Salivary Cortisol, Heart Rate, and Blood Lactate Responses During Elite Downhill Mountain Bike Racing

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Purpose: This study aimed to quantify the intensity profile of elite downhill mountain bike races during competitions. Methods: Seventeen male downhill racers (22 ± 5 y; 185.1 ± 5.3 cm; 68.0 ± 3.9 kg; VO2peak: 59.4 ± 4.1 mL·min·kg⁻¹) participated in the International German Downhill Championships in 2010. The racers’ peak oxygen uptake and heart rate (HR) at 2 and 4 mmol·L⁻¹ blood lactate (HR₂ and HR₄), were assessed during an incremental laboratory step test (100 W, increase 40 W every 5 min). During the races, the HR was recorded and pre- and postrace blood lactate concentrations as well as salivary cortisol levels were obtained. Results: During the race, the absolute time spent in the “easy” intensity zone was 23.3 ± 6.8 s, 24.2 ± 12.8 s (HR₂–HR₄) in the “moderate” zone, and 151.6 ± 18.3 s (>HR₄) in the “hard” zone. Eighty percent of the entire race was accomplished at intensities >90% HRpeak. Blood lactate concentrations postrace were higher than those obtained after the qualification heat (8.0 ± 2.5 mmol·L⁻¹ vs 6.7 ± 1.8 mmol·L⁻¹, \(P<.01\)). Salivary levels of cortisol before the competition and the qualification heat were twice as high as at resting state (\(P<.01\)). Conclusions: This study shows that mountain bike downhill races are conducted at high heart rates and levels of blood lactate as well as increased concentration of salivary cortisol as marker for psycho-physiological stress.

Keywords: blood lactate, cycling, heart rate, off-road

Elite downhill riders usually compete in at least 25 competitions and associated qualification heats per year, sometimes with repeated runs per competition. There are only a few studies that analyze the exercise intensity profile of championship downhill cycling races. One field-based study that investigated 17 trained male downhill cyclists showed the intermittent physiological nature of downhill mountain biking by means of heart rates of 168 ± 9 beats·min⁻¹, as well as peak and mean power outputs of 834 ± 129 W and 75 ± 26 W respectively.¹ In contrast, several studies have described the exercise-intensity profile of road cycling and cross-country mountain biking.²⁻⁴ Due to excessive speeds and challenging race courses, one would assume that besides physical stamina, well-tuned downhill mountain bikes and bravery are paramount for success in elite downhill mountain biking. In order to quantify the psycho-physiological stress, recent studies have examined salivary cortisol levels in different disciplines.⁵⁻⁷ A recent review by Gatti and de Palo⁸ shows that cortisol plays a crucial role in the physiological and behavioral response to a psycho-physiological challenge, with the activation of the hypothalamic–pituitary–adrenal axis stimulating the hormone release from the adrenal cortex.⁹ Salivary cortisol as a representative variable of circulating free cortisol has been recommended as an indicator of training stress.¹⁰ The marker’s growing popularity is also based on the fact that this procedure avoids the stress caused by venipuncture.¹¹ Therefore, salivary cortisol can be used to determine psycho-physiological stress during single and repeated exercise bouts.¹¹,¹²

The psycho-physiological profile of downhill racing can be useful to understand the demands of these special racing events. From a practical point of view, valid competition data may aid in designing proper conditioning programs for elite riders. Furthermore, as races also contribute to training knowledge of the exercise-intensity profile is helpful in controlling the overall training load imposed on the downhill racers. Since there is limited knowledge regarding the exercise intensity of elite downhill mountain bike racing, the aims of this study were to quantify and to describe the psycho-physiological intensity of downhill races by monitoring heart rate, blood lactate, and salivary cortisol responses during competition.
Methods

Participants

The 17 healthy, nonsmoking, elite male MTB downhill racers (means ± SD: 22 ± 5 y of age; 185.1 ± 5.3 cm tall; with a body weight of 68.0 ± 3.9 kg; peak oxygen uptake: 59.4 ± 4.1 mL·min⁻¹·kg⁻¹) participating were all highly experienced in the performance of laboratory exercise procedures, as well as in MTB downhill racing. The participants were instructed to be adequately hydrated and to refrain from consuming alcohol for 24 h and food or caffeine for 3 h before each test. Before the study, athletes were informed of the protocols and gave their written informed consent to participate. All procedures were in accordance with the ethical standards of the journal and conducted in accordance with the Declaration of Helsinki. All laboratory testing was conducted at the German Sport University in Cologne, Germany.

Experimental Design

The athletes were tested in the laboratory, as well as during the qualification heat and the race for the international German Downhill Championships 2010.

During laboratory testing, all riders performed an incremental exercise test to exhaustion on an electromagnetically braked ergometer (SRM GmbH, Jülich, Germany). The seat, handlebars, and pedals were adjusted for comfort. The protocol consisted of 5 min of pedaling at 100 W, followed by a stepwise (40 W) increase in power output every 5 min with strong verbal encouragement until exhaustion was experienced. The participants were asked to maintain a cadence of 95 ± 2 rpm. The test was terminated when the cadence fell below 75 rpm.

Oxygen uptake was measured using an open circuit breath-by-breath spiirograph (nSpire, Zan 600 USB, Oberthulba, Germany) throughout the testing, using standard algorithms with dynamic accounting for the time delay between the gas consumption and volume signal. The spirograph was calibrated before each test, using calibration gas (15.8% O₂, 5% CO₂ in N; Praxair, Düsseldorf, Germany) targeting the range of anticipated fractional gas concentration administered with a precision 1 L syringe (nSpire Health GmbH, Oberthulba, Germany). All respiratory data were averaged every 30 s. The highest values for oxygen uptake within the last 30 s of the test were used for statistical analysis. The criteria for VO₂peak were (a) plateau in oxygen uptake, ie, an increase of less than 1.0 mL·min⁻¹·kg⁻¹ despite an increase in power output, (b) respiratory exchange ratio greater than 1.10, (c) ± 5% of age predicted maximal heart rate, and (d) maximal capillary blood lactate greater than 8 mmol·L⁻¹ after exercise. In all cases, at least three of the four criteria were met.

Heart Rate (HR) was measured by using a Polar telemetric HR-System (Polar Wear Link System and Polar S810i HR monitor, Polar Electro Oy, Kempele, Finland). All data were averaged every 5 s. The highest obtained value was defined as the peak heart rate.

Blood samples for analyses of lactate were collected in a capillary tube (Eppendorf AG, Hamburg, Germany) from the left ear lobe. Lactate was analyzed by an amperometric-enzymatic procedure using Ebio Plus (Eppendorf AG, Hamburg, Germany). All analyses were performed in duplicate and the means were utilized for statistical analysis.

Based on the blood lactate curves, which were obtained from the incremental testing, straight-line interpolation power output (P2 and P4) and HR (HR2 and HR4) at 2 and 4 mmol·L⁻¹ was defined as the intensity corresponding to a blood lactate concentration of 2 and 4 mmol·L⁻¹, respectively. Heart rate and power output were identified by straight-line interpolation between the two closest points according to previous studies. From these data, three intensity zones were established to describe the exercise intensity profile of cross-country competitions: (1) “low” for intensities below a heart rate corresponding to P2, (2) “moderate” for intensities between heart rates corresponding to P2 and P4, and (3) “hard” for intensities above P4.

The race day: During the qualification and championship race, all athletes had to cover 1.6 km of downhill track, starting at an altitude of 610 m and ending at 240 m. The race course distance was measured with an odometer which was attached to one of the rider’s bikes during a qualification race. The odometer’s measures were prechecked on a measuring section which is used for the calibration of surveying instruments. The error measures were 199 ± 1 m on a 200 distance, measured fivefold. The elevation data was obtained from precise hiking maps as well as from the information received by the event organizer. The course mainly existed of technically challenging single-track trails and forest roads with gravel and numerous turns, jumps and “drop-offs.” The ambient temperature was +29°C for both races and the course surface was dry.

During the qualification and championship races, heart rate was recorded every 5 s using an heart rate monitor with an individually coded heart rate transmitter (Polar Wear Link System and Polar S810i HR monitor, Polar Electro Oy, Kempele, Finland). After each race, heart rate data were downloaded using the specific software and subsequently analyzed (Polar Precision Performance software, Polar Electro Oy, Kempele, Finland). In addition, 2 min before and directly after each race blood samples for analysis of capillary blood concentration were obtained from the right ear lobe of each rider. At the same time points, as well as 1 d before the qualification race (baseline) salivary samples were collected for the later analysis of cortisol.

The participants were instructed not to consume any energy bars or energy drinks for 1 h before the collection of salivary samples. They were asked only to drink water if needed. For sampling, the subjects were required to rinse out their mouths with water. For each sample, the participants were asked to place a cotton wad from a saliva collection tube in their mouth until the cotton was saturated, and then place the tube containing the wad...
samples were stored at –20°C until analysis. Levels of salivary cortisol (ng·mL⁻¹) were determined by using human ELISA kits (Cortisol (Salivary) ELISA SLV-2930; DRG Instruments GmbH, Germany).

**Statistical Analysis**

Repeated-measures ANOVA were employed to analyze differences in the variables at all time points of analysis. If global significance was thereby obtained, Bonferroni post hoc analysis was utilized to identify differences between the time points. All data were checked for normality as well, with no need for further transformation. The sphericity assumption was met. An alpha of \( P < 0.05 \) was considered to be statistically significant and all analyses were carried out with the Statistica (version 7.1, StatSoft Inc., Tulsa, OK, USA) software package for Windows. The effect size Cohen’s \( d \), defined as \( \frac{\text{difference between the means}}{\text{standard deviation}} \), was calculated for comparing the variables. The thresholds for small, moderate, and large effects were defined as 0.20, 0.50, and 0.80, respectively, and the highest effect sizes are documented in Table 1.

**Results**

The mean peak values for oxygen uptake and heart rate during laboratory testing were 59.5 ± 4.1 mL·min·kg⁻¹ and 194 ± 6 beats·min⁻¹, respectively. Table 1 shows the different responses in the two downhill races, as well as the average exercise intensity expressed as average heart rate, and percentage of race time (relative time) spent in the three intensity zones. Generally, the absolute heart rate values during the championship race were higher than in the qualification heat (\( P < 0.05 \); effect size: 0.56). Postrace blood lactate concentrations were also higher after the championship race than in the qualification heat (\( P < 0.01 \); effect size: 0.59). Baseline values for salivary cortisol were 4.9 ± 2.3 ng·mL⁻¹. There were no differences between cortisol levels before and after the qualification heat or in the championship race, but these values were significantly elevated when compared with baseline levels (\( P < .01 \); best effect size: 1.42). During the championship race, the absolute time spent in the “easy” intensity zone was 23.3 ± 6.8 s, the “moderate” intensity zone 24.2 ± 12.8 s, and in the “hard” intensity zone 151.6 ± 18.3 s. Relative and absolute times spent in the “hard” intensity zone were significantly higher during the championship race compared with the qualification heat (\( P < 0.05 \); effect size: 0.76).

**Discussion**

To the best of our knowledge, this is the first study to report salivary cortisol, heart rate, and blood lactate responses during elite downhill mountain bike racing. The main findings of this study were as follows: (1) high heart rate response during qualification and championship races, (2) high metabolic responses (7–8 mmol·L⁻¹

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Qualification Heat</th>
<th>Championship Race</th>
<th>Cohen's d</th>
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<tbody>
<tr>
<td>Racing time (s)</td>
<td>194.4 ± 13.7</td>
<td>187.3 ± 15.5*</td>
<td>0.48</td>
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<tr>
<td>Heart rate (1·min⁻¹)</td>
<td></td>
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<tr>
<td>Before</td>
<td>136 ± 9</td>
<td>138 ± 10</td>
<td>0.21</td>
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<tr>
<td>After</td>
<td>187 ± 8</td>
<td>194 ± 8*</td>
<td>0.87</td>
</tr>
<tr>
<td>Average heart rate (1·min⁻¹)</td>
<td>179 ± 8</td>
<td>183 ± 6*</td>
<td>0.56</td>
</tr>
<tr>
<td>Blood lactate (mmol·L⁻¹)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Before</td>
<td>0.9 ± 0.5</td>
<td>0.9 ± 0.5</td>
<td>0.00</td>
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<tr>
<td>After</td>
<td>6.7 ± 1.8</td>
<td>8.0 ± 2.5*</td>
<td>0.59</td>
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<tr>
<td>Salivary cortisol (ng·mL⁻¹)</td>
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<tr>
<td>Before</td>
<td>8.3 ± 2.9</td>
<td>9.4 ± 4.1</td>
<td>0.30</td>
</tr>
<tr>
<td>After</td>
<td>9.4 ± 3.9</td>
<td>9.3 ± 3.7</td>
<td>0.02</td>
</tr>
<tr>
<td>“Easy” intensity zone (% of race time)</td>
<td>13.6 ± 3.5</td>
<td>11.8 ± 3.8</td>
<td>0.49</td>
</tr>
<tr>
<td>“Moderate” intensity zone (% of race time)</td>
<td>13.2 ± 6.7</td>
<td>12.1 ± 6.3</td>
<td>0.16</td>
</tr>
<tr>
<td>“Hard” intensity zone (% of race time)</td>
<td>73.2 ± 3.6</td>
<td>76.1 ± 4.0*</td>
<td>0.76</td>
</tr>
</tbody>
</table>

*Note. All values are presented as means ± SD.

*\( P < .05 \) with respect to differences between the qualification heat and the championship race.
blood lactate concentration) and (3) a two-fold increase in levels of salivary cortisol during the day of competition compared with baseline values.

The group of downhill mountain bikers in this study have lower peak oxygen uptake values (59.5 ± 4.1 mL·min⁻¹·kg⁻¹) compared with the reported values in a group of elite Italian (75.2 mL·kg⁻¹·min⁻¹)²⁴ and Austrian mountain bikers (68.4 mL·kg⁻¹·min⁻¹).¹⁴ The peak oxygen uptake data of the participants in the present study suggests that mountain bike downhill competitions demand a good aerobic capacity, although not as high as during cross-country mountain bike racing.

Profiling physiological demands during a mountain bike downhill competition presents several challenges. Measuring oxygen uptake as a variable during racing is highly desirable, but portable gas analyzers would add additional stress to the athletes due to the weight of the device and the face mask. Furthermore, the portable device itself, as well as the limited visibility through the mask, constitute safety concerns and, as such, cannot be used during mountain bike downhill racing. For this reason, the most accessible and primary variable during mountain bike downhill racing remains heart rate monitoring. A substantial number of scientific papers have described the exercise intensity based on heart rate data during road and off-road cycling.²⁻⁴

The mean heart rate during racing in the present study is somewhat higher than that found in previous studies (183 ± 6 vs 168 ± 9 beats·min⁻¹). Comparing data from different studies of downhill mountain biking races is challenging since the events may differ in length, course design, and ambient temperature, cycling equipment, surface condition, and the rider’s technical skills. Since the race in the present study was ~60 s longer compared with the study by Hurst and Atkins (2006), one could assume that the additional race duration may explain the higher mean heart rate values. The downhill riders monitored in the present study were able to maintain intensities > 90%HRₚᵉᵃᵏ for 80% of the entire race and a significant percentage of the total race time at intensities above HRₑ. Based on the laboratory data, this exercise intensity would refer to 90–95% of peak oxygen uptake and would mean that elite mountain bike downhill racing would be executed at high cardio-respiratory demands. However, the interpretation of exercise intensity based on heart rate and laboratory data may be biased. It is well known that the activation of the sympathetic nervous system, due to nervousness and excitement, will lead to increased heart rate and respiratory responses¹⁵,¹⁶ and therefore overestimate the actual exercise intensity. In addition, elevated heart rate and oxygen uptake may result from the involvement of upper body isometric muscle activity without directly being involved in energy production. In this context, previous studies showed that the heart rate is influenced by the intensity of isometric contraction and the mass of the contracted muscles¹⁷ and also may overestimate the actual exercise intensity.

Another way to describe the exercise intensity profile during cycling competitions is the use of lactate thresholds determined in laboratory tests, such as HR₂ or HRₑ.²⁻⁸ During the championship race in the present study, 76.1 ± 4.0% of the time was spent in the “hard” intensity zone, that is, to a blood lactate concentration > 4 mmol·L⁻¹.¹⁵ To verify this exercise intensity, blood lactate concentrations measured at the end of the race revealed values clearly above 4 mmol·L⁻¹ (8.0 ± 2.5 mmol·L⁻¹). Due to the fact that lactate concentrations are high after racing when compared with pre-racing values, it may be assumed that energy is mainly derived from anaerobic lactic and aerobic pathways.

Another main finding of the present investigation is that levels of salivary cortisol were 1.9-fold elevated when compared with baseline values. It has been shown that cortisol plays a central role in the physiological and behavioral responses to a psycho-physiological challenge with the activation of the hypothalamic–pituitary–adrenal axis that stimulates the hormone release from the adrenal cortex.⁹ It should be known that, from a biological perspective the perception of fear and threat (in this case the racing situation), would be the main stimulus for inducing a hypothalamic–pituitary–adrenal axis.¹⁹ Riders with lower pre- and/or post- cortisol responses may show better racing results. However, correlation analysis of pre to post racing levels of cortisol vs. racing time revealed no correlation (r = –.46; P = .08) and based on this analysis, the racing performance seems to be independent from salivary cortisol levels. However, the racing time in mountain bike downhill is dependent on other factors such as course design, cycling equipment, surface condition, and the rider’s technical skills. These factors could explain why there is no statistical relationship between racing time and salivary cortisol levels in the present data. At this point, it still remains unclear, if higher levels of salivary cortisol, as a marker for mental stress, will affect the overall mountain bike downhill performance. Nevertheless, the two-fold increase in levels of salivary cortisol during the day of competition compared with baseline values are a sign of mental stress. Elevated levels of salivary cortisol indicate an involvement of the hypothalamic–pituitary–adrenal axis stimulating the hormone release from the adrenal cortex,¹⁶ which, in turn, activates the sympathetic nervous system, visible in the increased prestart heart rate (136 ± 9 and 138 ± 10 beats min⁻¹).

The results of the present study of elite mountain bike downhill racing may be used as a scientifically based source for adjusting conditioning protocols to the characteristic demands of the discipline. For practical purposes, Figure 1 is a description of the time distribution of heart rate expressed relative to HRₚᵉᵃᵏ. The present data from mountain bike downhill racing showed (1) approximately 80% of the entire race is spent at intensities > 90% HRₚᵉᵃᵏ, (2) 40–60 s after the start, all riders cycle at intensities > 95% HRₚᵉᵃᵏ (3) on average, the riders showed a high amount of anaerobic
contribution to energy production (8.0 ± 2.5 mmol·L⁻¹ blood lactate) and (4) salivary cortisol concentration is twice the amount compared of the baseline values. This data emphasizes the necessity of the riders developing a good level of aerobic and anaerobic capacity and the ability to cope with mental stress.

Since races of minor importance are part of the general conditioning program, heart rate monitoring can assist coaches in quantifying the overall training load imposed on their athletes. Due to the special technical designs of different downhill mountain bikes, such as crank diameter, it was not possible to mount special cranks for power output measurement. Although it is an increasingly popular to assess power output to describe exercise intensity in cycling, from a practical point of view heart rate monitoring remains the most useful tool for coaches and athletes. However, external load indicators, that is, power meters, may provide useful complementary information for creating conditioning programs.

**Figure 1** — (A) The heart rate distribution of elite mountain bike downhill racers during a championship race. To aid in the clarity of the chart, only data from six of the racers is shown. (B) Mean racing time of all racers spent at different percentages of HRpeak.

**Practical Application and Conclusion**

In conclusion, this study shows that mountain bike downhill competitions are conducted at high individual heart rates as well as high levels of blood lactate and salivary cortisol. The psycho-physiological profile of the investigated group of elite downhill riders suggests that mountain bike downhill racers require good aerobic and anaerobic power and need to cope with mental stress. The exercise-intensity profile described in this study can be used by coaches to define specific conditioning programs for downhill mountain bikers involved in championship events.

**Acknowledgments**

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References