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Abstract: Many amateur and professional players start racing at an early age. The aim is to explore the characteristics of heart rate and speed patterns recorded during competition. We investigated the body composition and cardiorespiratory characteristics of three elite adolescent athletes, their heart rate, and speed patterns in the laboratory and competition. There is no difference between the three riders' anthropometric and body composition values, except for training age (TA), where rider (b) started riding three years ago. The intra-race heart rate patterns of the three riders showed similarities in several places and differences in several places. This was also true for the speed patterns. The differences between races were more pronounced in the heart rate pattern.

Keywords: motocross performance; young MX riders; physiological-, anthropometric-, and cardiorespiratory characteristics

1. Introduction

The motocross is a popular off-road sport, characterized by irregular, natural terrain of dirt and sand, with different levels and obstacles [1]. The number of participants in the sport has increased worldwide. Many amateur and professional players start racing at an early age. The motocross races are held on a motocross track (distance between 1200 and 2500 meters), with a duration of 15 to 30 minutes, depending on the event. Thus, in motocross, the movement of the riders is continuous and acyclic, requiring a constant isometric contraction of the arms and legs to control the motorcycle (weighing ~ 60-80 kg) due to constant and rapid changes of direction, jumps, turns, and braking. Premature muscle fatigue can result in reduced performance during the race and this has a profound effect on the rider's performance [2]. In addition, a high fatigue index may increase the risk of accidents and injuries during motocross training.

Previous review studies on motorsport have highlighted the importance of anthropometric parameters, and metabolic and cardiorespiratory systems (anaerobic and aerobic capacity ($VO2_{peak}$))[3]. In addition to these, the quality of neuromuscular responses [4], kinesthetic perception

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[5], and human performance in a broader sense [6]. Motorsport requires the ability to exert high upper limb forces [7], as well as the physiological adaptation to changes induced by physical work (largely isometric) during racing [8]. The isometric and/or eccentric muscle contractions are necessary to absorb the shocks caused by the traction and the changes in the handling of the motorcycle on rough terrain with sharp bends [8].

In addition to the duration of the competitions, other features such as the amount of special warm clothing used for protection and the psychological stress involved also increase the physical demands of the sport. Recently, it has been reported that motocross induces increased plasma oxidative stress and damage [9]. Since significant psychoemotional stress management is required during races, thus additional catecholamine release is possible, this may have a significant impact on the heart rate profile during races. This study aims to analyze the anthropometric, circulatory, and lower limb muscle strength properties measured in the laboratory. It also aims to analyze the characteristics of heart rate and velocity patterns recorded during competition on an individual basis as a potential determinant of performance.

2. Materials and Methods

Subjects

The study included (n=3) 14-year-old male (MX) riders. All three boys have national and international experience. The competition consisted of two races, with the winner being the rider who achieved the best result based on the placings in the two races. The description of the structure of the racetrack is presented in Figure 1.

Figure 1. Description of the racetrack structure: Satellite image of the motocross competition. Legend: Piliscsév, Motorsport Centrum (Hungary). Classification: national and international FIM-registered track. Track length: 1990 m., track width: 6-8 m., level difference: 30 m., number of jumps: 14, number of bends: 13, track surface: earthy clay, sandy in places. Temperature: 18-20 C, soil quality: ideal, watered. Number of competitors: ~160, in different categories.

Anthropometry and Body Composition

Anthropometric characteristics were measured by a qualified ISAK-accredited expert (level 1) according to the standardized procedures of the International Society of Kinanthropometry. According to standardized guidelines, body height (BH) was measured to the nearest 1 mm with a calibrated Soehlne Electronic Height Rod 5003 (Soehlne Professional, Germany). Body mass (BM) (measured to the nearest 0.1 kg), BMI, body composition characteristics, and relative skeletal muscle mass (M%), were determined by bioelectrical impedance with an InBody720 body composition analyzer.

Examination of the Circulatory and Respiratory System

The circulatory and respiratory systems were performed at the Laboratory of Exercise Physiology of the Fehér Miklós Football Academy, using a Piston-type instrument (EN ISO 13485:2016, Budapest, Hungary). Ergo-spirometric tests were performed before the start of the competition season, following a progressive intensity protocol until voluntary exhaustion, on a treadmill (Pulsar 4. 0, h/p/Cosmos Sports & Medical GmbH, Nußdorf, Germany). During the test, the

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recorded circulatory and respiratory characteristics were used to create the initial profile of the Polar Team Pro (resting heart rate (HR_{rest}), and maximum heart rate (MP). The test protocol began with an initial speed of 5 km/h (walking) for one minute and continued at 8 km/h. Thereafter, treadmill speed was increased by 2 km/h every two minutes with a continuous inclination of 2°.

We calculated the ratio of minute ventilation/carbon dioxide and oxygen production (VE/VCO2), (VE/O2). These ratios reflect the increase in ventilation in response to CO2 production [10]. Changes in VE/VCO2 slope may also be caused by an increase in the number of chemoreceptors, peripheral ergoreceptor response, ventilatory dead space, and muscle mass involved in exercise [11]. The anaerobic threshold pulse (VT_1) was determined after completion of the exercise test; for all subjects, using the V-slope method developed by Beaver et al. [12].

Measurements during the Race (Polar Team Pro)

Heart rate (HR) and movement data were recorded using the Polar Team Pro® system (Polar Electro, Kempele, Finland). The system consists of a chest belt containing a sensor unit (Polar H7 Bluetooth 4.0 smart chest strap) with built-in ECG electrodes, a 10 Hz integrated GPS, and a 200 Hz micro-electromechanical system motion sensor. The data is transferred to Polar Beat software (v3.5.4). During the races, we recorded the average ($HR_{mean\%}$), minimum ($HR_{min\%}$), and maximum ($HR_{max\%}$) heart rate, about the hundredth percentile, the number of sprints (No. sprint), the maximum speed ($Speed_{max}$), and calculated the training load (TL).

Examination of the Strength of Both Bilateral Hamstring and Extensor and Abductor Muscles

Hip isometric strength was measured using the "ForceFrame®" Strength Testing System (VALD Performance Pty Ltd., Brisbane, Australia) following a tension protocol [13]. For the implementation, participants were asked to lie supine under the system. The outer side of both knees was placed on the padded load cell (100 Hz) at an angle of 60° (hip flexed at 60°). Participants were first asked to perform an isometric contraction of the hip adductor (AD) for 5 s, followed by a 5 s isometric contraction of the abductor muscle (ABD) for 5 s after a 5 s rest period. After 45 seconds of rest, the same procedure was repeated and the results were automatically saved by the Ipad.

The strength of the hip (ABD) and (AD) was determined from the maximum slip (N) of three trials. These values were then converted to joint moments (N/m) based on the length of the right leg (distance between the anterior superior iliac crest and lateral ankle bone). The results of the isometric contraction tests were used to calculate two additional parameters.

The hip AD/ABD force ratio and hip AD force/hip ABD force on the homolateral leg, and the relative bilateral force asymmetry (force imbalance between the limbs was calculated using the formula [(dominant leg muscle strength - non-dominant leg muscle strength)/dominant leg muscle strength] × 100.

3. Results

Laboratory Tests

The results measured in the laboratory for the three competitors are included in Table 1. There is no difference between the three riders' anthropometric and body composition values, except for training age (TA), where rider (b) started riding three years ago. Also among the cardiorespiratory characteristics, rider (b); (VE/VO_2=41.18; VE/VCO_2=33.41) has lower oxygen and carbon dioxide utilization than his two counterparts *(Table 1.).*

Table 1. Anthropometric, body composition, and cardiorespiratory and lower limb muscle strength data of the three motocross riders.

Riders	a	b	c
Ranking	(1;1)	(13;14)	(7;2)
Age (year)	14.03	13.82	14.42
TA (year)	11	**3**	10

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BH (cm)	163.21	164.83	165.42
BM (kg)	54.62	56.81	57.3
BMI	22.0	21.0	21.7
M%	43.65	42.76	41.57
BSA	1.72	1.76	1.78
HR_{rest} (beat×min^{-1})	67	69	73
MP (beat×min^{-1})	197	200	198
VE/VO2	35.96	**41.18**	33.68
VE/VCO2	28.63	**33.41**	28.38
VT_1 (beat×min^{-1})	173	178	177
W/kg	4.79	5.04	4.91
L Max Force (N)	278.3	269.4	281.3
R Max Force (N)	276.9	268.4	280.6

Abbreviation: TA=training age (year), BH=body height (cm), BW=body weight (kg), M%=percentage muscle mass, BSA=body surface area (cm^{-2}), MP=maximal pulse (beat×min^{-1}), VE/VO2=oxygen utilization, VE/VCO2=carbon dioxide utilization, VT_1= respiratory threshold pulse rate (beat×min^{-1}), W/kg=relative performance, L Max Force (N)= Left leg isometric strength, R Max Force (N)=Right leg isometric strength.

Field Tests

The heart rate characteristics as a percentage of the total race are not different for the three runners and the two races. The number of sprints (No. sprint=183) was the smallest in the first race of rider (c), the maximum speed ($Speed_{max}$= 103.6 km/h) was the highest in rider (a), while the training load (TL) =95.3) was the highest in rider (b) in the second race *(Table 2).*

Table 2. Locomotor and mechanical characteristics recorded during the two races.

Riders	a	b	c
Ranking	(1;1)	(13;14)	(7;2)
$HR_{mean\%}$	94.3$_1$; 93.7$_2$	94.51$_1$; 90.3$_2$	97.6$_1$; 95.2$_2$
$HR_{min\%}$	97.3$_1$; 92.0$_2$	94.3$_1$; 88.0$_2$	92$_1$; 92.3$_2$
$HR_{max\%}$	102$_1$; 96.8$_2$	99.8$_1$; 94.2$_2$	100.3$_1$; 98.5$_2$
No. sprint	218$_1$; 213$_2$	233$_1$; 194$_2$	**183$_1$;** 197$_2$
$Speed_{max}$	91.3$_1$; **103.6$_2$**	**80.3$_1$;** 90.2$_2$	90$_1$; 91.3$_2$
TL	89$_1$; 94$_2$	93$_1$; **95.3$_2$**	87$_1$; 93.6$_2$

Abbreviation: $HR_{mean\%}$=relative average pulse, $HR_{min\%}$= relative minimum pulse, $HR_{max\%}$= relative maximum pulse, No. sprint=number of sprints, $Speed_{max}$=highest speed during a race, TL=training load.

The heart rate (Hr) and movement data measured during the competition are shown in Figures 2–5. These figures illustrate the three riders' heart rate and speed patterns at different stages.

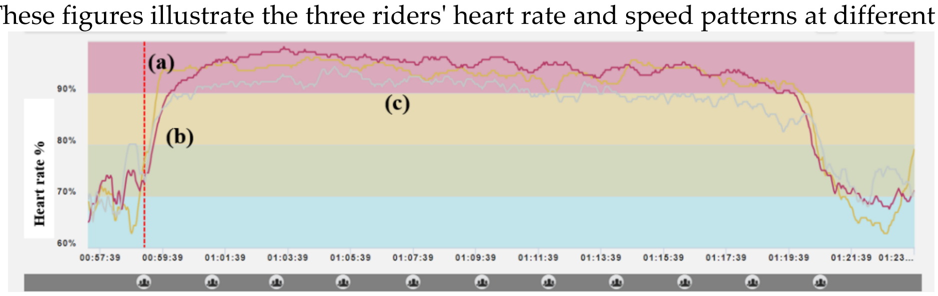

Figure 2. Heart rate (Hr%) patterns of three riders at the first race. Legend: The heart rate pattern of rider (a) is shown by the yellow line, rider (b) is burgundy, and rider (c) is grey.

In the first third of the race, all three riders worked at over 90% of their heart rate. This dropped steadily over the next third of the distance. The biggest decline was in the third period of the distance for **(c)**, which decreased to 90-80% *(Figure 2).*

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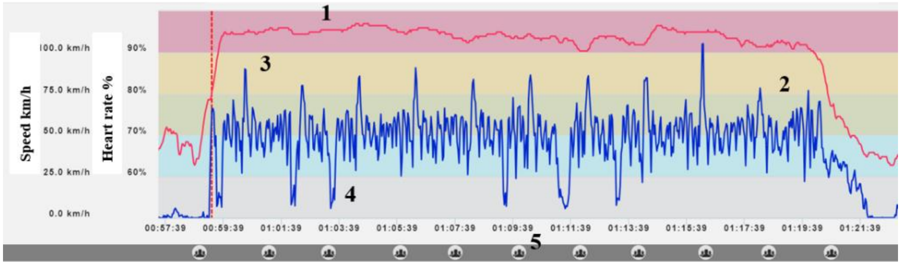

Figure 3. Heart rate (Hr%) and speed patterns of one rider **(a).** Legend: The red line marked with the number one (1) - shows the heart rate pattern, the number two (2) (blue line) - the speed, the blue peak with the number three (3) - is the speed in the straight section of the track, and the blue line marked with the number four (4) - the reduced speed during the corner, number five (5) shows the number of completed laps.

There were several significant falls in speed in the first three laps of the race, and then this pattern shows a balanced speed behavior in the following stages. In the middle part of the race, the speed decreased several times again, and then leveled off in the last part, reaching its maximum value (<100km/h) *(Figure3)*.

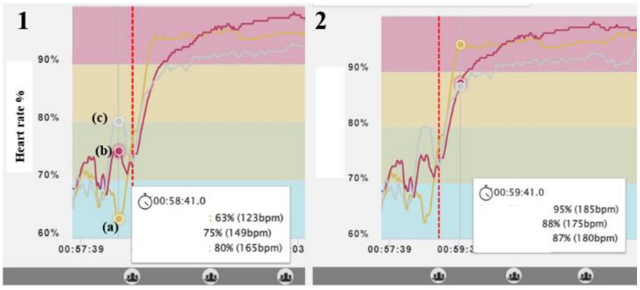

Figure 4. Heart rate at the moment before the start and one minute after the start. Legend: The heart rate pattern of rider **(a)** is shown by the yellow score point, rider **(b)** is the burgundy score point, and rider **(c)** is the grey score point. The white rectangle shows the heart rate of the three riders (Figure 1). Competitor **(a)** is 123 bpm, competitor **(b)** is 149 bpm, and competitor **(c)** is 165 bpm. The second figure shows the heart rate one minute after the start, **(a)** 185 bpm, **(b)** 180 bpm, **(c)** 175 bpm.

Before the race, rider (a) has the lowest heart rate (63%; 123 bpm), while rider (c) has the highest (80%; 165 bpm). One minute after the race starts, rider (a) has the highest heart rate (95%; 185 bpm), while riders (b) and (c) are almost similar *(Figure 4.)*.

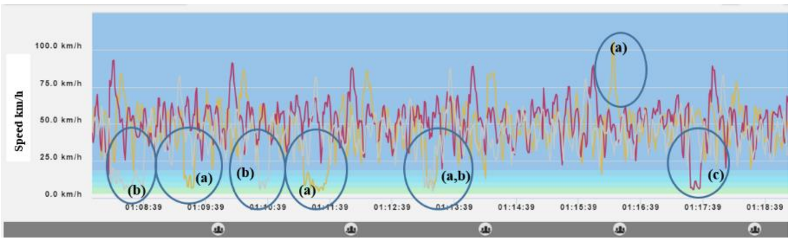

Figure 5. Speed patterns of three riders. Legend: The figure shows a highlighted stage of the race (1:08:39-1:18:30). The speed patterns of the three riders (a,b,c) are shown at different stages of the course (see Figure 3).

In the first third of the race, alternating between (b) and (a) riders, the decrease in speed is more frequent. In the second half of the race, this is no longer the case for these two riders, and rider (a) has a significantly higher speed (<100km/h). The speed decrease of rider (c) is observed in the last lap (~0 km/h), *(Figure 5.)*

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The three riders, in the first race, achieved different heart rate percentages in the first lap [**(a)**=98%; **(b)**=95%; **(c)**=92%)]. Riders **(a)** and **(b)** raced at the same level they started at until nearly halfway through the distance, while rider **(c)** increased his heart rate (100%) steadily, similarly until halfway through the distance. From halfway through the distance, riders **(a)** and **(b)** steadily increased their heart rate until the end of the distance, maintaining the difference in favor of rider **(a)**. Rider **(c)**'s heart rate dropped from 100% to 98%. In the second race, all three riders' heart rates increased slightly (~2%) and then gradually decreased. The heart rate pattern of rider **(b)** shows the largest decrease (~3%). The speed pattern at the start of the first race was the same for riders **(a)** and **(c)**, but lower for rider **(b)** (~12km/h) and held until the second-to-last lap. Riders **(a)** and **(c)** had nearly the same speed until the end of the race. In the second race, the speed pattern of the three riders is almost unchanging. Rider **(a)** was faster than the two others by more than 10km/h in laps 8-10 *(Figure 6)*.

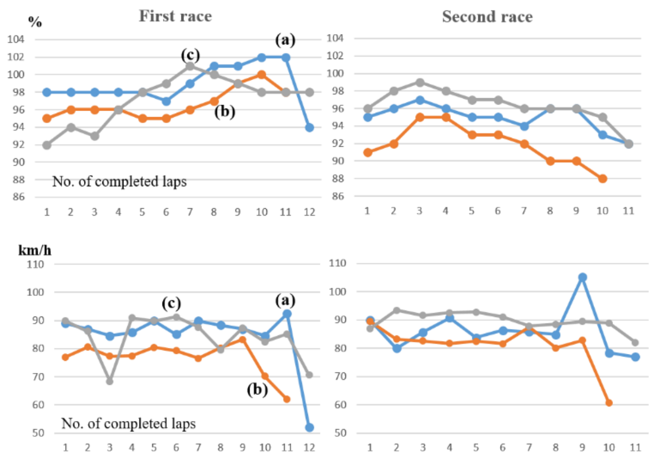

Figure 6. The differences between the heart rate (%) and speed patterns of the three riders tested in the first and second race. Legend: Blue, solid line showing the **(a)** rider's heart rate pattern, Orange solid line showing the **(b)** rider's heart rate pattern, grey line showing the **(c)** rider's heart rate pattern. The bottom two graphs show the speed pattern of the same riders.

4. Discussion

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

In the present study, we investigated the body composition and cardiorespiratory characteristics of three elite adolescent athletes, their heart rate, and speed patterns in the laboratory and competition. We found no differences in the above factors *(Tables 1 and 2),* except (b) age at training and quality of oxygen-carbon dioxide utilization. Since very little data are available on the motocross activity of adolescent children, we can only assume that the much shorter training age affects the quality of the race routine [14]. There is a debate between the physiological and psychological demands of different types of high-speed motocross [15]. The results of the present study show that physiological demands are significant in motocross. Heart rate (HR) showed similar values to previous studies where HR reached 90-100% of the maximum value. Thus, the present results emphasize the functional role of the cardiovascular system [16]. It is known that during hand and lower limb exercises, there is a disproportionate increase in heart rate compared to VO2. This finding may be consistent with a disproportionate increase in HR relative to VO2 during exercise and competition that requires a high rate of isometric contraction of the forearm musculature in particular [17]. It may therefore follow that in our study we can similarly interpret the HR results and hypothesize that the specific upper (lower) limb isometric contractions characteristic of motocross stimulates the metaboreflex and explain at least in part the increased HR. On the other hand, high HR values may also be due to psychological effects [18]. There may be a significant increase in urinary catecholamine release after competition. These stress hormones, in addition to exhaustive exercise, contribute to elevated HR values in these sports.

Although physiological stress is extremely high during motocross, the current study also revealed psycho-emotional characteristics. Before the start of the race, the heart rates of the three competitors' adolescents ranged from 123 to 165 bpm *(Figure 4).* Although surprisingly high heart rates were observed during the races, respiratory responses and blood lactate concentrations indicated that motocross requires a predominantly aerobic metabolism. If metabolic characteristics measured in the laboratory are identified by heart rate patterns and fitted in parallel with heart rates recorded during competition, it can be said that racing occurs between the respiratory breakpoint (VT) and the respiratory compensation point (RCP), [14]. However, it must be accepted that the heart rate pattern measured in laboratory conditions - i.e. the rate of linear increase - is below the values recorded during competition *(Figure 2).* The differences in heart rate and speed measured during the two races did not support the in-race rankings *(Figures 2 and 4).* It can be taken as a fact that the second race showed poorer results for the riders in both characteristics, regardless of the ranking. It can also be said that the results per lap for the three characteristics studied often vary randomly, mainly at the expense of age-appropriate concentration and retention. Thus, it can be said that the relative similarity of the physiological characteristics did not have a major influence on the final ranking in the race. This implies that it is the technique of riding, tactical maturity, spatial orientation, and several other elements that, together with physiological characteristics, determine the final ranking. It appears that a more comprehensive multisystem approach is needed to describe the performance of motorcyclists in competition [19].

In summary, then, we can say that absolute maximum values or absolute values alone during motorcycling do not explain performance. A combined analysis of the physiological, psychological, and cognitive elements mentioned above and an interpretation of their proportions can help to achieve successful performance.

5. Limitation

In our research, we investigated anthropometric, body composition, and circulatory system characteristics in the laboratory and competition. We did not investigate psychological and cognitive aspects. Monitoring these together may be important to understand the impact of the elements present during motocross.

Future Research

It is important to stress that further work is needed to develop the individual profiles of the competitors. There is a need to show how best to prepare them by creating evidence-based methodologies and performance model-based training protocols. The technical background of motorsport is constantly evolving. However, fewer studies are presenting physiological, psychological, and biomechanical studies, especially for children and adolescent riders. During training and competitions, the use of devices that help to monitor circulatory, respiratory, and metabolic changes in the body is recommended. Future research is needed to improve cultural resistance to motorcycle racing and to invest in riders by providing evidence-based applications that improve race performance.

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Informed Consent Statement Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement: The data presented in this study are available on request from the corresponding author without undue reservation.

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Conflicts of Interest The authors declare no conflict of interest.

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