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Research article

Physiological Demands of Simulated Off-Road Cycling Competition

Gerhard Smekal [1], Serge P. von Duvillard [2]✉, Maximilian Hörmandinger [1], Roland Moll [1], Mario Heller [3], Rochus Pokan [1], David W. Bacharach [4], Linda M. LeMura [5] and Paul Arciero [6]
[1]Department of Sport Physiology, Institute of Sports Sciences, University of Vienna, Austria; [2] Department of Sport Science and Kinesiology, University of Salzburg, Salzburg, Austria; [3] Section of Biomechanics, Kinesiology and Applied Computer Science, Institute of Sports Sciences, University of Vienna, Austria; [4] Human Performance Laboratory, St. Cloud State University, St. Cloud, Minnesota, USA; [5] Department of Biology, Le Moyne College, Syracuse, New York, USA; [6] Department of Health and Exercise Sciences, Skidmore College, Saratoga Springs, New York, USA.

Abstract
The purpose of the study was to measure the demands of off-road cycling via portable spirometry, leg-power output (PO), heart rate (HR) and blood lactate (BLa) concentration. Twenty-four male competitive cyclists (age: 29±7.2 yrs, height: 1.79 ± 0.05 m, body mass: 70.0 ± 4.9 kg, VO_{2peak}: 64.9 ± 7.5 ml·kg^{-1}·min^{-1}) performed simulated mountain bike competitions (COMP) and laboratory tests (LabT). From LabT, we determined maximal workload and first and second ventilatory thresholds (VT1, VT2). A high-performance athlete (HPA) was used for comparison with three groups of subjects with different sport-specific performance levels. Load profiles of COMP were also investigated during uphill, flat and downhill cycling. During the COMP, athletes achieved a mean oxygen uptake (VO_{2COMP}) of 57.0 ± 6.8 ml·kg^{-1}·min^{-1} vs. 71.1 ml·kg^{-1}·min^{-1} for the HPA. The PO_{COMP} was 2.66±0.43 W·kg^{-1} and 3.52 W·kg^{-1} for the HPA. PO_{COMP}, VO_{2COMP} and HR_{COMP} were compared to corresponding variables at the VT2 of LabT. LabT variables correlated with racing time (RT_{COMP}) and PO_{COMP} ($p < 0.01$ to <0.001; *r*-0.59 to -0.80). The VO_{2peak} (LabT) accounted for 65% of variance of a single COMP test. VO_{2COMP}, PO_{COMP} and also endurance variables measured from LabTs were found as important determinants for cross-country performance. The high average VO_{2COMP} indicates that a high aerobic capacity is a prerequisite for successful COMP. Findings derived from respiratory gas measures during COMPs might be useful when designing mountain bike specific training.

Key words: Off-road cycling, mountain biking, oxygen uptake, power output, lactate, heart rate.

Introduction

The history of off-road cycling or mountain biking (MB) began in the mid 1970s. Popularity of MB rapidly developed from a minority group activity to a worldwide sport. The implementation of the first World Championship in Durango (USA) in 1990 and the first MB competition (COMP) at the Olympic Games in Atlanta in 1996 further contributed to shift MB toward a professional sport.

Current COMPs are typically performed on rocky dirt trails, sometimes complicated by tree roots, and commonly consist of alternating technical descents, flat sections and hill climbs. Previous findings indicate that data derived from road cycling can only be partially transferred to off-road events (Impellizzeri et al., 2005b; Impellizzeri and Marcora, 2007; Lee et al., 2002).

To date, only limited empirical evidence is available to assess and compare the physiology of off-road cyclists to provide a scientific basis to monitor training progress.

Earlier studies used primarily heart rate (HR) to determine workload profiles (Faiss et al., 2007; Gregory et al., 2007; Hurst and Atkins, 2006; Impellizzeri et al., 2002; 2005b; MacRae et al., 1999; Nishii et al., 2004; Prins et al., 2007; Seifert et al., 1997; Stapelfeldt et al., 2004). Other investigations used blood lactate (BLa) measures (Gregory et al., 2007; MacRae et al., 1999; Nishii et al., 2004) to ascertain information regarding the metabolic demand during competitive off-road cycling and some studies (Gregory et al., 2007; MacRae et al., 1999; Nishii et al., 2004; Stapelfeldt et al., 2004) have evaluated power output (PO) during COMP.

However, the pattern of workload observed in COMP limits the utility of BLa measures to determine metabolic demand. Since BLa accumulation in COMP occurs quickly, depending on the course (Bond et al. 1991), it may reflect only periods of high intensity work rather than overall load profile of COMP. Also HR response is problematic to assess load profile of MB as it may be influenced by psychological stress performing COMPs (Baron et al., 1992). Furthermore, HR is known to be behind instantaneous changes in power output (Jagoda et al., 2014) and HR even at given PO increases in the time course of exercise (Soares-Caldeira et al., 2012).

Power measures derived from MB pedals represent exertion of force expended by lower limbs and not overall physical activity pattern since off-road cycling on rough terrain requires recruitment of additional muscle mass to handle the bike, stabilize the body against gravity, and respond to heavy vibration (Fraiss et al., 2007; Rittweger et al., 2002).

Considering these above mentioned limitations of single parameters utilized in previous investigations, the main aim of our study was to describe the load profile of COMPs in subjects with different sport-specific performance via the combination of BLa measures and real-time measures of PO, HR and respiratory gas parameters. These normative data may be useful to coaches, athletes and sport scientists working with competitive athletes. We also sought to identify whether laboratory tests (LabT) can serve as predictors for sport specific MB perfor-

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mance.

Methods

Subjects

Twenty-four healthy male competitive off-road cyclists (mean ± SD: age 29 ± 7.2 years, height: 1.79 ± 0.05 m, body mass: 70.0 ± 4.9 kg, VO_2peak: 64.9 ± 7.5 ml·kg^{-1}·min^{-1}) participated in this study. Athletes participating in this study ranged from competitive amateur racers (5 subjects) to competitive athletes with national ranking (18 subjects). Additionally, one "high performance athlete" (HPA) (age: 26 years, height: 1.84 m, body mass: 75.0 kg, VO_2peak: 79.9 ml·kg^{-1}·min^{-1}) that had been in the top 10 of the 2012 Olympic Games volunteered for this study. Subjects were asked to refrain from intense training within 48 h before all tests. Furthermore, the athletes had to record nutritional intake and fluid consumption during a period of 48 h prior to both tests and were asked to utilize the same procedure prior to both trials (LabT, COMP).

The University of Vienna Ethics Committee approved the study and all subjects agreed and signed an informed consent prior to participation.

Laboratory Tests (LabT)

One-minute incremental cycle ergometer tests to maximal voluntary exhaustion were conducted on an electronically braked cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands) according to performance level of the subjects. Based on previous exercise tests LabT were designed to last between 15 to 20 min (starting load 20W; increment size 20 W·min^{-1}, 25 W·min^{-1} or 30 W·min^{-1}). During each trial, participants pedaled at their preferred cadence between 70 to 100 rev·min^{-1}. VO_2peak was determined as the highest mean 30 s value calculated from breath-by-breath measures during LabT. Tests were administered one week prior to the simulated COMP. Respiratory gas measures were conducted using a wireless portable ergo-spirometry system (Oxycon Mobile Pro, Jäger, Würzburg, Germany) in breath-by-breath mode. Volume and gas calibration of the portable system was conducted before each test according to the manufacturer's guidelines. In both test series' (LabT and COMP) BLa was determined utilizing a fully enzymatic-amperometric method (Eppendorf ESAT 6666, Hamburg, Germany). HR was determined by means of a chest-belt telemetry monitor (Polar Mod. T61, Kempele, Finland) transmitted to the portable system.

LabT was utilized to determine PO, VO_2, HR, VE, RER and BLa at maximal workload and respiratory thresholds (VT1 and VT2) (Table 1). Duration was recorded at the final stage of LabT and utilized for linear extrapolation of PO at maximum load. The VT1 introduced by Wasserman (Wasserman and McIlroy, 1964) was defined using the following criteria: first upward shift in VE, an increase in VE/VO_2 without an increase of VE/CO_2 and an increase in oxygen end-tidal volume ($PETO_2$). The VT2, as reported by Beaver et al. (1986) and originally termed respiratory compensation point, was identified by a second upward shift in VE, an increase in VE/CO_2 and a decrease in carbon dioxide end-tidal volume ($PETCO_2$). Determining VT1 and VT2 from LabT, three phases of aerobic-anaerobic transition (Skinner and McLellan, 1980) were established: 1) Phase 1 constitutes predominant aerobic energy supply (end of VT1); Phase 2 is the compensation phase (between VT1 and VT2); and Phase 3 is the decompensation phase (beginning of VT2). LabT data were deemed useful to provide relevant information to other measures made during COMP trials.

Mountain Bike Competition/"Cross Country" (COMP)

The COMP was conducted in a wooded area, on a hilly, rocky, single trail with many roots and curves. The entire COMP was divided into four identical laps. The distance for one lap was 6,087 ± 69 m (Figure 1), the overall distance of the COMP, consisting of 4 laps, was 24,348±195 m. Distance was recorded using a bicycle computer in each case and given as mean of all athletes. The course was chosen as a typical cross country course (single

Table 1. Laboratory tests (LabT). Data are given for relative power output (PO), oxygen uptake (VO_2), heart rate (HR), pulmonary ventilation (V_E), respiratory exchange ratio (RER), and blood lactate concentration (BLa). Data are shown at maximal load, at the ventilatory threshold 1 (VT1) and at the ventilatory threshold 2 (VT2). Data are means (±SD) for all subjects (n = 24) and for a high performance athlete (HPA).

Data determined from Laboratory Testing (LabT): All Subjects (n = 24)			
Variables	**Maximum Load/VO_2peak**	**VT1**	**VT2**
Power output (W)	394 (51)	186 (48	299 (47)
Power output (W·kg^{-1})	5.64 (.64)	2.67 (.65	4.30 (.62)
VO_2 (ml·kg^{-1}·min^{-1})	64.9 (7.5)	34.6 (7.1	50.8 (6.6)
HR (bpm)	188 (10)	133 (10)	165 (14)
VE (l·min^{-1})	161 (21)	55 (16)	90 (17)
RER	1.18 (.09)	.88 (.05)	1.00 (.04)
BLa (mmol·l^{-1})	10.6 (2.9)	1.2 (.8)	3.2 (.9)
Data determined from Laboratory Testing (LabT): High Performance Athlete (HPA)			
Variables	**Maximum Load/VO_2peak**	**VT1**	**VT2**
Power output (W)	500	300	405
Power output (W·kg^{-1})	6.67	4.00	5.40
VO_2 (ml·kg^{-1}·min^{-1})	79.9	48.1	64.4
HR (bpm)	183	146	170
VE (l·min^{-1})	188	94	126
RER	1.28	0.98	0.93
BLa (mmol·l^{-1})	8.3	0.9	1.9

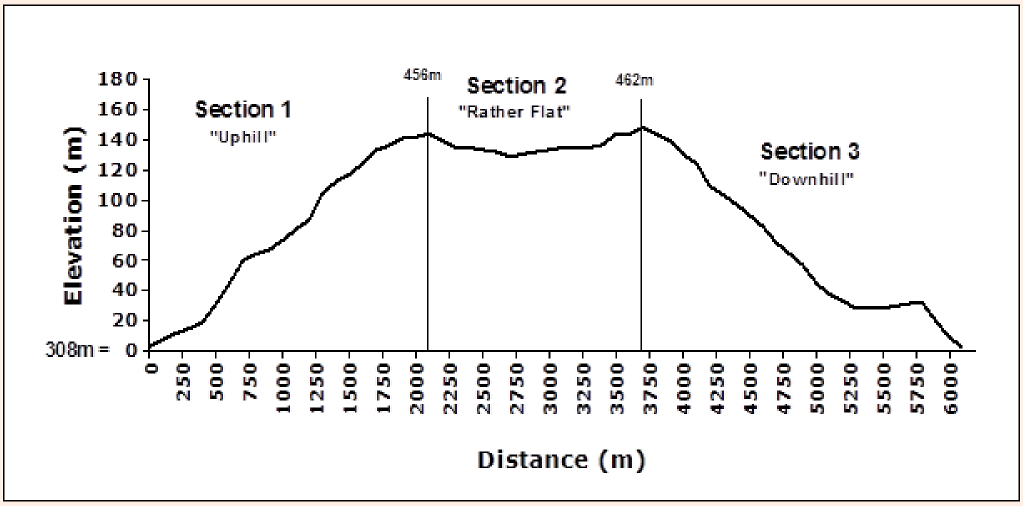

Figure 1. Schematic diagram of the mountain bike course (one of four identical laps). Each lap was divided in three sections: Section 1: uphill section (uphill; start at an elevation of 318m; length ~2095m; and ended at an elevation of 456m). Section 2: rather flat terrain (flat; length ~1553m, and ended at an elevation of 462m). Section 3: downhill section (downhill; start at an elevation of 462m; length ~ 2439m; and finished at the starting point).

competition with repeated identical laps) according to UCI Cycling Regulation E0414 (Version on 4.04.14). The characteristics of the course made it possible to divide the rounds into three sections (Figure 1): 1) Start with section 1 (GPS: longitude: 48.247310, latitude: 16.267591; starting at an elevation of 308 m; ending at an elevation of 456 m); uphill section, distance: 2,095 ± 19 m, average grade: 7.1%¸ highest grade (distance of 100 m): 15.0%; ground condition: alternation of stony ground with roots, sometimes covered with leaves 2) Section 2: (GPS: longitude: 48.51893; latitude: 16.248302, ending at an elevation of 462 m); rather flat terrain; maximal altitude deviation of 15 m; length 1,553 m ± 23 m; ground condition: hard ground often covered with gravel and granite-grit; 3) Section 3 (GPS: longitude: 48.54545; latitude: 16.265741; finishing at the Section 1/Start); downhill section with narrow curves; length 2,439 ± 27 m, average grade: 6.3%; highest grade (distance of 100 m): 10.5%; ground condition: hard ground with stones, sometimes covered with leaves. Values for altitude and elevation were determined from a special map utilized in orienteering competitions.

All COMP's were performed using an identical cycle (Mountain-Bike: Specialized Epic Comp 2005, Morgan Hill, California, USA; frame: Epic-FSR-M4 Aluminum; suspension strut: Specialized AFR inertia, Brain Fade; suspension fork: Fox F100 RL, Specialized). All subjects were equipped with a powermeter and the identical portable spirometry system during LabT.

During the COMP, data collection was conducted utilizing the same spirometry system as during the LabT. A powermeter (SRM/MTB, Jülich, Germany) allowed for on-line measures of power output and cadence during COMP. Both systems were synchronized and data were sampled in time intervals of 5 s. During COMP field variables were measured (RT, POCOMP, HRCOMP, VO_2COMP, VECOMP, RERCOMP, BLaCOMP and cadence (see Table 2). Raw data from SRM and spirometry were synchronized to 5 s intervals. This was the shortest constant interval to be depicted from both the spirometry system and the SRM system utilizing the manufacturers software. Blood samples for determination of BLa were taken immediately after completion of each lap of COMP resulting in interruptions of approximately 30 s for blood collection after each lap. Method of blood sampling and BLa measures was identical with that utilized in laboratory.

Statistical analyses

Statistical analyses were conducted using Statistica Software (Version 6.0, StatSoft, Inc. Tulsa, OK, USA). The results were expressed as mean ± SD. Measure of the linear correlation between two variables was calculated using Pearson Product Moment Correlation. The level of significance was set at $p < 0.05$. Normal distribution of the sample was evaluated utilizing Shapiro-Wilk-Test in all cases. Evaluation of differences between means of field variables recorded during the four laps as well as recorded during uphill, nearly flat and downhill cycling was conducted by one-way analysis of variance (ANOVA) with repeated measures. Post-hoc comparison was made by employing the Least Significance Test. A k-means cluster analysis for three clusters based on RTMBC was used to separate data into three groups of subjects with different sport-specific performance capacity. The analysis of variance (ANOVA) and Tukey HSD tests were employed to detect significant differences between clusters (for field as well as for laboratory variables).

Results

Table 1 depicts results of LabT for study variables determined for power output at VT1, VT2 and maximum load for all subjects, including the criterion HPA. Table 2 shows results of the simulated COMP. All values in Table 2 were calculated for the entire COMP and for each lap.

Table 2. **Mountain bike competition (COMP): Data represent racing time (RT_{COMP}), power output (PO_{COMP}), cadence, oxygen uptake (VO_{2COMP}), heart rate (HR_{COMP}), pulmonary ventilation (VE_{COMP}), respiratory exchange ratio (RER_{COMP}) and blood lactate concentration (BLa_{COMP}) and are depicted for the entire COMP and for every lap. Values are (means ± SD) for all subjects (n = 24) and for a high performance athlete (HPA).**

Data determined form Mountain Bike Competition (COMP): All Subjects (n=24)					
Variables	**Entire COMP**	**Lap 1**	**Lap 2**	**Lap 3**	**Lap 4**
Racing time (hh:mm:ss)	01:05:49 (:06:02)	00:15:57 (:01:2) [abc]	00:16:25 (:01:36) [a]	00:16:36 (:01:09) [b]	00:16:26 (:01:38) [c]
Power output (W)	186 (33)	192 (34) [abc]	184 (31) [a]	180 (33) [af]	186 (36) [cf]
Power output (W·kg^{-1})	2.66 (.43)	2.75 (.45) [abc]	2.65 (.43) [a]	2.59 (.43) [af]	2.67 (.47) [cf]
Cadence (rev·min^{-1})	70 (7)	70 (7)	70 (7)	69 (7)	70 (8)
VO_2 (ml·kg-1·min^{-1})	57.0 (6.8)	59.1 (6.9) [abc]	56.8 (7) [a]	55.7 (7.2) [b]	56.4 (6.8) [c]
Heart rate (bpm)	169 (13)	169 (12)	169 (13)	170 (11)	171 (12)
VE (l·min^{-1})	115 (19.5)	120 (21) [bc]	116 (19) [d]	111 (18) [bd]	113 (21) [c]
RER	.89 (.04)	.91 (.06) [abc]	.88 (.04) [a]	.88 (.04) [b]	.89 (.04) [c]
BLa (mmol·l^{-1})	6.0 (1.4)	6.7 (1.9) [abc]	5.9 (1.3) [a]	5.4 (1.4) [b]	5.9 (2.4) [c]
Data determined from Mountain Bike Competition (COMP): High Performance Athlete (HPA)					
Variables	**EntireCOMP**	**Lap 1**	**Lap 2**	**Lap 3**	**Lap 4**
Racing time (hh:mm:ss)	00:51:49	00:12:45	00:12:48	00:13:12	00:13:04
Power output (W)	264	274	256	253	274
Power output (W·kg^{-1})	3.52	3.65	3.41	3.37	3.65
Cadence (rev·min^{-1})	84	84	84	82	86
VO_2COMP (ml·kg^{-1}·min^{-1})	71.1	73.0	70.9	69.9	70.5
Heart rate (bpm)	181	179	182	181	181
VE (l·min^{-1})	172	172	170	172	174
RER	0.92	0.92	0.93	0.92	0.92
BLa (mmol·l^{-1})	6.7	6.2	6.8	6.3	7.3

[a] Lap1 vs. Lap2 significantly different ; [b] Lap1 vs. Lap3 significantly different. [c] Lap1 vs. Lap4 significantly different. [d] Lap2 vs. Lap3 significantly different. [e] Lap2 vs. Lap4 significantly different. [f] Lap3 vs. Lap4 significantly different

Values of field-testing (COMP) are also reported for the HPA (Table 2). When considering the racing time of single laps of COMP, the first lap was completed significantly faster than the subsequent three laps. That was associated with significantly higher values for PO_{COMP}, VO_{2COMP}, and BLa_{COMP} in lap 1 (Table 2). The higher VO_2 was found in lap 1 that was also accompanied by a higher ventilatory effort (V_{ECOMP}) (Table 2). In contrast, no differences between the single laps were found for HR.

In approximately 12% of entire RT, we found no or low PO (less than 30 Watt) determined from the SRM powermeter. When manually eliminating phases of no or low PO from 5 s measures (phases of rolling, downhill riding, and racing through sharp turns) the average PO_{COMP} of athletes increased from 2.64 ± 0.43 W·kg^{-1} to 3.13 ± 0.49 W·kg^{-1} and from 3.52 W·kg^{-1} to 4.11 W·kg^{-1} for the HPA, respectively.

The entire data set of 24 subjects with a broad range of performance capacities was additionally divided into three groups based on RT_{COMP} (k-means cluster analysis for three clusters based on RT). The ANOVA and Tukey HSD-test revealed significant differences in RT_{COMP} between the three groups ($p < 0.001$ in all cases; see Table 3). Tables 3 and 4 depict data of the three clusters calculated for COMP and LabT. These variables represent the physical activity pattern and endurance performance of cyclists with different sport specific MB levels.

Table 3. **LabT data for three clusters (Good, Medium and Low Performance) consisting of subjects with significantly different racing time (clusters calculated by k-means analysis). Data are shown for variables measured and for performance variables of Laboratory Tests (LabT). For descriptions of variables see Table 1 and Table 2. Values are (means ± SD).**

Data determined from Laboratory Testing (LabT)			
Variables	**Cluster 1 (n = 5) Good Performance**	**Cluster 2 (n = 12) Medium Performance**	**Cluster 3 (n = 7) Low Performance**
Age (years)	29.8 (7.8	29.4 (7.6)	27.7 (7.1
Height (m)	1.83 (.02)	1.77 (.04)	1.78 (.06)
Weight (kg)	73.4 (1.3) [a]	68.5 (5.1) [a]	69.4 (5.6)
Power output at VT1 (W)	255 (29) [ab]	173 (22) [a]	160 (47) [b]
Power output at the VT1 (W·kg^{-1})	3.48 (.28) [ab]	2.54 (.40) [a]	2.31 (.69) [b]
Power output at VT2 (W)	368 (26) [ab]	293 (14) [a]	262 (43) [b]
Power output at VT2 (W·kg^{-1})	5.02 (.28) [ab]	4.30 (.44) [a]	3.77 (.56) [b]
Peak VO_2 (ml·kg^{-1}·min^{-1})	74.2 (4.7) [ab]	65.5 (5.0) [ac]	57.3 (3.7) [bc]
VO_2 at VT1 (ml·kg^{-1}·min^{-1})	43.1 (3.5) [ab]	33.2 (4.5) [a]	31.1 (8.4) [b]
VO_2 at VT2 (ml·kg^{-1}·min^{-1})	58.8 (5.2) [ab]	50.4 (4.3) [a]	45.6 (3.7) [b]

[a] Good Performance vs. Medium Performance significantly different. [b] Good Performance vs. Low Performance significantly different. [c] Medium Performance vs. Low Performance significantly different.

Table 4. Data of three clusters (Good, Medium and Low Performance) consisting of subjects with significantly different racing time (clusters calculated by k-means analysis). Data are shown for variables measured during COMP. For description of variables see Table 2. Values are (means ± SD).

Data determined from Mountain Bike Competition (COMP)			
Variables	Cluster 1 (n = 5) Good Performance	Cluster 2 (n = 12) Medium Performance	Cluster 3 (n = 7) Low Performance
Racing time (s)	3444 (201) [ab]	3867 (118) [ac]	4362 (174) [bc]
Power output (W)	231 (2) [ab]	184 (17) [ac]	155 (19) [bc]
Power output ($W \cdot kg^{-1}$)	3.18 (.29) [ab]	2.69 (.27) [ac]	2.26 (.31) [bc]
Cadence ($rev \cdot min^{-1}$)	72 (9)	70 (7)	69 (5)
VO_{2COMP} ($ml \cdot kg^{-1} \cdot min^{-1}$)	64.8 (5.0) [ab]	57.5 (4.2) [ac]	50.7 (4.3) [bc]
Heart rate (bpm)	165 (17)	168 (7)	172 (19)
V_E ($l \cdot min^{-1}$)	129 (29) [b]	118 (13) [ac]	101 (14) [b]
RER	.90 (.09)	.89 (.03)	.91 (.03)
BLa ($mmol \cdot l^{-1}$)	5.9 (.9)	5.9 (1.5)	6.2 (1.6)

[a] Good Performance vs. Medium Performance significantly different. [b] Good Performance vs. Low Performance significantly different. [c] Medium Performance vs. Low Performance significantly different.

We were additionally interested in the question of whether a faster RT_{COMP} resulted in higher metabolic responses. When calculating a correlation between RT_{COMP} vs. variables of energy demand of COMP (PO_{COMP}, VO_{2COMP}, VE_{COMP}, HR_{COMP}, BLa_{COMP}) we found a significant negative correlation between RT_{COMP} vs. PO_{COMP} ($p < 0.001$; $r = -0.78$), RT_{COMP} vs. VO_{2COMP} ($p < 0.001$; $r = -0.83$) and RT_{COMP} vs. V_{ECOMP} ($p < 0.05$; $r = -0.60$). There was no evidence that BLa_{COMP} and/or cadence had an influence on RT_{COMP}. When examining ventilatory data, we found significant positive correlations between PO_{COMP} vs. VO_{2COMP} ($p < 0.001$; $r = 0.71$) and PO_{COMP} vs. V_{ECOMP} ($p < 0.01$; $r = 0.53$).

We further analyzed PO_{COMP}, VO_{2COMP}, and R_{COMP} when expressed as percentages of corresponding variables during LabTs. Mean PO_{COMP} was 61.9% of PO_{VT2} and 47.2% of PO_{max}, whereas VO_{2COMP} was 112% of VO_{2VT2} and 88% of VO_{2peak} and HR_{COMP} was 102% of HR_{VT2} and 90% of HR_{max}. Calculating differences by one-way ANOVA with repeated measures (post-hoc Least Significance Test), we found the percentages for PO were significantly lower than that detected for VO_2 and HR ($p < 0.001$ in all cases). The following values were found for the HPA: PO_{COMP} 67.8% of PO_{VT2}; 54.2% of PO_{max}; VO_{2COMP} 112% of VO_{2VT2}; 89% of VO_{2peak} and HR_{COMP} 102% of HR_{VT2}; and 91% of HR_{max}. The comparison of COMP and LabT data for all subjects are also presented in Figures 2A, 2B and 2C.

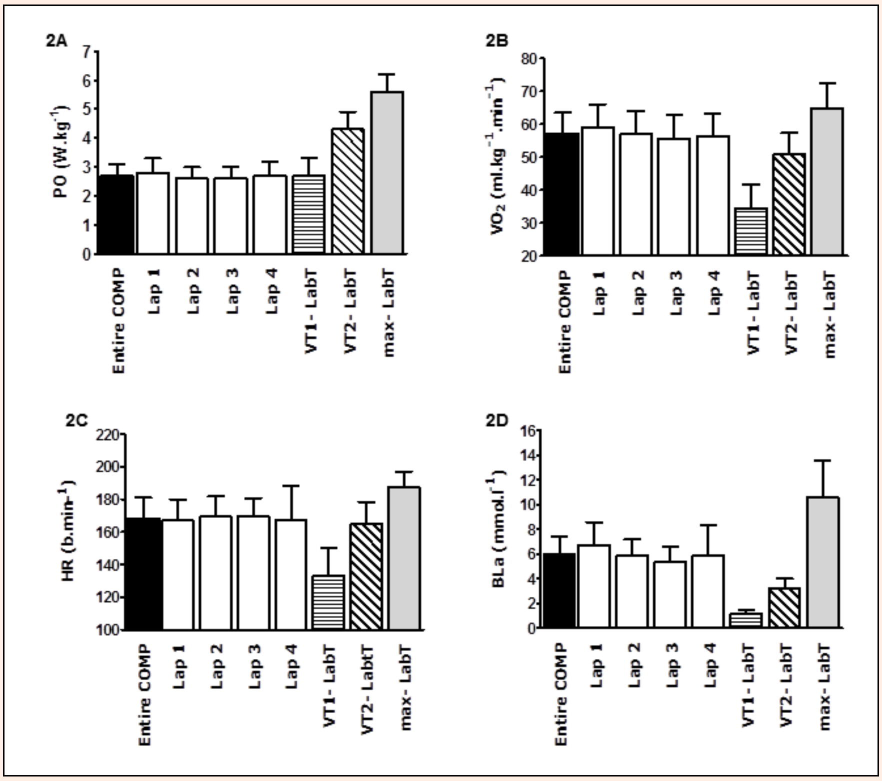

Figure 2. **PO (2A), VO_2 (2B), HR (2C) and BLa (2D) during COMP. Values represent the mean of the entire COMP (2A-2C: average of 5 s; 2D: average of 4 laps) and for every lap. Values are related to variables of LabT (VT1, VT2, and max). Values are means ± SD for all subjects (n = 24).**

Table 5. Mountain bike competition (COMP): Data (means ± SD) are presented for sections Uphill, Flat and Downhill (see Figure 1) for all subjects (n = 24) and for a high performance athlete (HPA). For legend of variables see Table 3. Values are (means ± SD).

Data determined form Mountain Bike Competition (COMP): All Subjects (n=24)			
Variables	**Section 1 (Uphill)**	**Section 2 (Nearly Flat)**	**Section 3 (Downhill)**
Power output (W)	226.1 (41.7) [ab]	175 (32.9) [ac]	101 (26) [bc]
Power output ($W \cdot kg^{-1}$)	3.24 (.55) [ab]	2.52 (.43) [ac]	1.44 (.35) [bc]
Cadence ($rev \cdot min^{-1}$)	79 (9) [ab]	74 (7) [ac]	54 (12) [bc]
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	62.5 (7.9) [ab]	55.9 (7.3) [ac]	45.6 (6.0) [bc]
HR (bpm)	172 (14) [b]	170 (13) [c]	159 (14) [bc]
V_E ($l \cdot min^{-1}$)	126 (21) [ab]	115 (22.7) [ac]	91 (17) [bc]
RER	.91 (.04) [ab]	. 88 (.04) [ac]	.86 (.65) [bc]
Data determined from Mountain Bike Competition (COMP): High Performance Athlete (HPA)			
Variables	**Section 1 (Uphill)**	**Section 2 (Nearly Flat)**	**Section 3 (Downhill)**
Power output (W)	328	259	149
Power output ($W \cdot kg^{-1}$)	4.37	3.45	1.99
Cadence ($rev \cdot min^{-1}$)	89	97	64
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	76.6	69.7	59.2
HR (bpm)	184	185	171
V_E ($l \cdot min^{-1}$)	185	185	137
RER	0.95	0.93	0.87

[a] Section1 vs. Section2 significantly different. [b] Section1 vs, Section3 significantly different. [c] Section2 vs. Section3 significantly different.

Table 6. Results of correlation coefficients (r) between the variables of racing time and PO_{COMP} vs. endurance variables of LabTs (PO and VO_2 measured at maximal workload, VT1 and VT2). Values are presented for all subjects (n = 24).

Variables	Racing time	POCOMP
Maximal power output ($W \cdot kg^{-1}$) = PO_{max}	-.78 ***	.72 ***
Power output at VT1 ($W \cdot kg^{-1}$) = PO_{VT1}	-.63 **	.65 **
Power output at VT2 ($W \cdot kg^{-1}$) = PO_{VT2}	-.77 ***	.76 ***
Peak $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) = VO_{2peak}	-.80 ***	.77 ***
VO_2 at VT1 = VO_{2VT1}	-.59 **	.66 **
VO_2 at VT2 = VO_{2VT2}	-.75 ***	.68 ***

** p < 0.01; *** 0 < 0.001

Our COMP trail was divided into three sections with different gradients, uphill, flat and downhill terrain (Figure 1). The COMP values calculated for the three sections are presented in Table 5. In addition, we provide information regarding the intensity pattern determined during COMP. The COMP variables of PO_{COMP}, VO_{2COMP}, and HR_{COMP} were compared with maximal values measured during LabT (Figure 3), whereby the total time spent at various percentage bands (10% bands) are expressed as percentage of peak values determined in LabT_(Figures 3A, 3B and 3C). The variables of cardiopulmonary demands (VO_{2COMP}, HR_{COMP}) appeared at considerably higher percentage ranges (Figures 3B and 3C) when compared to PO_{MTB} (Figure 3A). For VO_{2COMP} (Figure 3B) the most frequent intensity range was 100-110% of VO_{2peak} (29.2% for the entire RT_{COMP}) and the most frequent intensity range for HR_{COMP} (Figure 3C) was 90-100% of HR_{max} (60.6% for the entire RT_{COMP}). In contrast, for PO_{COMP} the highest value found in a percentage band was found between 50-60% of PO_{max} of LabT (18.4% for the entire RT; Figure 3A**)**. This result again demonstrates the essential differences of P_{COMP} compared to variables of cardiopulmonary demands and VO_2 during COMP.

Finally, we assessed performance measurements of COMP (RT_{COMP} and PO_{COMP}) to endurance measures of LabT to determine the relationship and association of these variables. We calculated the correlation between RT_{COMP} and P_{COMP} and endurance variables of LabT (PO and VO_2) determined at maximal workload and at VT1 and VT2 (Table 6). No correlation was found for BLa during LabT (BLa_{COMP} vs. BLa_{max}, BLa_{VT2} and BLa_{VT1}).

The association between sport specific performance of COMP (RT_{COMP}) and results of LabT are also supported by our clusters showing that in the cluster with the shortest RT_{COMP} (good performance; Table 3) all endurance variables of subjects (Table 3) were significantly higher than those observed in the other two clusters with significantly lower RT_{COMP} (p < 0.001 between Cluster “Good Performance” vs. “Low Performance” in all cases and p < 0.01 between Cluster “Good Performance” vs. “Medium Performance” in all cases).

Discussion

The main aim of this study was to assess load profile of COMP (“Cross Country”). To our knowledge, this is the first study evaluating oxygen costs of an entire COMP using open circuit spirometry. Combining VO_2 with measures of PO, HR and blood lactate may provide additional information about the external workload and metabolic response of athletes performing COMP. Our group of competitive MB cyclists and a single high level professional MB cyclist were used for that purpose.

Regarding the mean VO_{2peak} determined from our LabT (Table 1), there are MB studies reporting higher VO_{2max}/VO_{2peak} values (Baron, 2001; Impellizzeri et al., 2002; 2005a; 2005b; 2008; Lee et al., 2002; Nishii et al., 2004; Wilber et al., 1997), others with comparable values (Gregory et al., 2007; Prins et al., 2007; Stapelfeldt et al., 2004) and others with lower values (Faiss et al., 2007; MacRae et al., 1999) (Table 7). Our subjects exhibited a broad range of aerobic capacities (Table 1) and sport specific performance (Table 2). We divided the group into three clusters based on RT_{COMP}. The resulting clusters of good, medium and low performance document aerobic power of three groups of MB cyclists with significantly different sport specific abilities (Table 3).

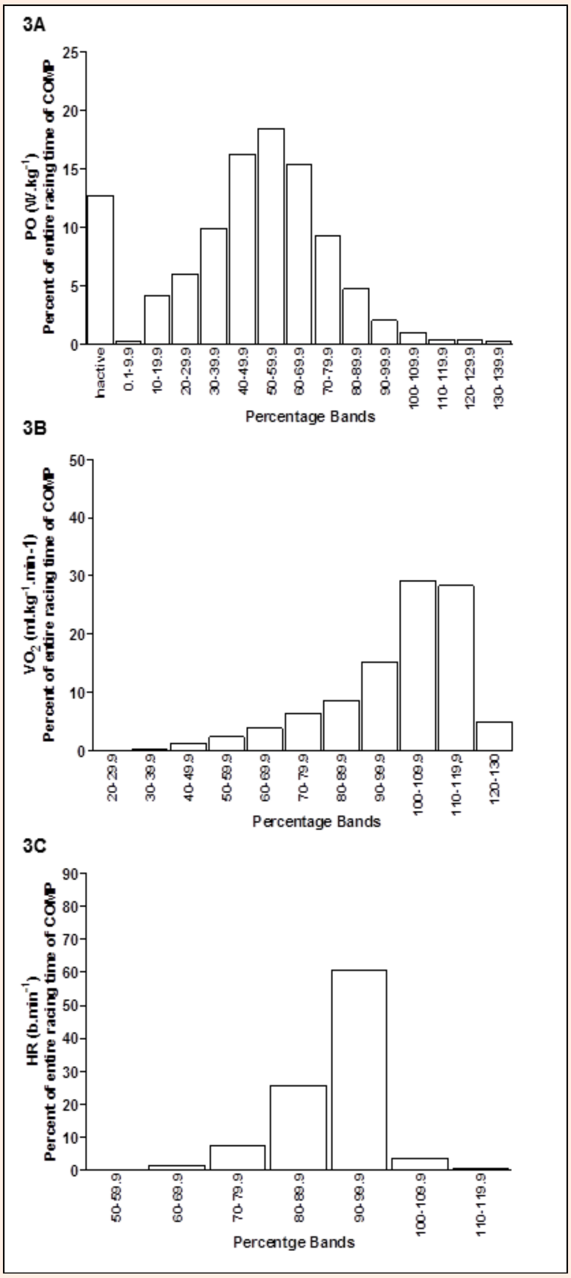

Figure 3. Mountain bike competition: Percentage of total time spent at various percentage bands (10% bands) expressed as percentage of peak values determined from LabTs. Values are shown for PO (3A), VO_2 (3B) and HR (3C). Values are means ± SD for all subjects (n = 24). The term inactive (Figure 3A) depicts the inactive phases of COMP (no power output or power output of less than 30 W).

The mean maximal power (PO_{max}) determined from LabT for all subjects in our investigation (Table 1) was lower than that of Impellizzeri et al. (2005a), Impellizzeri et al. (2005b), Nishii et al. (2004), Lee et al. (2002) and Wilber et al. (1997), comparable with results of Baron (2001) and Impellizzeri et al. (2002) and higher than those reported by Gregory et al. (2007), MacRae et al. (1999), Prins et al. (2007) and Stapelfeldt et al. (2004) (Table 7). The PO_{max} found for the three clusters of good, medium, and low performance participants were significantly different ($p < 0.001$; Table 3).

The data determined for the HPA (Table 1) during LabT were lower than the highest values (VO_{2max} of 86.1 $ml·kg^{-1}·min^{-1}$ and PO_{max} of 7.4 $W·kg^{-1}$) reported by Impellizzeri et al. (2005a) for a single elite cyclist. Comparing data of HPA (Table 1) with mean values of Earnest et al. (2009) who examined 26 professional road cyclists that repeatedly participated in Grand Tours (Tour de France and Vuelta), we found higher VO_{2peak} (75.8 ± 5.5 9 $ml·kg^{-1}·min^{-}$1) and lower PO_{max} (7.06 ± 0.51 $W·kg^{-1}$) for the HPA.

We additionally determined VO_2 and PO at VT1 and at VT2 (Table 1) for athletes and found only a single study that utilized a comparable threshold concept (Impellizzeri et al. 2005a). The authors presented higher mean values (56.8 ± 4.8 $ml·kg^{-1}·min^{-1}$ for VO_{2VT1}, 67.3 ± 4.8 $ml·kg^{-1}·min^{-1}$ for VO_{2VT2}, 4.1 ± 0.6 $W·kg^{-1}$ for PO_{VT1} and 5.4 ± 0.4 $W·kg^{-1}$ for PO_{VT2}) for their MB athletes_compared to our sample. The HPA (Table1) again exhibited lower values at VT1 and VT2 compared to the highest values measured for a single athlete by Impellizzeri (2005a) (VO_{2VT1}: 67.5 $ml·kg^{-1}·min^{-1}$, VO_{2VT2d}: 75.0 $ml·kg^{-1}·min^{-1}$, PO_{VT1}: 5.2 $W·kg^{-1}$ and PO_{VT2}: 6.1 $W·kg^{-1}$). The mean BLa observed at VTs was relatively low (Table 1). For example, Smekal et al. (2012) determined BLa_{VT2} of 4.5 ± 1.1 $mmol·l^{-1}$ in a group of 62 subjects (42 men and 20 women) with a broad range of VO_{2peak} (34.1 to 74.8 $ml·kg^{-1}·min^{-1}$).

Characteristics of the COMP trail and racing time

The COMP trail was a rocky, hilly single trail with many roots and stones in a wooded area. The entire distance consisted of four identical laps (Figure 1) comprising ~24,348 m (average for entire four laps of RT_{COMP} was 1:05:24 ± 6:03 (h:mm:ss; Table 2, Table 3). As expected, the fastest RT_{COMP} was completed by the HPA (0:51:49; see Table 2). As mentioned above, the course was chosen as a cross country course (single competition with repeated identical laps) according to UCI Cycling Regulation E0414 (Version on 4.04.14). The average RT_{COMP} was somewhat shorter than specified for a Cross-Country Olympic XCO (UCI sanctioned race between 1:15:00 and 1:30:00) and longer than a Cross-Country Short Circuit XCC, Short Track (UCI sanctioned for races with a duration of 00:30:00 to 01:00:00 hh:mm:ss). Our athletes started the COMP with high ambition – a fact that was demonstrated by a significantly faster first lap than the following three laps (Table 2). This pacing strategy may be surprising in the light of previous data suggesting that uniform racing pace may be advantageous for cycling time trials (Atkinson et al., 2000; 2003; Impellizzeri and

Table 7. Results of previous MB studies reporting VO_2max/VO_2peak ($ml \cdot kg^{-1} \cdot min^{-1}$) and POmax (Watt and Watt·kg^{-1}). Values are (means ± SD).

Author	Level	(n)	$\dot{V}O_{2max/peak}$	PO_{max} (Watt)	PO_{max} (Watt·kg^{-1})
Baron (2001)	Elite	25	68.4 ± 3.8	384 ± 34	5.5 ± 0.4
Gregory et al. (2007)	Elite	11	67.1 ± 3.6	367 ± 32	5.1 ± 4.4
Impellizzeri et al. (2002)	Elite	5	75.9 ± 5.0	368 ± 31	5.7 ± 0.5
Impellizzeri et al. (2005a)	Elite	12	76.9 ± 5.3	426 ± 40	6.4 ± 0.6
Impellizzerri (2005b)	Elite	13	72.1 ± 7.4	392 ± 35	6.0 ± 0.4
Lee et al. (2002)	Elite	7	78.3 ± 4.4	413 ± 36	6.3 ± 0.5
MacRae et al.(2000)	Amateur	6	58.4 ± 2.3	389 ± 41	5.1 ± 0.3
Nishii et al. (2004)	Elite	9	67.8 ± 5.8	380 ± 35	6.0 ± 0.5
Prins et al. (2007)	Amateur	8	63.6 ± 5.7	272 ± 37	5.1 ± 0.4
Stapefeldt et al. (2004)	Elite	9	66.5 ± 2.6	368 ± 25	5.3 ± 0.3
Wilber et al. (1997)	Elite	10	70.0 ± 3.7	420 ± 42	5.9 ± 0.3

Elite = Competitive cyclist at international level. Amateur = Competitive cyclist at national/amateur level.

Marcora, 2007; Mattern et al., 2001) but there are also findings suggesting that the pacing strategy observed in our investigation is not unusual in cross-country cycling (Impellizzeri et al., 2002; Stapelfeldt et al., 2004). The faster racing time of lap 1 also resulted in significantly higher values for PO_{COMP}, VO_{2COMP}, V_{ECOMP} and BLa_{COMP} (Table 2). In contrast, HR_{COMP} was similar and not significantly different between all four laps, demonstrating that HR measures are not sensitive to ascertain load profiles of off-road events (Smekal et al. 2003).

Physiological profile of COMP/VO_2, HR

The average VO_{2COMP} calculated for all subjects was 57.0 $ml \cdot kg^{-1} \cdot min^{-1}$ or 12.0% lower than the VO_{2peak} determined in LabT, and 13.1% higher than the $\dot{V}O_{2VT2}$ (Figure 2B, Tables 1 and 2). No significant differences were found between the clusters in this context. Despite significantly different sport specific performance capacity observed between the clusters, COMP was completed within comparable intensity. For the HPA, the VO_{2COMP}, corresponded to 88.9% of VO_{2peak} or 110.4% of VO_{2VT2}.

However, these data refer to the fact that riders during cross-country MB exhibit a considerable high intensity. This observation is in line with findings reported by Impellizzeri et al. (2002) and Impellizzeri and Marcora (2007). Impellizzeri et al. (2002) monitored nine MB athletes (six under 23 years old and three elite/UCI categories) calculating a somewhat lower mean percentage of 84 ± 3% of VO_{2peak} from HR data measured during different MB competitions. But in this study, the mean duration of races was longer 147 ± 15 min than in our investigation. Comparing our recent data with those determined from another off-road event in running (orienteering), athletes of the Austrian National Team showed an average VO_2 during simulated competitions (mean duration 57:44 min) of 83.0 ± 3.8% of athlete's VO_{2max} obtained in a TT. However, the high percentage of VO_{2COMP} with respect to VO_{2max} of LabT illustrates the aerobic abilities that are required to meet the physiological demand of off-road cycling.

The findings of high oxygen costs of MB are supported by the VO_2 time duration. Expressing the total time spent at various percentage bands (10% bands) as percentages of peak values determined from LabTs, the highest intensity band for VO_{2COMP} (Figure 3B) was found between 100-109.9% of VO_{2peak} (29.2% for the entire RT_{COMP}). These VO_{2COMP} values are likely attributable to high muscular effort and greater engaging muscle mass of the athletes not only for maintaining the workload and cadence but also for bike handling, bike and body stabilization working against gravity, rolling resistance and heavy bike vibration (Fraiss et al., 2007; Rittweger at al., 2002). This notion is supported by the finding that during downhill sections VO_2 values decreased, corresponding to no less than 70% of VO_{2peak} (Table 5).

Regarding the respiratory gas exchange measures, only a few papers are comparable to our study. To our knowledge, only a single investigation is currently available that measured VO_2 during a short phase of MB cycling (Fraiss et al. 2007). But these data are not really comparable to ours, since cyclists were instructed to cycle at a HR corresponding to the HR determined at their anaerobic threshold (LA concentration of ~4.0 $mmol \cdot l^{-1}$).

The HR_{COMP} (Table 2, Figure 2C) was 169 ± 13 bpm corresponding to 89.8% of HR_{max} and 102.2% of HR_{VT2} (Figure 2C). These values are similar to those reported in the literature. Impellizzeri et al. (2002) found an average HR_{COMP} of 171 ± 6 bpm (mean of 4 COMP) for well trained, competitive MB cyclists with a mean VO_{2peak} of 75.0 ± 6 $ml \cdot kg^{-1} \cdot min^{-1}$ corresponding to 90.0 ± 3% of HR_{max}. However, in this study, the racing distance was longer, ranging between 33 and 44 km. In a different investigation of simulated COMP with a mean RT_{COMP} of 1:36:33 hour, Impellizzeri et al. (2005b) measured a HR_{max} of 90.0 ± 4%. Stapelfeldt et al. (2004) examined 11 national team cyclists (9 male, 2 female) during 15 races (RT_{COMP} between 1:58 and 2:27 hours) and calculated an average HR_{COMP} of 177 ± 6 bpm for male cyclists with a HR_{max} of 91.7%. In a study published by Gregory et al. (2007) investigating nine A-class MB cyclists with a mean VO_{2peak} of 67.1 ± 3.6 $ml \cdot kg^{-1} \cdot min^{-1}$ reported a mean HR_{COMP} of 91.2% of HR_{max} during a simulated COMP (mean RT_{COMP} of 61:33 min).

When assessing HR times (Figure 3C) and dividing the entire RT_{COMP} into percent ranges of 10%, the most frequent percent range was between 90-99.9% of HR_{max} (60.6% for the entire RT_{COMP}). In practice, HR values during off-road cycling events support the findings of high demand of whole body cardiopulmonary requirements. Assessing the average HR of the four laps of our COMP, we observed the average HR of all laps to be very similar (Figure 2C, Table 2). In contrast, PO and $\dot{V}O_2$

were significantly higher in lap 1 resulting in a significantly faster RT in lap 1 (Table 2).

Physiological measures of COMP/PO, BLa, cadence

The component of PO_{COMP} was substantially different compared to variables of cardiopulmonary demands and VO_2 of COMP (VO_{2COMP} and HR_{COMP}). The relative PO_{COMP} calculated for all subjects (2.66 ± 0.43 $W \cdot kg^{-1}$; see also Tables 1 and 2) accounted for 47.2% of PO_{max} and 61.9% of PO_{VT2}. As demonstrated in Figure 2A, Tables 1 and 2, the mean PO_{COMP} calculated for all subjects was similar to PO_{VT1} determined during the LabT (PO_{VT1}: 2.67 $W \cdot kg^{-1}$). The mean PO_{COMP} value for our total group of cyclists was higher compared with the PO measured in a group of German National Team cyclists (Stapelfeldt et al. 2004) during 15 races (3.5 $W \cdot kg^{-1}$). Nevertheless, in the investigation of Stapelfeldt, RT was longer (mean RT: 2:08 h). In another study by Nishii et al. (2004), they reported a higher mean PO (3.76 and 3.78 $W \cdot kg^{-1}$) when comparing two different suspension systems during off-road cycling (RT of 30 min). The HPA (Table 2) revealed a higher PO_{COMP} in comparison to the group of German National Team MB cyclists tested by Stapelfeldt et al. (2004) and Nishii et al. (2004).

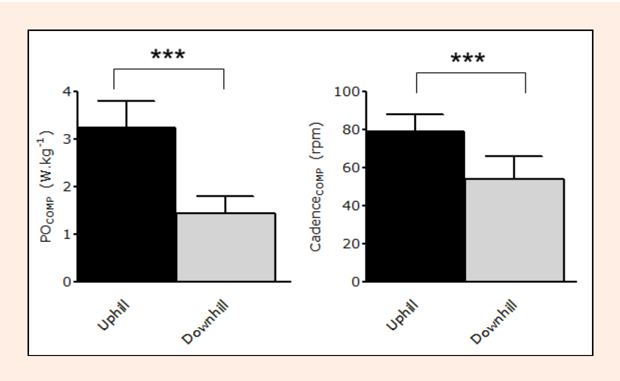

Figure 4. Power output and cadence during uphill and downhill phases of COMP. *** $p < 0.001$.

However, the relatively low values of PO_{COMP} in our group of cyclists were also influenced by the periods of cycling where there was no or very low force production applied to the pedals, particularly during the downhill portion (Table 5, Figure 4). By manually eliminating low power output phases and removing time with no or very low power output (less than 30 Watts) from the data set the average PO_{COMP} increased from 2.64 ± 0.43 $W \cdot kg^{-1}$ to 3.13 ± 0.49 $W \cdot kg^{-1}$. After removal of these low PO phases, the PO_{COMP} corresponded to only 59.0% of PO_{max}, 77.4% of PO_{VT2} and 124.7% of PO_{VT1}. Compared to our HPA, the mean PO_{COMP} increased from 3.52 $W \cdot kg^{-1}$ to 4.11 $W \cdot kg^{-1}$ during active phases.

As previously mentioned, the increase in VO_{2COMP} and HR_{COMP} may be attributed to the larger muscle mass simultaneously working to fulfill the demand of MB. It cannot be ruled out that blood flow to lower limbs may have been reduced (Volianitis et al., 2003) in these conditions. This assumption is supported by findings showing that depending on exercise intensity, blood flow to exercising leg muscles is reduced due to the recruitment of additional muscle mass (e.g. arm exercise) (Bangsbo et al., 1997; Richardson et al., 1997; Richter et al., 1992; Savard et al., 1989), thus negatively influencing leg muscle oxygenation. As a result, leg muscle performance and force production might be considered to be impaired. The low P_{COMP} measured in the present study may also have been influenced by the topography of our trail, which was difficult to maneuver, consisting of a variety of roots, curves, sometimes loam and cluttered with large stones. This was especially true during the uphill stages. This terrain characteristic may have forced athletes to react with much caution when pedaling and required strategic and technical knowledge of each cyclist. That has been subsequently confirmed by the athletes.

The blood lactate concentration (BLa_{COMP}) (mean of four laps) was 5.98 ± 1.38 $mmol \cdot l^{-1}$ (Table 2), while no differences were observed between the clusters (Table 3). This BLa_{COMP} was nearly identical with that reported by Nishii et al. (2004) and lower than that found by Gregory et al. (2007) and MacRea et al. (1999), who determined mean BLa values between 8.0 and 9.0 $mmol \cdot l^{-1}$. However, in the investigation of Nishii et al. (2004) that was similar to ours, blood samples were collected after a longer period of downhill riding, while in the study of Gregory et al. (2007) the downhill passage prior to blood sampling was very short (600 m). In the study of MacRea et al. (1999) the BLa was measured following an uphill section. The BLa measured in sports with intermittent workload are substantially influenced by the high intensity work, the amount and duration of phases and the time of blood sampling following these sections. Consequently, BLa measures during off-road cycling similar to off-road running (Smekal et al., 2003) may not be appropriate to evaluate varying load profiles and may lead to inaccurate estimates of a physical activity pattern of MB.

Concerning cadence during COMP, there were no significant differences with respect to laps (Table 2) as well as between the three clusters with different COMP performances (Table 4). A higher cadence was found for the HPA compared to all subjects (Table 2 and Table 4). However, our approach using mean values may be problematic to describe the variable cadence accurately under these conditions.

Relationship between RT vs. other study variables of field testing

It is not surprising that faster RT_{COMP} resulted in higher load profiles, a finding that has been documented by significant correlations found between RT_{COMP} vs. PO_{COMP}, VO_{2COMP}, V_{ECOMP} and HR_{COMP}. There was no evidence of an influence of BLa_{COMP} and cadence associated with RT_{COMP}. Despite the above described differences between PO_{COMP} and VO_{2COMP}, these two variables were significantly and positively correlated. In addition, V_{ECOMP} was correlated with PO_{COMP}, indicating higher ventilatory effort with higher workload.

Association between LabT and COMP variables

We further found that endurance variables were credible predictors for sport specific performance of RT_{COMP} and PO_{COMP}. This statement is supported by significant correlations between RT_{COMP} and P_{COMP} and variables of aerobic power (LabT; Table 6). This result underlines the necessity for sport specific abilities of successful MB performance. Our study is in agreement with others who also reported significant correlations between RT_{COMP} and endurance variables determined from LabT (Gregory et al., 2007; Impellizzeri et al., 2005a; 2005b). In spite of these reported results, only 65% of the variance could be explained by a single endurance variable (Table 6). Comparisons between LabT and COMP (Tables 1, 2 and 5) demonstrate the different practical relevance of variables. Data determined from LabT may be utilized to supplement specific abilities of MB athletes on a cycle ergometer, while findings originating from COMP could be especially considered when designing mountain bike specific training.

Finally we want to refer to some limitations. As mentioned before, the average RT_{COMP} due to loading capacity of the batteries (time for warming up and calibration procedure of the spirometry system, for slowly cycling to the starting point and for performing COMP) was somewhat shorter than specified for a Cross-Country Olympic Competition. Furthermore, within the UCI guidelines, there is a considerable variation concerning the characteristics of a course. Our course (chosen by two semi professional MB trainers) was very rocky with many roots and curves. Participants (including the HPA) described the trail as competitive and technically selective. However, the question is whether data derived from only a single course really reflects the broad spectrum possible for cross-country cycling competitions. We also have to concede that all athletes used the same MB cycle for COMP. This approach seemed practicable, since an accurate service and preparation of equipment (SRM system and cycle) could be completed on evenings prior to tests. Only a short warm-up phase of approximately 10 min remained for participants to become acquainted with the MB cycle (however, during the entire phase of COMP measures there was no critique about the cycle).

Conclusion

The present study resulted in the following main findings: 1) HR and BLa measures were not sufficiently sensitive to ascertain the load profiles of COMP. Therefore, respiratory gas and power output measures are helpful to provide new insights to the physiological profile of cross-country cycling. 2) During COMP, very high oxygen costs exist, probably influenced by the high muscle mass simultaneously working to fulfill the demands of the COMP. On the other hand, based on data determined from LabT (maximum, VT1 and VT2) PO_{COMP} turned out to be lower when compared to VO_{2COMP}, likely caused by phases of no or very low force production applied to the pedals (particularly during the downhill phases), by the rocky trail with many roots and stones forcing athletes to react with caution and maybe also by a lower blood flow and leg muscle oxygenation due to the recruitment of a high number of muscle groups. 3) An excellent endurance cycling ability appears to be a prerequisite for COMP, but good sport-specific abilities are also needed for successful off-road cycling. 4) Data determined from LabT might be utilized to describe semi-specific abilities of MB athletes on a cycle ergometer, while data originating from COMP might be useful when designing MB-specific training. 5) Our data only measured a single MB trail, hardly reflective of the broad spectrum of possible cross-country courses. Therefore, generalization of these results is limited.

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Authors declare no conflict of interest.

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Key points

- Cross- country cycling is characterized by high oxygen costs due to the high muscle mass simultaneously working to fulfill the demands of this kind of sports.
- Heart rate and blood lactate concentration measures are not sensitive enough to assess the energy requirements of COMP. Therefore, respiratory gas and power output measures are helpful to provide new information to physiological profile of cross-country cycling.
- An excellent cycling-specific capacity is a prerequisite for successful off-road cycling.
- Data determined from LabT might be utilized to describe semi-specific abilities of MB- athletes on a cycle ergometer, while data originating from COMP might be useful when designing a mountain bike specific training.

AUTHOR BIOGRAPHY

Gerhard SMEKAL
Employment
Prof., Institute of Sports Science, Depart. of Exercise Physiology, Univ. of Vienna
Degree
MD
Research interests
Exercise Physiology, Applied Physiology, Exercise Science, Sports Analysis, Nutrition
E-mail: gerhard.smekal@univie.ac.at

Serge P. von DUVILLARD
Employment
Visiting Professor, Depart. of Sport Science and Kinesiology at the Univ. of Salzburg
Degree
Ph.D., FACSM, FECSS
Research interests
Applied/Exercise Physiology, Testing and Monitoring and Testing of Elite Athletes, Biomarkers of Performance, Exercise Biochemistry, Exercise Cardiology, Cardiac Rehabilitation
E-mail: spvonduvillard@aol.com

Max HÖRMANDINGER
Employment
Institute of Sports Science Depart. of Exercise Physiology, Univ. of Vienna Austria
Degree
MS
Research interests
Exercise Physiology, Applied Physiology, Exercise Science
E-mail: mexx.hoermandinger@gmx.at

Roland MOLL
Employment
Institute of Sports Science Depart. of Exercise Physiology Univ. of Vienna Austria
Degree
MS
Research interests
Exercise Physiology, Applied Physiology, Exercise Science
E-mail: info@dynamo-fit.at

Mario HELLER
Employment
Institute of Sports Science Depart. of Biomechanics Kinesiology and Applied Computer Science Univ. of Vienna Austria
Degree
Ph.D.
Research interests
Sports and Exercise Biomechanics, Analysis of Technique, Surface Electromyography, Applications in Motor Control, Fatigue and Perception of Effort
E-mail: mario.heller@univie.ac.at

Rochus POKAN
Employment
Institute of Sports Science Depart. of Exercise Physiology Univ. of Vienna Austria
Degree
MD, FACSM
Research interests
Exercise Physiology, Applied Physiology, Internal Medicine, Cardiology, Exercise Science
E-mail: rochus.pokan@univie.ac.at

David W. BACHARACH
Employment
Professor, St. Cloud State University Director, Human Performance Laboratory St. Cloud, Minnesota, USA
Degree
PhD, FACSM
Research interests
Exercise Physiology, Alpine skiing, Elite Athlete Testing
E-mail: dwbacharach@stcloudstate.edu

Linda M. LeMURA
Employment
President, LeMoyne College Syracuse, New York, USA
Degree
Ph.D., FACSM
Research interests
Pediatric obesity, pediatric applied physiology, lipid metabolism, energy metabolism, athlete testing
E-mail: lemuralm@lemoyne.edu

Paul J. ARCIERO
Employment
Prof., Depart. of Health and Exercise Sciences Director, Human Nutrition & Metabolism Lab, Skidmore College Saratoga, and Research Prof., Psychology Department, Union College, Schenectady, NY
Degree
Ph.D., FACSM
Research interests
Bioenergetics, Nutrition, Exercise, and Physical Activity Interventions, Effects on Energy Metabolism, Sport and Athletic Performance Nutrition, Nutrition & Supplementation, Prevention of Obesity, Diabetes, and Cardiovascular Disease, Optimal Nourishment for Health and Performance
E-mail: parciero@skidmore.edu

✉ **Serge P. von Duvillard, Ph.D., FACSM, FECSS**
Department of Sport Science and Kinesiology, University of Salzburg, Rifer Schlossallee 49, A-5400 Hallein/Rif, Austria