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PHYSIOLOGICAL ASSESSMENT OF MOTORCYCLE RACERS FOR THE EVIDENCE-BASED TRAINING

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Abstract

Motorcycle racers are subjected to extreme physical and physiological stresses that can affect their performance. This research aimed to investigate physiological factors that may influence performance and to make recommendations for effective training design. Three international-level Hungarian motorcycle racers were studied in laboratory, competition, and race simulation environments. Their mean age was 20.33 years (± 2.3), sport age 15.66 years (± 3.78), body weight 73.9 kg (± 8.7), and height 1.78 m (± 0.1). Resting measurements, load tests, and track tests were performed during the study. To analyze exercise stress in competitive conditions, we used heart rate monitoring and lactate measurements during the final round of the 2024 World Endurance Championships and a track test in Hungary. The laboratory measurements identified three athletes with different fitness statuses, who demonstrated significant individual differences in both cardiovascular and metabolic load during racing. The results showed that the pilot with greater aerobic capacity had a higher relative heart rate and lower lactate levels, whereas the pilot with greater anaerobic capacity showed the opposite. This suggests that energy production processes differ between riders. Aerobic capacity primarily supports recovery and more economical energy production, while anaerobic fitness can provide the performance needed for high-intensity activities. Striking the right balance can be the key to optimizing riders' performance.

Keywords: *rider performance, cardiovascular load, lactate, heart rate, laboratory tests*

THEORETICAL BACKGROUND

Motorcycle racing imposes significant demands on the cardiovascular and metabolic systems, as evidenced by elevated heart rate during races (HR_{max} 90 %+) and increased post-race blood lactate levels (6 $mmol \cdot L^{-1}$) (D'ARTIBALE et al., 2008). Anaerobic capacity, tolerance to metabolic acidosis, and gas exchange efficiency are notably higher in more successful riders (MICHALIK et al., 2022). In a study by D'Artibale and colleagues (2013), an amateur and a professional rider were examined under identical conditions using a telemetry-based spirometer. The amateur rider covered 40% less distance within the designated time interval than the professional, with oxygen consumption increasing to four times the baseline, while the professional's rose to seven times the baseline. Another study determined the maximum heart rate and ventilatory thresholds of young riders in a laboratory setting. When comparing heart

rate values measured during a motocross race with lab results, it was evident that the riders repeatedly entered anaerobic zones (IHÁSZ et al., 2024).
Additional research has quantified the specific physical stresses experienced by professional riders. For example, D'Artibale (2018) reported that elite riders perform repeated braking and cornering maneuvers within each lap, generating significant postero-anterior and lateral inertial forces that require both eccentric and isometric muscle activation. Pre- and post-season evaluations indicate that structured training enhances lower-body explosive strength, grip strength, and lumbar isometric force, which translates to improved race performance (RODRÍGEZ-PÉREZ et al., 2018). Moreover, seasonal changes in anaerobic capacity correlate with fatigue resistance and competitive success, emphasizing the importance of maintaining high anaerobic fitness throughout the racing season (MICHALIK et al., 2023).
The study aimed to compare the circulatory (HR_{max}, rVO_{2max}) and metabolic (BL_1HR, BL_2HR) characteristics measured in the laboratory and during racing among three internationally ranked motorcycle road racers. Another objective is to contribute to the development of evidence-based training methods. Motorcycle racing, while highly demanding physiologically, also raises important questions about long-term athlete health, recovery, and sustainable performance. Understanding the cardiovascular and metabolic loads encountered during both laboratory tests and real racing conditions is essential not only for optimizing training but also for supporting athletes' well-being and preventing burnout or overtraining. By linking physiological insights to broader aspects of sustainable human performance, this study aims to contribute to both competitive success and the long-term health of riders.

METHODS

PARTICIPANTS

Three Hungarian motorcycle road racers competing at the international level participated in our study. As members of the Hungarian Endurance Racing Team (HERT), they competed in the final round of the 2024 Endurance World Championship (EWC). Their average age was 20.33 years (SD 2.3), with an athletic history of 15.66 years (SD 3.78), a body mass of 73.9 kg (SD 8.7), and a height of 1.78 m (SD 0.1). Measurements were conducted at two locations: the Circuit Paul Ricard in France (using a BMW M 1000 RR motorcycle, 5673 m long track, 15 turns, top speed of 343 $km \cdot h^{-1}$) and, in October, at the Euro-ring in Hungary (using a Kawasaki Ninja 400 motorcycle, 2750 m long track, 14 turns, top speed of 155 $km \cdot h^{-1}$).

LABORATORY PROTOCOL

The exercise protocol was performed on an HP Cosmos Quasar treadmill (HP Cosmos, Nussdorf-Traunstein, Germany). The initial speed was set at 6 $km \cdot h^{-1}$ with a 1° incline, and it was increased by 2 $km \cdot h^{-1}$ every 3 minutes. After each 3 3-minute stage, the

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treadmill belt was stopped for 1 minute to collect a blood sample. The protocol continued until the athlete voluntarily terminated the test. Continuous verbal encouragement was provided to support the athletes during the test. To determine the threshold values of Blood Lactate$_1$ (BL_1) and Blood Lactate$_2$ (BL_2), the blood lactate concentration–time curve was analyzed. The BL_1 value was defined as the first significant inflection point.

In contrast, the BL_2 value was determined graphically using the Distance Maximum (D_{max}) method, based on mathematical analysis of the steepest section of the curve. Heart rate was continuously monitored during both exercise and recovery phases using a Polar H10 chest strap (Polar Electro, Kempele, Finland), which uses ECG technology and samples at 200 Hz. Respiratory gas exchange was measured continuously with a Vyntus CPX metabolic cart (Vyaire Medical, Mettawa, IL, USA), from which oxygen uptake (VO_2), carbon dioxide production (VCO_2), and respiratory exchange ratio (RER) were recorded across exercise intensities. Blood lactate concentration was determined using a Biosen C-Line Sport lactate analyzer (EKF Diagnostics, Barleben, Germany) from capillary blood samples taken at the end of each exercise stage. Blood sampling was performed from the earlobe during the 1-minute rest periods following each speed increment.

TRACK PROTOCOL

During the Endurance World Championship, the average heart rate (HR_{avg}), maximum heart rate (HR_{max}), and, in the case of the Euro-ring, the heart rate recovery values (rHR) at 15, 30, 60, and 120 seconds were recorded. Lactate measurements were taken using the Lactate Scout Sport (EKF Diagnostics, Barleben, Germany) handheld lactate meter, with 0.3 μL blood samples from the earlobe. Resting lactate values were recorded during the 5 minutes before each ascent, and post-exercise lactate values were recorded during the 1-2 minutes following the descent.

RESULTS

The physiological parameters obtained from the laboratory and track tests allowed for the description of the endurance and recovery profiles of the three athletes (Table 1). Based on lactate values, heart rate measurements, and heart rate recovery indicators, distinct fitness levels and physiological responses to exercise were identified.

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Table 1: Anthropometric, cardiovascular, and metabolic characteristics of the participants

Riders	"a"	"b"	"c"
Age (y)	19	22	19
Racing experience (y)	14	20	13
Body weight (kg)	74.4	82.4	65.0
Body height (cm)	171.6	190	172.4
BL_1 ($mmol \cdot L^{-1}$)	1.24	1.41	1.6
BL_1 heart rate (HR); (bpm)	146	132	133
BL_1 heart rate (HR_{max}%)	73.70	69.8	66.5
BL_1 speed ($km \cdot h^{-1}$)	8.8	7.9	8.0
BL_2 ($mmol \cdot L^{-1}$)	3.6	3.88	4.7
BL_2 heart rate (HR); (bpm)	186	178	184
BL_2 heart rate (HR_{max} %)	93.9	94.2	92
BL_2 speed ($km \cdot h^{-1}$)	13.6	13.0	13.0
Max lactate ($mmol \cdot L^{-1}$)	8.1	12.4	11.19
HR_{max} (bpm)	198	187	200
rVO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	53.2	51.3	49.6

Legend: Racing experience = number of years spent riding motorcycles (y), BL_1 = first lactate threshold ($mmol \cdot L^{-1}$), BL_1 heart rate = heart rate associated with the first lactate threshold (bpm), BL_1 heart rate HR_{max} % = heart rate at BL_1 as a percentage of maximum heart rate (%), BL_1 speed = running speed corresponding to the first lactate threshold ($km \cdot h^{-1}$), BL_2 = second lactate threshold ($mmol \cdot L^{-1}$), BL_2 heart rate = heart rate associated with the second lactate threshold (bpm), BL_2 heart rate HR_{max} % = heart rate at BL_2 as a percentage of maximum heart rate (%), BL_2 speed = running speed corresponding to the second lactate threshold ($km \cdot h^{-1}$), Max lactate = maximum measured blood lactate level ($mmol \cdot L^{-1}$), HR_{max} = maximum heart rate (bpm), rVO_{2max} = relative maximum oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$).

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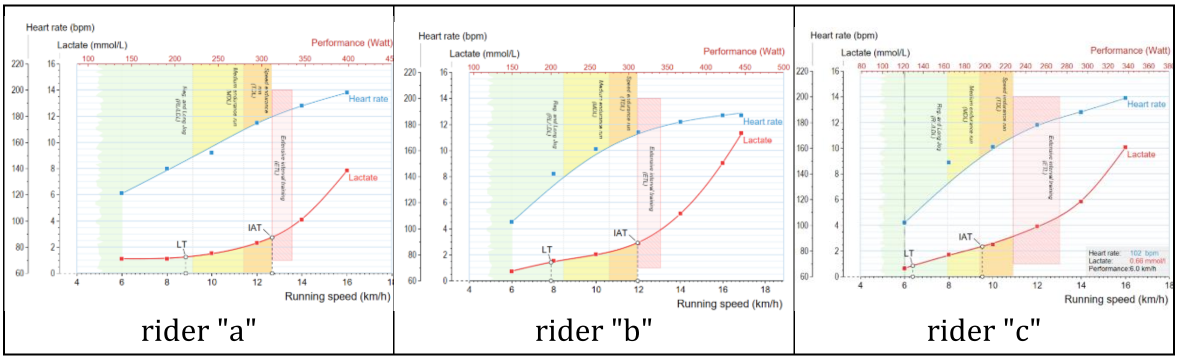

Figure 1: Serum lactate results recorded during the load test for the three athletes. Based on the study's results, three athletes with distinct fitness profiles were identified.

Legend: Serum lactate (BL) results measured in the laboratory for the three athletes. The lactate threshold (LT: the point at which blood lactate begins to rise above resting levels) and individual aerobic threshold (IAT: the highest intensity at which lactate production and clearance are balanced) values shown on the graph were automatically generated by the measurement system. The background colors indicate training zones: green – basic endurance, yellow – threshold training, red – high-intensity/interval.

Figure 1 illustrates that athlete "a" has a higher level of baseline endurance compared to the others, which is indicated by the later appearance of the first breakpoint (8.8 $km \cdot h^{-1}$), lower lactate value (1.24 $mmol \cdot L^{-1}$), and higher heart rate (146 bpm). However, as the load increases, the lactate level suddenly rises in the higher-intensity zones, the anaerobic range is relatively narrow, and the maximum lactate value is also lower (8.1 $mmol \cdot L^{-1}$). Athlete "c" has weaker basic endurance, as evidenced by the immediate rise in lactate level (1.6 $mmol \cdot L^{-1}$) at a lower speed (8 $km \cdot h^{-1}$). Nevertheless, in higher-intensity zones, they can perform over a wider range, with a higher BL_2 value (4.7 $mmol \cdot L^{-1}$) and a lower heart rate (184 bpm). The average post-exercise lactate values measured at the Endurance World Championship and the Euro-ring, compared with the BL_1 and BL_2 values measured during laboratory tests, show distinct patterns among the athletes (Figure 2). Athlete "b" had lactate values above BL_2 in both cases (4.2 - 5.4 $mmol \cdot L^{-1}$), while athletes "a" and "c" had higher values at the World Championship ("a" 3.78 $mmol \cdot L^{-1}$; "c" 5.95 $mmol \cdot L^{-1}$) and lower values at the Euro-ring ("a" 3.2 $mmol \cdot L^{-1}$; "c" 4.23 $mmol \cdot L^{-1}$) compared to their BL_2 values ("a" 3.6 $mmol \cdot L^{-1}$; "b" 3.88 $mmol \cdot L^{-1}$; "c" 4.7 $mmol \cdot L^{-1}$).

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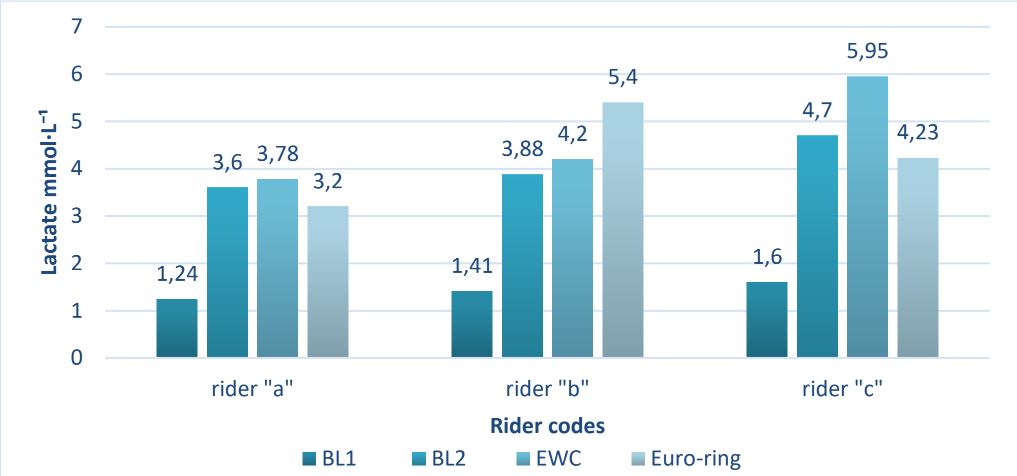

Figure 2: Completed sections and lactate values recorded after leaving the track

Legend: BL_1 = first lactate breakpoint measured in the laboratory ($mmol \cdot L^{-1}$), BL_2 = second lactate breakpoint measured in the laboratory ($mmol \cdot L^{-1}$), EWC = average lactate values for every stint at the Endurance World Championship (EWC) in which at least 4 laps were completed continuously, Euro-ring = average post-exercise lactate values for all stints at the Euro-ring, except for the first free practice (FP1).

Figure 3 shows a comparison of the relative heart rate values corresponding to the laboratory-measured BL_1 and BL_2 thresholds, as well as the average and maximum heart rate values measured during the race at the Euro-ring and the Endurance World Championship. The average relative heart rate values of the "a" (HR_{max} = 96 % [EWC], 94 % [Euro-ring]) and "b" (HR_{max} = 96 % [EWC], 100 % [Euro-ring]) riders are higher than those of the "c" rider (HR_{max} = 92 % [EWC], 91 % [Euro-ring]).

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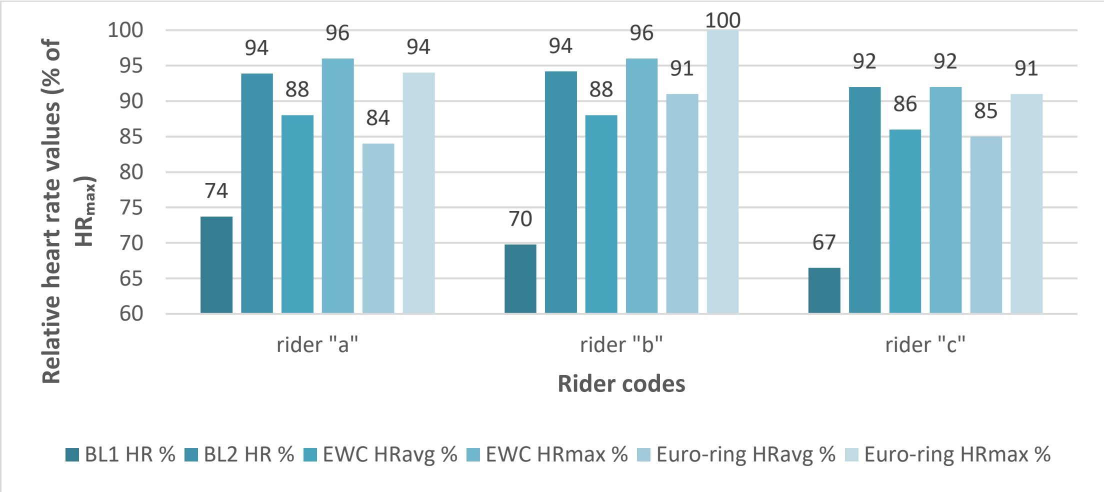

Figure 3: The average (HR%) and maximum relative heart rate (HR_{max}%) values of the competitors.

Legend: BL_1 HR_{max} % = heart rate at BL_1 as a percentage of the maximum heart rate (%), BL_2 HR_{max} % = heart rate at BL_2 as a percentage of the maximum heart rate (%), EWC HR_{avg} % = average relative heart rate (%) values during any stint in the Endurance World Championship (EWC) where at least four continuous laps were completed, EWC HR_{max} % = maximum relative heart rate (%) values during any stint in the Endurance World Championship (EWC) where at least 4 continuous laps were completed, Euro-ring HR_{avg} % = average relative heart rate (%) values during all stints on the Euro-ring except for the first free practice (FP1), Euro-ring HR_{max}% = maximum relative heart rate (%) values during all stints on the Euro-ring except for the first free practice (FP1).

The presentation of heart rate recovery values measured on the Euro-ring can also provide useful insights into the athlete's endurance and recovery capabilities. In particular, the values measured after the race simulation show greater variability in heart rate recovery dynamics than those measured previously (Figure 4).

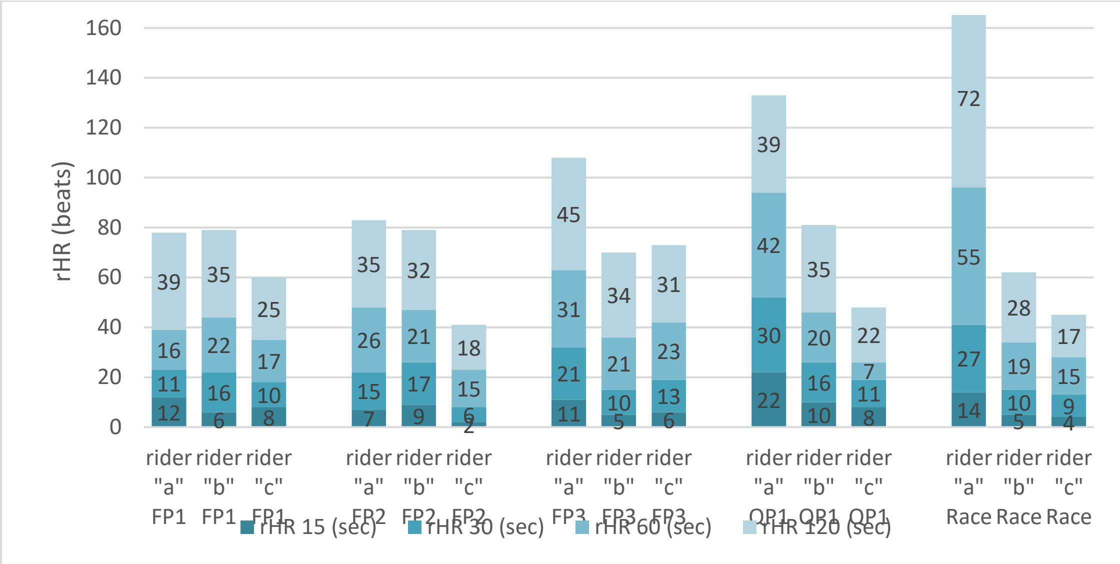

Figure 4: Heart rate recovery (HR) values during the track test (Euro-ring) for each athlete, for the respective stint (beat).

Legend: rHR = heart rate recovery measured at 15, 30, 60, and 120 seconds after descent (beats).

At the Euro-ring, regarding the 120-second post-race heart rate recovery (rHR 120), the "a" athlete showed an outstanding value (72 beats), the "b" athlete showed a 28-beat reduction, and the "c" athlete showed only a 17-beat reduction. Thus, for the "c" athlete, the slowest recovery response was observed.

CONCLUSIONS

In this study, we examined three athletes with different fitness levels. Absolute lactate levels and heart rate data collected during the competition alone are insufficient to accurately assess performance, as the athletes have different fitness levels. The comparison of the laboratory-measured BL_2 threshold and the average post-race lactate values on the track reveals that the athlete with better endurance ("a") has lower lactate values. At the same time, the other two riders ("b" and "c") show significantly higher values. This suggests that the athletes' energy production processes differ, and that the role of anaerobic glycolysis varies during the workload. However, it is important to note that all three athletes' performances occur at intensities around the BL_2 threshold, indicating that considering the individual endurance profile is crucial for effective energy supply during the load. The lower maximum heart rate of athlete "c" may indicate that their body is more efficient in anaerobic energy production and better adapted to the intensity around BL_2. This means that anaerobic energy production is more prominent in their case, allowing them to operate more comfortably in this load zone than the other two athletes. The aerobically trained athlete ("a") had faster heart rate recovery and lower lactate values. This difference is particularly important in repeated loads, such as during a race weekend or even during a single lap. On longer straights, riders can partially recover, and faster heart rate recovery can affect their physiological stress and energy levels. Faster heart rate recovery may enable more effective regeneration before the next intense phase. Overall, aerobic capacity primarily supports recovery and more efficient energy production, while anaerobic fitness helps ensure performance during high-intensity activities. Establishing the right balance may be key to optimizing the athletes' performance.

LIMITATIONS

This study has certain limitations. Three athletes participated in the investigation; therefore, the generalizability of the findings is strongly limited. Although the tests were conducted both on the track and in the laboratory, the comparison between the two environments yields only limited conclusions due to the small sample size.
In the future, we plan to expand the study with a larger sample size and a more detailed, comprehensive protocol, enabling more robust conclusions and stronger support for practical applications.

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To enhance the quality of this manuscript, we used the Grammarly Writing and Grammar Checker Application software.

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