L^{-1} (W)	263 ± 25	318 ± 31*
Power FBLC 2mmol.L^{-1} (W)	198 ± 36	267 ± 39*
Relative power FBLC 4mmol.L^{-1} (W/kg)	3.8 ± 0.3	4.3 ± 0.3*
Relative power FBLC 2mmol.L^{-1} (W/kg)	2.9 ± 0.5	3.6 ± 0.4*
EST 1		
Mean Power (W)	390 ± 31	475 ± 15*
Mean Power (W/kg)	5.6 ± 0.1	6.3 ± 0.1*
EST 2		
Mean Power (W)	387 ± 30	469 ± 12*
Mean Power (W/kg)	5.6 ± 0.2	6.3 ± 0.4*
Complete EST		
Mean power (W)	388 ± 29	466.3 ± 21*
Mean power (W/kg)	5.5 ± 0.3	6.2 ± 0.5*
Peak power (W)	541 ± 66	658 ± 57*
Peak power (W/kg)	7.7 ± 0.5	8.8 ± 1.2
Body Composition		
Body mass	69.6 ± 5.6	75.1 ± 5.1
Skeletal muscle mass (kg)	41.3 ± 4.4	44.2 ± 4.2
Skeletal muscle mass (%)	59.5 ± 4.3	58.8 ± 2.4
Thigh girth 1cm distal gluteal fold (cm)	55.3 ± 2.8	57.4 ± 1.3
Sum of 6 skinfolds (mm)	46.9 ± 8.0	45.4 ± 11.3
Sum of 8 skinfolds (mm)	61.1 ± 10.2	57.8 ± 13.1

There was a significant interaction between terrain and velocity zone, F(3.15, 22.01) = 6.429, p= 0.002. Analysis of simple main effects showed significant differences between technical and non-technical terrain in the 0-10, 10-20 and 20-30 km.h^{-1} zones as shown in figure 3 below.

There was a significant interaction between terrain and bicycle loading (F(2.38, 16.65) = 35.29, p = 0.000). Analysis of simple main effects showed significant differences in percentage time in bicycle load zone between terrain for all zones except 0-2 and 4-6g (see figure 4).

There was also a significant interaction between terrain and athlete loading (F(2.17, 15.18) = 81.82, p = 0.000). Analysis of simple main effects showed significant differences in percentage run time in athlete load zone between terrain for all athlete load zones except 3-3.5 and 3.5+ g as shown in figure 5 below.

On stage 1 Rider B was fastest by 2.9s (see table 2). This was achieved during both the top section and road section (see figure 3). Rider C recorded the quickest

Table 2: Mean time (s), athlete load (A.U.), bicycle load (A.U.), mean heart rate (HR) for full course of stages 1 and 2 (*n*=4) and individual time to complete stage sections (s). * indicates significant mean difference between full course stage 1 & 2, $^{\#}$indicates significant difference between athlete load and bicycle load (p <0.05).

Stage (full course)	Time (s)	Athlete load (A.U.)	Bicycle load (A.U.)	Mean HR (%max)	Maximum HR (%max)
1	171.1 ± 15.5	49.4 ± 3.7	281.0 ± 7.7$^{\#}$	87 ± 4	94 ± 1
2	212.7± 6.43	60.9 ± 4.6*	352.7 ± 8.8$^{*\#}$	87 ± 3	95 ± 4

Stage 1 – time to complete section (s)

Rider	Top (T)	Road (NT)	Open (T)	Wood (T)	Total
A	44.5	26.9	73.9	21.0	166.3
B	42.3	25.5	71.3	20.9	160.0
C	43.3	27.9	71.0	20.8	162.9
D	57.8	38.6	76.6	21.2	194.2

Stage 2 - time to complete section (s)

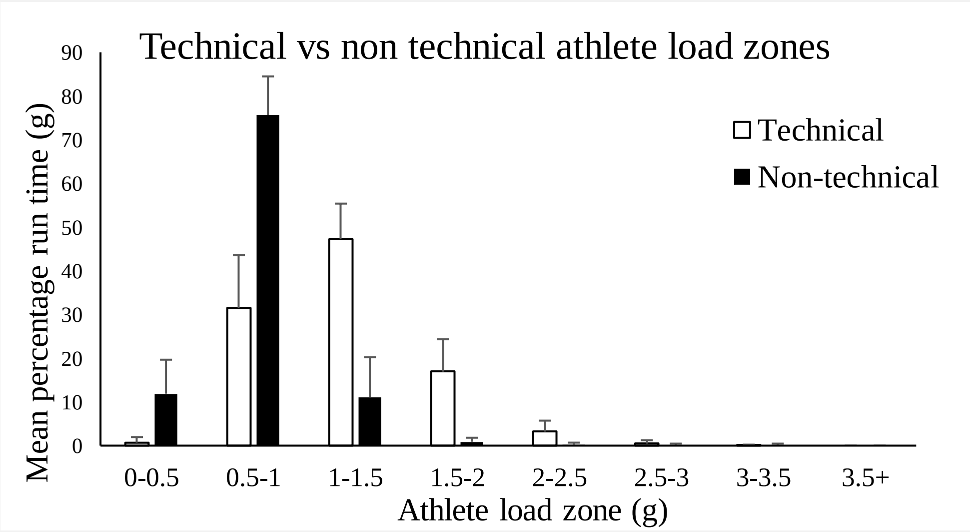
Rider	Top (T)	Upper wood (T)	Middle wood (T)	Road (NT)	Lower wood (T)	Total
A	24.6	43.7	49.5	22.6	70.7	212.1
B	24.5	48.4	51.0	21.1	66.5	211.5
C	24.8	45.6	48.3	21.0	64.1	203.8
D	24.7	47.3	52.0	24.6	70.7	219.2

speeds in the open and wood section, however the advantage was marginal in comparison to time lost previously and thus did not result in a winning time.

On stage 2 Rider C had the fastest time of 203.8s; 7.7s quicker than second fastest rider B (see table 2). Rider C won the stage by going fastest on the middle wood and road section before extending his advantage in the lower wood section going 2.4s faster than second placed rider B and 6.6s faster than third placed rider A. The winning rider gained time in the most technical sections and did not relinquish any time in the non-technical pedalling sections. In both stages, the winning rider was consistently in the top 2 fastest times for each section with the exception of the top section of stage 2.

There was a significant almost perfect negative correlation between mean bicycle load and overall stage time during stage 1 and stage 2 as shown in figure 6 below.

Figure 5. Percentage time spent in athlete load zones during technical and non-technical terrain. Data presented as mean ± SD (n= 4).



Discussion

This study aimed to define the physiological characteristics of elite and non-elite enduro mountain bike athletes and to identify the demands of an international enduro race. The main findings of this study demonstrated that elite enduro athletes have a large aerobic capacity and the ability to produce greater power at submaximal workloads, when compared to non-elite counterparts. This reflects the prolonged overall duration of enduro events and suggests the elite riders are working at a relatively lower workload than non-elite riders during time limited transition stages. Elite and non-elite athletes exhibited similar VO_{2peak} values, however elites produced significantly greater absolute peak power suggesting peak power output contributes to successful enduro racing performance. Furthermore, elite riders produced greater relative and absolute power at FBLC (2mmol.L^{-1} and 4mmol.L^{-1}) in comparison to non-elite counterparts, suggesting that the elite athletes are capable of completing the transition stages of an enduro event at a submaximal workload and thus contributing to successful performance. Additionally, blood lactate clearance appears to be crucial during the race stages as Hassenfratz et al. (2012) showed an average post stage blood lactate concentration of 15.2 mmol.L^{-1}. The absence of a peak lactate value from the laboratory in this study is a limitation and should be considered in future research in enduro mountain biking performance. The importance of submaximal workload capacity was further enhanced by larger wattages demonstrated at RER=1 in the elite group, thus suggesting elite athletes can work at greater wattages before shifting to carbohydrate as the predominant fuel source, which should translate into improved performance. EST data shows that elite riders are able to repeatedly produce more power over shorter durations suggesting improved recovery between maximal efforts. However, as previous work has shown that pedalling is not crucial to descending performance in XC (Miller et al. 2016) and DH (Hurst & Atkins 2006) further research in the field is required to explore fully the relationship with power output and performance in enduro.

Periods of near-maximal, intermittent power output during enduro race stages has previously been documented (Hassenfratz et al. 2012). The data presented here shows that the elite group have a superior ability to recover and reproduce short bursts of near-maximal power output when compared to non-elite athletes, suggesting increased intermittent power output is crucial for successful enduro performance. In comparison to other disciplines, elite and non-elite enduro athletes showed relative VO_{2peak} values only marginally lower than reported of national level (Novak & Dascombe 2014) XC athletes. Elite enduro athletes also demonstrated comparable absolute and relative power at VO_{2peak} and FBLC 4mmol.L^{-1} to national level XC athletes (Impellizzeri et al. 2005) suggesting the physiological profile of elite enduro athletes shows more similarities with XC athletes than DH athletes. In summary, elite enduro athletes can produce more power at VO_{2peak} combined with improved ability to repeatedly produce near maximal power output when compared to non-elite athletes.

The aim of this field study was to evaluate the use of GPS and accelerometer technology to identify the difference in terrain profiles during an international race and to determine components of successful enduro mountain bike race performance based on this data. The main findings were 1) terrain significantly altered the activity profile, 2) winning performance was determined by time to complete technical and non-technical sections and 3) reduced run time was significantly negatively correlated with mean bicycle load. Athlete and bicycle load profile showed that technical terrain resulted in significantly increased time in higher load zones when compared to non-technical terrain despite a higher average velocity over non-technical terrain. The GPS accelerometer technology demonstrated a sensitivity that was able to detect changes in terrain and accumulated workload in enduro mountain bike racing, showing this could potentially be used for monitoring athlete performance and load in the future.

The GPS unit attached to the bicycle recorded significantly greater accumulated load when compared to the accumulated load measured at the torso, supported by previous work showing that accelerations are attenuated significantly between the bicycle and the rider's torso by the rider's limbs (Macdermid et al. 2014). Reduction in accelerations at the torso are deemed necessary to maintain balance and coordination, both of which are critical to maintain control of the bicycle (Mester et al. 1999). Given the difference between accumulated load at the bicycle and torso observed here, the dissipation of accelerations between bike and torso is proposed to contribute to the overall workload of piloting the bicycle over technical terrain more so than non-technical terrain, similar to the findings of Macdermid et al. (2015). Therefore it is feasible (in addition to analysis of power output) that GPS accelerometer technology allows quantification of workload components contributing to sustained elevation of HR during negotiation of technical terrain (Hassenfratz et al. 2012; Hurst & Atkins 2006). However, this workload may also influenced by suspension type, set up, and rider technique ; the assessment of which was beyond the scope of this study and is thus a limitation of the data presented (Macdermid et al. 2017). In addition, the trend for elite riders to have a greater mass and predicted muscle mass may be a requirement to withstand higher mean load associated with reduced run time shown here.

Values of accumulated athlete load presented here are slightly lower than values presented in elite DH riders, likely due to reduced velocity of enduro riders (19-23kmh^{-}1) compared to DH riders (25-30kmh^{-1}) (Hurst et al. 2013) and can also be influenced by terrain type, course design or the increased suspension travel of a DH bike (200mm) compared to the enduro bicycles (140-160mm) used here. As enduro athletes compete on several stages in one day potentially for multiple successive days, the implications of the accumulating workload may be significant over the course of a race event. In the present study faster athletes spend a greater percentage of run time in higher bike load zones highlighting the increased demand placed on faster athletes. This highlights the importance of specific conditioning programmes designed to prepare the athlete to cope with the increased overall workload demands. During EWS races where stages and transitions can be more than 4-5 times greater in length (Enduro Mountain Bike Association 2016) than seen in this current study, accompanied by greater velocities even more load could be placed on the athletes, thus warranting further research. As one international level enduro athlete has been shown to produce 457-821W for 20% of the duration of a 15 minute race stage, it is suggested that a high capacity for propulsive workload is also likely to be crucial for long stage durations (Hassenfratz et al., 2012). Future work should also aim to quantify the workload of the transition stages in enduro racing in addition to the demands of the race stages. This would be particularly relevant at EWS races where transitions can be ~2hours long with overall durations of up to 9 hours and thus place significant demands on the athlete in addition to the workload of the race stages.

The relationship between skill level in piloting the bike over technical terrain and the consequent overall loading on the athlete requires further research. The present study demonstrated that faster riders moved quicker through technical sections, thus suggesting a greater level of skill in comparison to slower riders. However this relationship is multifactorial and not reliant on load alone, therefore future research should focus on the influence of bike setup including factors such as wheel size and suspension type and set up, to determine the associated impact on performance.

Individual analysis shows that stage winning performance featured consistently competitive times through both the most technical sections of the race stage and the non-technical uphill/mixed gradient sections. This suggests that skill development in piloting the bike is a crucial component that should be part of training programme but also indicates that elite enduro athletes must also be able to produce large bouts of power to cover uphill and flat sections of smoother terrain within a stage. Additionally, the ability to negotiate technical terrain immediately following large anaerobic bursts both within the stages and during the transition phases between stages is essential for successful competition. This is supported by individual analysis showing that the winning rider on stage 1 completed the uphill road section 2.4 seconds quicker than any other rider and was able to maintain this advantage over subsequent technical sections. The physiological characteristics measured within this study appear to corroborate this assertion, as the elite enduro athletes displayed values of peak aerobic power output similar to those of national level XC racers (Novak & Dascombe 2014).

In conclusion, successful performance in enduro mountain biking requires a large aerobic and anaerobic capacity coupled with adequate skill and technique to ensure high velocities can be sustained over differing types of terrain. Athletes and coaches should consider suitable conditioning to prepare the athlete for the accumulated load associated with enduro racing. Use of a GPS accelerometer based activity profile allows more detailed analysis of workload than traditional means with the ability to describe components of successful performances in enduro mountain bike racing.

Practical Applications

Defining the physiological characteristics of elite enduro mountain bike athletes allows coaches and athletes to tailor their training plans accordingly following needs analysis. This study shows that both technical ability and physical fitness are crucial for performance and therefore enduro athletes cannot rely on one component alone for successful performance. GPS/accelerometer units may be used to further quantify intensity and performance in enduro mountain biking to manage athlete load across a season of racing and competition.

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Conflict of interest

The authors have no personal or financial relationships with other people or organisations that could have inappropriately influenced this work.

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