Cross-Country Mountain Biking

Subjects: Physiology

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Mountain biking (MTB) is an off-road cycling discipline, performed on a course composed of a variety of unpaved terrain, which normally include technical or non-technical ascent, descent and flat (UCI regulations, Part 4 mountain bike, version from 11 February 2020). This modality can be practiced by people of all ages, male and female, from children to elderly in a recreational and/or professional manner. However, practitioners should be able to ride technique circuits usually composed of obstacles. For this, unlike road cycling, the bike is equipped with a shock absorption system and wider tires composed of shorter knobs in order to improve bicycle comfort and performance. The start (individual or in mass), duration and distance to be covered change according to each event. Normally, the competitions are played individually, but can also occur in teams (e.g., CAPE EPIC, South Africa, competed in pairs).

power output intensity anthropometry pacing suspension

1. Format of Competition in the Mountain Biking

Currently, the UCI considers the following seven formats of MTB competition: XC; downhill; four-cross; endure; pump track; alpine snow bike; and E-MTB. Among them, XC is the most popular, with eight events (**Table 1**), including the XCO. Although XCO is the top XC-MTB event, other events, such as the cross-country stage race (XCS), cross-country marathon (XCM) and cross-country short track (XCC), have gained the attention of the public, coaches, amateurs and professional cyclists. Therefore, characteristics of these XC-MTB events will be presented in the next session.

Table 1. Types of cross-country mountain biking events.

Event	Abbreviation	Race Time (min)	Circuit Distance (km)
Olympic cross-country	XCO	80–100	4–6
Cross-country marathon	XCM	-	20–160
Cross-country point-to-point	XCP	-	-
Cross-country short track	XCC	20–60	<2
Cross-country eliminator	XCE	< 3	0.5–1.0
Cross-country time trial	XCT	-	-

Event	Abbreviation	Race Time (min)	Circuit Distance (km)
Cross-country team relay	XCR	-	-
Cross-country stage race	XCS	-	-

Data are absolute values. -: race time and/or distance are not well defined or described by UCI regulations.

Main XC-MTB Competitions of the

The circuit of XC-MTB events is composed of a significant amount of uphill, downhill and flat terrains. The course can have natural and/or artificial obstacles, such as tree stumps or tree trunks, rock gardens, stairs, bridges and drops. In official competitions, the obstacles are inserted according to each event, and their use must be preliminarily approved by technical delegates or the commissaires' panel. Paved roads are permitted, but should not exceed 15% of the total course. The technical difficulty level, total distance, altitude of the circuit, number of laps and total race time for men and women are defined according to each type of event (UCI regulations, Part 4 mountain bike, version from 11 February 2020). For example, while the total race time in XCO is between 80 and 100 min, in XCC, the competition lasts between 20 and 60 min. In addition, the XCO course is comprised of very technical sections that have a high degree of difficulty, while in XCC, the course is comprised of very few technical sections, and these have a low difficulty. The circuit of each event must be clearly defined before the start of the competition, and its access is granted only during the event and official training periods.

2.1. XCO

According to the current UCI regulations (Part 4 mountain bike, version from 11 February 2020), the XCO circuit must be 4–6 km in length. The number of laps is not fixed, but the total race time must last between 80 and 100 min. This total race time has not been the same throughout the years, being reduced for both men and women (**Table 2**). Total race distance and the total elevation gain were also reduced from 34 ± 3 km and 1430 ± 378 m [1] to 28 ± 5 km and 1248 ± 197 m, respectively [2]. In addition, athletes and coaches have reported that the degree of difficulty of the technical sections has been increased in recent years, making the circuit more complex and challenging. These changes influenced the physiological responses and mechanical demands of the competition [3].

Table 2. Race time, physiological responses and mechanical demands to XCO competition obtained from published studies in English on the topic.

Study (Male)	Race Time (min)	HR (% HR max)	PO (W)	PO ($W \cdot kg^{-1}$)	PO (% PO Max)	CA (rpm)	CA-ETSNP (rpm)	Speed (km/h)
Impellizzeri et al. (2002) [1]	147 ± 15	90	-	-	-	-	-	-
Stapelfeldt et al. (2004) [4]	128 ± 17	91	246 ± 12	3.6 ± 0.2	66.9	-	-	-
Granier et al. (2018) [2]	90 ± 9	91	283 ± 22	4.3 ± 0.3	68.0	68 ± 8	83 ± 7	19.7 ± 2.1

Study (Male)	Race Time (min)	HR (% HR max)	PO (W)	PO (W·kg^{-1})	PO (% PO Max)	CA (rpm)	CA-ETSNP (rpm)	Speed (km/h)
Prinz et al. (2021) [3]	82 ± 13	91	255 ± 37	3.9 ± 0.4	68.9	64 ± 6	-	-
Study (Female)								
Stapelfeldt et al. (2004) [4]	108 ± 4 [5][6]	92	193 ± 1	3.1 ± 0.2	64.3	-	-	-
Prinz et al. (2021) [3]	77 ± 11	93	186 ± 18	3.6 ± 0.4	71.3	64 ± 2	-	-

Data are mean ± SD or only mean. HR: heart rate; PO: power output; CA: cadence; ETSNP: excluding the time other places on the grid are defined according to the last published individual UCI XCO ranking. Unclassified riders spent not pedaling; -: not evaluated.

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adopted the XCC result to define a part of the starting grid of the XCO. In these competitions, the top 24 finishers of the XCC event, which normally takes place two days before the XCO competition, start in the front rows. The other places on the grid are defined according to the last published individual UCI XCO ranking. Unclassified riders will be allocated by drawing lots.

Physiological Responses and Mechanical Demands of the XCO

In addition to monitoring and evaluating performance, sport researchers used portable devices to describe the physiological responses and mechanical demands of the XCO competition [1][2][3][4]. Although few studies have described these responses and demands in the XCO, it is possible to summarize its requirements (**Table 2**). For men, a slight increase in mean heart rate (HR) (expressed as %HR maximal), mean absolute power output (PO) (W), relative PO (W·kg^{-1}) and expressed as %PO maximal were identified throughout the years. For women, a slight increase in mean HR (expressed as %HR maximal), relative PO (W·kg^{-1}) and PO expressed as %PO maximal, but a decrease in absolute PO (W), were also reported. Female cyclists maintain a higher intensity than men cyclists during XCO.

Only the two more recent studies measured cadence (CA) during XCO competition [2][3] (**Table 2**). The results showed that the CA selected by the riders was higher than these reported in the laboratory tests considered most effective [8][9], mainly when time spent not pedaling was excluded. Unlike laboratory tests where the PO is constant, the XCO circuits are extremely complex, which include technical sections such as rolling over obstacles, requiring a high CA and PO variation according to the demands of each section, limiting the ability to identify an optimal cadence [10]. It is probable that this CA selected by the riders during XCO resulted from a specific competition demand rather than by physiology and biomechanics factors [10]. In fact, during a cycling Gran Tour, professional riders selected different CA at different stages of the competition [11]. Lastly, there seems to be no effect of sex on CA selection [3].

A feasible tool for controlling training intensity and identifying the requirements of a competition is categorization in intensity zones, according to HR and PO. Generally, these zones are categorized into 1 to 3, 4 or 5 intensity ranges. Of the four studies analyzed, one study used the HR correspondent to the first and second threshold to determine the intensity zones, separating these into three zones [1]. Another study used the PO that corresponded to maximal oxidative power (MOP) for the first and second threshold, separating these into four zones [4], and two

other studies also used the PO that corresponded to MOP for the first and second threshold, but separating these into five intensity zones [2][3]. The percentage of time spent in the intensity zones during XCO is summarized in **Table 3**. It was observed that the time spent in different intensity zones during XCO was modified throughout the years. Considering more recent studies [2][3], ~43% of the total race time in XCO is performed at high intensity (above the second threshold), with ~28% of the aforementioned 43% performed above MOP.

Table 3. Percentage of time spent in different intensity zones during XCO.

Study (Method)	<10% of MOP	<FT *	Between FT and ST	>ST #	>MOP
Impellizzeri et al. (2002) [1] (HR)		18 ± 10	51 ± 9	31 ± 16	
Stapelfeldt et al. (2004) [4] (PO)		39 ± 6	19 ± 6	20 ± 3	22 ± 6
Granier et al. (2018) [2] (PO)	25 ± 5	21 ± 4	13 ± 3	16 ± 3	26 ± 5
Prinz et al. (2021) [3] (PO)	28 ± 4	18 ± 8	12 ± 2	13 ± 3	30 ± 9

Data are mean ± SD. HR: heart rate; PO: power output; MOP: maximal oxidative power; FT: first threshold; ST: second threshold. <: below; >: above. *: value can be below FT or between 10% of MOP and FT. #: value can be above ST or between ST and MOP.

XCO is performed with a coefficient of variation of PO of 75.8 ± 5.2% [2], showing that the athlete increases (e.g., during uphill sections) and decreases (e.g., during downhill sections) the PO repeatedly in order to maintain a high speed throughout the laps. Although the literature reported a higher coefficient of variation of PO for men than women (80.1 ± 6.3% vs. 75.1 ± 4.0%), no significant difference between them is reported [3].

Recently, the level of effort put in above the MOP was also measured [3]. Cyclists performed at an average level of 334 ± 84, with an average duration of 4.3 ± 1.1 s, and an average interval of 10.9 ± 3.0 s. The average PO of the effort was 7.3 ± 0.6 $W \cdot kg^{-1}$, which corresponds to 135 ± 9% of the MOP. When the efforts were separated into five duration-based categories ((1 to 5 s); (6 to 10 s); (11 to 15 s); (16 to 20 s); and (>20 s)), the highest level of effort put in was recorded between 1 and 5 s (261 ± 73), while the lowest level of effort was recorded between 16 and 20 s (6 ± 3). Therefore, the ability to perform at high-intensity for a short duration and with low recovery intervals could be a decisive parameter for achieving success in the XCO competition [3].

2.2. XCS

XCS is a stage race competition that includes several XC-MTB event modalities across consecutive days. Some XC-MTB events are performed only in XCS, such as XCT and XCP, except XCE (UCI regulations, Part 4 mountain bike, version from 11 February 2020). Thus, the total distance, time and altitude of the circuit, as well as the definition of the start, depend on the type of race of each stage. The competitions are performed between four and nine days, with only one stage being performed per day. In addition, one of the stages must contain a long-distance course according to the characteristics of the XCM competition. There is no minimum time to complete each stage, but there is a maximal time that is defined by the organization of each event. Normally, XCS is performed in doubles, but competitions performed by individuals or teams of up to six riders can be carried out. The XCS winner will be the rider or team that completes all the stages in the lowest accumulated time.

South Africa Cape Epic is considered one of the main XCS events. It consists of eight stages carried out in eight consecutive days. In 2022, the athletes covered a total distance of 681 km with 16,900 m of elevation gain. The characteristics of the event are presented in **Figure 1**. It is interesting to note that there is a high variation in total distance, altitude and elevation gain among the stages, which could influence the physiological responses and mechanical demands among them. The winning race time was 27:44 h.

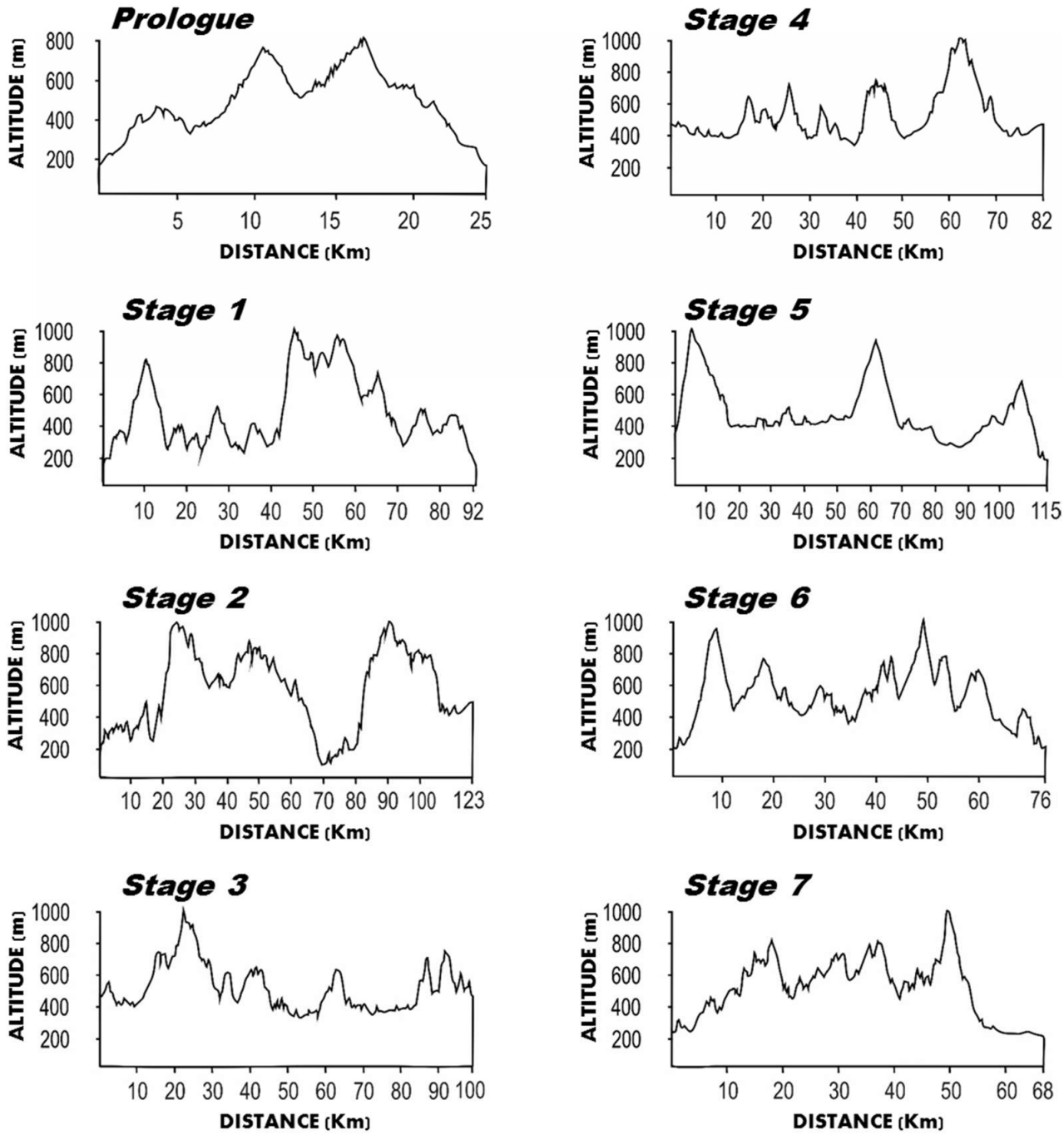

Figure 1. Characteristics of the Cape Epic event.

Physiological Responses and Mechanical Demands of the XCS

Interestingly, there are few studies that examine the exercise intensity during the XCS competition [12][13]. In 2008, Wirnitzer and Kornexl [13] examined exercise intensity during the Transalp Challenge, a competition that comprised of an eight-day stage race, with a total distance covered of 662 km (average of 83 ± 25 km/stage) and total elevation gain of 22,500 m (average of 2810 m/stage), respectively. The authors used the HR that corresponds to the lactate thresholds, which were established previously in the laboratory, to determine the four intensity zones. Briefly, zone 1 was established as the intensity below 2 mmol/L lactate (LT2); zone 2 was established as the intensity between LT2 and 4 mmol/L lactate (LT4); zone 3 was established as the intensity between LT4 and 6 mmol/L lactate (LT6); and zone 4 was established as the intensity above LT6. In general, the average HR (expressed as %HR maximal), considering all the stages, was 79%, and the average time spent in zones 1 to 4 was 36 ± 12, 58 ± 13, 4 ± 8 and 2 ± 9% of the total race time, respectively. Throughout the competition, the athletes were not able to maintain a high intensity in the last stages. In addition, a decrease in maximal HR was recorded after the first stage.

More recently, Reinpõld, Bossi and Hopker [12] examined the mechanical demands of the Cape Epic event. The authors defined the intensity zones using the PO and HR that correspond to the percentage of the respiratory compensation point (RCP). According to the PO, zones 1 to 5 were defined as the intensity below 55%, between 56 and 75%, between 76 and 90%, between 91 and 105% and above 106% of the RCP, respectively. According to HR, zones 1 to 5 were defined as the intensity below 68%, between 69 and 83%, between 84 and 94%, between 95 and 105% and above 106% of the RCP, respectively. The analyses were performed during the prologue and stages 1, 2 and 6, while data from stage 6 were not included in the statistical analysis. The results showed that cyclists spent more time in zones 1 and 2, and spent less time in zones 4 and 5 during stage 2, when compared to the prologue. In addition, cyclists were able to maintain a higher intensity in the prologue when compared to the stage 2. That is, the average PO generated in the prologue (3.08 ± 0.74 $W \cdot kg^{-1}$) was higher than that generated in stage 1 (2.43 ± 0.66 $W \cdot kg^{-1}$) and 2 (2.22 ± 0.70 $W \cdot kg^{-1}$). The coefficient of variation of the PO in the prologue, stage 1, 2 and 6 was 64.4 ± 9.6%, 71.4 ± 11.8%, 78.7 ± 13.6% and 72.3 ± 15.3%, respectively. It is important to highlight that these results reported by Reinpõld, Bossi and Hopker's [12] study should be interpreted with caution, because the analyses were performed with only six cyclists of different performance levels, which could reveal a low statistical power (statistical power < 0.8), increasing the probability of a type II error [14]. Moreover, the authors analyzed only three of the eight stages. In addition, it is important to highlight that the prologue is remarkably shorter than the others, which could contribute to the differences between the data of this stage and the others. Therefore, new studies must be developed, involving a larger sample size and analyzing all the stages of the competition to clarify the physiological responses and mechanical demands of the Cape Epic.

In general, the studies suggest that most of the time of the XCS competition is performed at low and moderate intensity, with variation in PO throughout the stages, demanding high energy production rates via the oxidative and non-oxidative energy systems. Furthermore, cyclists tend to spend more time at high intensity (above the second threshold) in the first stage, reducing throughout the competition.

2.3. XCM

XCM is a mass start event, composed of a course with a distance of 60 to 160 km, without a minimum time to complete the race. According to UCI regulations (UCI, Part 4 mountain bike, version from 11 February 2020), the XCM can be carried out in a single lap or in a maximal number of three laps. For a single lap, the start and finish lines of the circuit may be located at the same place. Paved or unpaved sections, and a technical section, such as a rock garden, single track and jumps, may be included in the course. However, the majority of the competition is performed on wider roads and relatively few sections of high technical degree.

The starting grid in XCM is determined by the following order: first, according to last published UCI MTB marathons series ranking; second, according to the last published UCI XCO individual ranking and finally, unclassified riders will be allocated by drawing lots. Despite being one of the most practiced competition, no study that measures the physiological responses and mechanical demands of the XCM competition has been developed. Novak et al. (2018) [15] measured PO and oxygen uptake during a 4-h MTB competition. However, the aim of the research was to cross-validate previously developed predictive MTB performance models in a new cohort of off-road cyclists. Furthermore, the event evaluated by the authors was not in line with the recommendations of the UCI regulations (Part 4 mountain bike, version from 11 February 2020). Therefore, future studies are required to examine these responses in XCM.

2.4. XCC

XCC is performed on a circuit of approximately 2 km. The number of laps is not fixed, but the race time must be between 20 and 60 min, which, in international competitions, results in about 7–8 laps for men and 6–7 laps for women. The type of terrain of the circuit is similar to that of the XCO, but the technical sections are considered of low difficulty and the number of ascents and descents is reduced, resulting in lower total elevation gain. The number of participants is limited to 40 cyclists and the starting grid is defined according to the ranking classification, which may differ among the events. For example, in the XC-MTB World cup, the XCC start grid is defined by the top 16 cyclists of the last published XCO World Cup individual ranking, and the other places on the grid are defined according to the last published individual UCI XCO ranking. To compete in XCC, the rider must be registered and confirmed in the XCO that occurs in the same week, using the same bike in both events (UCI regulations, Part 4 mountain bike, version from 11 February 2020).

Despite the XCO being the premier XC-MTB event, the XCC has become popular in recent years. Indeed, in addition to the prizes, the results of this event add points to the UCI individual ranking and define the top 16 positions of the XCO start grid (as demonstrated in Section 2.1). Moreover, in the year 2021, a world championship was developed for this event. However, important factors in overall performance, such as mechanical and physiological aspects of this competition, are currently lacking.

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