DOI: 10.4025/jphyseduc.v34i1.3437

Original Article

MECHANICAL DEMANDS AND PACING PROFILE ADOPTED BY ELITE MOUNTAIN BIKERS DURING DIFFERENT CROSS-COUNTRY EVENTS[1]

DEMANDAS MECÂNICAS E PERFIL DE RITMO ADOTADO POR CICLISTAS DE MONTANHA DE ELITE DURANTE DIFERENTES EVENTOS DO CROSS-COUNTRY

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RESUMO
Diferentes ambientes competitivos parecem afetar as demandas físicas durante as competições esportivas. Assim, o objetivo deste estudo foi reportar as demandas mecânicas e o comportamento do pacing de doze homens ciclistas de montanha da categoria elite durante o cross-country de pista curta (XCC) e o cross-country Olímpico (XCO). Durante ambas as competições, o tempo total de corrida, velocidade, potência (PO) e cadência (CA) foram gravados. Como o tempo de prova do XCC é menor (21,0±0,5 vs 84,0±3,0 min; p<0,01), a velocidade média (26,6±0,6 vs 17,8±0,6 km/h; p<0,01), PO (365,0±26,7 vs 301,0±26,2 watts; p<0,01) e CA (81,2±4,7 vs 77,4±4,3 rev·min^{-1}; p=0,01) foram maiores que no XCO. Enquanto um ritmo variável foi adotado no XCC, um perfil positivo foi adotado no XCO. Além disso, os atletas adotaram um ritmo inicial mais conservador durante o XCC (abaixo da velocidade média da prova), mas um início mais rápido durante o XCO (velocidade acima da média da prova). Esses achados demonstraram que os parâmetros mecânicos e o ritmo adotados pelos ciclistas são diferentes entre o XCC e XCO. Portanto, ciclistas e treinadores devem desenvolver estratégias e métodos de treinamento específicos para obter sucesso em cada competição.
Palavras-chave: Potência. Intensidade. Cadência. Cross-country Olímpico. Cross-country pista curta.

ABSTRACT
Different competitive environments appears to affect the physical demands during the sports competitions. Thus, the aim of this study was to report the mechanical demand and pacing behaviour of twelve male elite mountain bikers on cross-country short track (XCC) and cross-country Olympic (XCO). During both competition, total race time, speed, power output (PO) and cadence (CA) were recorded. As the race time in the XCC is shorter (21.0 ± 0.5 vs 84.0 ± 3.0 min; p<0.01), the average speed (26.6 ± 0.6 vs 17.8 ± 0.6 km/h; p<0.01), PO (365.0 ± 26.7 vs 301.0 ± 26.2 watts; p<0.01) and CA (81.2 ± 4.7 vs 77.4 ± 4.3 rev·min^{-1}; p=0.01) were higher than the XCO. While a variable pacing was adopted during XCC, a positive profile was adopted in XCO. In addition, athletes adopted a more conservative starting pace during XCC (below average race speed) but a faster start during XCO (above average race speed). These findings demonstrated that mechanical parameters and pacing profile adopted by cyclists are different between XCC and XCO. Therefore, mountain bikers and coaches must develop specific strategy and training methods in order to obtain success in each competition.
Keywords: Power output. Intensity. Cadence. Cross-country Olympic. Cross-country short track.

Introduction

Mountain biking is an off-road cycling modality, which includes repeated technical uphill and downhill sections on a variety of terrain with many natural or man-made rock gardens, tree roots, mud and single tracks[2]. One of its most popular events is Cross-Country Olympic (XCO), which is included in the Olympic Games. In the XCO race, athletes start in a single group to complete several laps on a closed-loop of 4 to 6 km length (Union Cycliste Internationale regulations, Part 4 mountain bike, version from January 2022), lasting approximately 90 ± 10 min[3]. Despite the high interest in XCO, more recently the cross-country short track (XCC) event has drawn the attention of athletes and coaches. In addition to add point to the Union Cycliste Internationale world ranking, the results of this event have been used to determine the XCO starting grid. Moreover, an XCC world championship was developed in the year 2021. In the XCC race, 40 athletes start in a single group to complete several laps on a closed-loop of no more than 2.0 km length, lasting 20 to 30 min. The technical sections of XCC circuit have a low degree of difficulty and the elevation gain is shorter, when compared to XCO (Union Cycliste Internationale UCI regulations, Part 4 mountain bike, version from January 2022).

Both XCO and XCC competition represent a complex environment, exposing the participants to a numerous amount of information that may influence the regulation of pacing strategies adopted by the athletes[4,5]. Theoretical frameworks suggested that the pacing is regulated by the brain through afferent feedback from the peripheral systems and efferent neural commands[6], being based, among other factors, on the environmental conditions (such as diverse range of terrains), previous experience of similar exercise, knowledge of physical abilities and race format[4]. This process is continuous and extremely important, where a failure will compromise the overall performance of the athlete[4].

Researchers showed that, during XCO competition, athletes tend to adopt a fast start followed by a more even pacing, which is representative of a positive pace[3]. According to the authors[3], since the XCO é a mass-start event, the cyclists increase speed at the beginning of the race in order to place themselves in the front positions for avoiding congestion in sections composed of single track and turns in tight areas, which could impair their overall performance during such event. Nevertheless, as different competitive environments appeared to affect the regulation of the pacing over an exercise[7], it is still unclear if the athletes adopt the same pacing behavior during XCC. This analysis is important because understanding the differences among mountain biking competitions composed by different formats can provide important insights for cyclists to determine training and competition strategies to improve their performance in each event. The aim of this study therefore was to report how elite mountain biking athletes respond to different cross-country event performed during a stage of the mountain biking world cup. We hypothesized that the response of the athletes differ between the XCC and XCO competitions.

Methods

Sample

Data from twelve male elite mountain bikers (29.2 ± 4.8 yrs; range: 24 – 41 yrs) were assessed in this study approved by the local ethical committee (number 4.120.625) for human experiments and performed in accordance with the Declaration of Helsinki (2000). All athletes were registered by the local cycling confederation, had experience above 5 years in XCC and XCO racing settings and had been listed in the first 40 positions of the Union Cycliste Internationale world ranking. Three of these cyclists finished in the first five positions of the Union Cycliste Internationale world ranking and won at least once XCC or XCO competition in the Union Cycliste Internationale mountain biking world cup. The exclusion criteria were failure of the individual device used to data collect or any other factor, such as accidents with consequent injuries and mechanical failure of the bicycle, that could compromise the analysis. An informed consent form was not required because data were of public domain.

Cross-country short track (XCC) and cross-country Olympic (XCO) competitions and track course profile

The XCC and XCO races were performed during the 2021 Union Cycliste Internationale mountain biking World Cup competition, which involved repeated laps on a hilly closed-loop of approximately 1.17 and 3.6 km, respectively. All athletes cycled on the both XCC and XCO tracks before the competition. The number of laps, total race time, total race distance, total elevation gain and max altitude of both XCC and XCO are reported in table 1. XCC and XCO track comprised a combination of tarmac, cobblestones and dirt track composed of uphill, downhill and flat. Compared to XCO, XCC course involves few obstacles (such as rock gardens, tree roots and mud) of low degree of difficulty, which is preliminary approved by the Union Cycliste Internationale technical delegate (Union Cycliste Internationale regulations, Part 4 mountain bike, version from January 2022). The course of both XCC and XCO races (Figure 1) was measured by the researchers themselves of this study through the GPS device (Garmin® Edge, Kansas City, United States) used by a cyclist involved in this study.

Table 1. Course profile completed by cyclists on the cross-country short track (XCC) and cross-country Olympic (XCO) races

	XCC	**XCO**
Laps	8	SL + 6
Total race distance (km)	9.36	24.4
Total elevation gain (m)	174	1085
Max altitude (m)	775	846

Note: SL, start loop (~2.8 km length).
Source: Authors

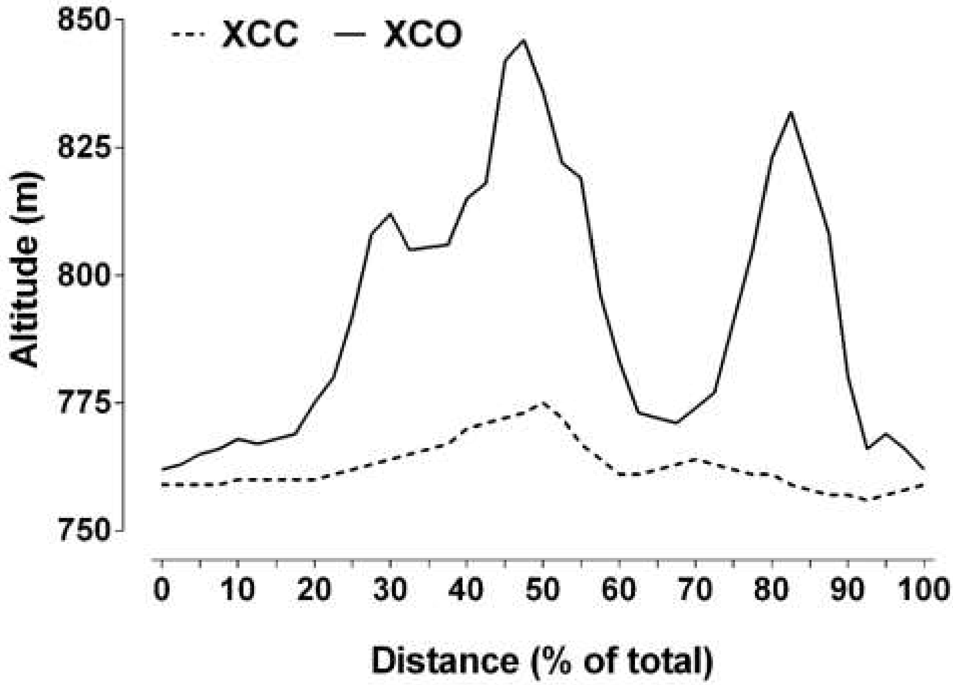

Figure 1. Cross-country short track (XCC) and cross-country Olympic (XCO) course profile for an individual lap
Source: Authors

Data collection

Athletes used their own devices (Garmin® Edge, Kansas City, United States; or Wahoo® elemnt bolt, United States) to record total race distance and time, speed, power output (PO), cadence (CA) (without excluded the time spent not pedaling) and elevation gain of both XCC and XCO competitions, which were posteriorly downloaded directly in the Strava® program by the athletes themselves. The brand of mobile power meter and cadence sensor used to measure PO and CA during both races was not identified. Strava is a mobile app, which athlete can record and/or share their own race or training data with the public. Therefore, the data were of public domain, and only publicly accessible sources were used. Previous studies have already used this program to collect data[8]. Two researchers of this study collected and analyzed the data of the Strava. Discrepancies in the data were resolved through mutual consensus between them.

Based on the Abbiss et al.[9] study, we correlated the total race time recorded by individual devices used by the athletes with official system of Union Cycliste Internationale mountain biking World Cup organization. For both XCC and XCO the association was classified as nearly perfect[10] (XCC: Pearson correlation coefficient = 0.994, $p < 0.01$; XCO: Pearson correlation coefficient = 1.00, $p < 0.01$). To evaluate pacing profile, we examined average speed lap by lap. The coefficient of variation (CV) of speed, PO and CA across laps was determined using standard deviation divided by the average value of variable multiplied by 100. It is important to highlight that the effects of external factors (such as crashes without consequent injuries and congestion) on the time race, speed, PO and CA in both XCC and XCO competitions were not determined. Therefore, no attempt was made to exclude these from analysis [9].

Statistical analysis

The data analyses were performed using the IBM SPSS (Version 23) and GraphPad (PRISM®, 6.0, San Diego, USA) statistical program. The normality of the data was checked using Shapiro-Wilk test. A one-way analysis of variance (ANOVA) for repeated measures or Friedman test was conducted to compare the PO, CA and speed, across the laps in XCC and XCO races. When necessary, a Bonferroni's post-hoc test was employed. To compare overall values of average PO, CA and speed between XCC and XCO competitions, a dependent Student t-test or Wilcoxon test was used. Pearson´s or Spearman´s bivariate correlations test was performed for verify correlation between speed and PO across laps, using a scale to analyze the correlation coefficient (proposed by Hopkins - www.sportsci.org): < 0.1, trivial relationship; 0.1 - 0.3, low; 0.3 - 0.5 moderate; 0.5 - 0.7, strong; 0.7 - 0.9, very strong; > 0.9, nearly perfect. Due to device recording failures, PO and CA analyses were performed with seven and nine cyclists, respectively. The level significance adopted was $p \leq 0.05$.

Results

Race time, speed, power output and cadence

Cyclists finished both XCC and XCO races without injury or faced mechanical problems. As the duration of the XCC is shorter than the XCO, cyclists completed the XCC competition in a lower peak speed, but with significantly higher average speed, PO and CA. The CV of speed, PO and CA across laps was similar between competitions (Table 2).

Table 2. Race time and mechanical values during both XCC and XCO races

	N	*XCC*	*XCO*	P_{value}
Race time (min)	*12*	*21 ± 0.5*	*84 ± 3.0*	*<0.01*
Speed$_{mean}$ (km/h)	*12*	*26.6 ± 0.6*	*17.8 ± 0.6*	*<0.01*
Speed$_{peak}$ (km/h)	*12*	*47.4 ± 1.2*	*51.8 ± 2.0*	*<0.01*

	N	*XCC*	*XCO*	P_{value}
CV of Speed (%)	*12*	*4.3 ± 1.5*	*3.4 ± 1.8*	*0.158*
PO_{mean} ***(W)***	*7*	*365.0 ± 26.7*	*301.0 ± 26.2*	*<0.01*
PO_{peak} ***(W)***	*7*	*1251.6 ± 122.8*	*1215.1 ± 112.1*	*0.478*
CV of PO (%)	*7*	*8.9 ± 4.1*	*6.4 ± 2.8*	*0.192*
CA_{mean} $(rev \cdot min^{-1})$	*9*	*81.2 ± 4.7*	*77.4 ± 4.3*	*0.011*
CA_{peak} $(rev \cdot min^{-1})$	*9*	*130.1 ± 18*	*147.6 ± 15.7*	*0.055*
CV of CA (%)	*9*	*2.9 ± 1.1*	*2.5 ± 1.2*	*0.489*

Note: *Data are mean ± SD; CV = coefficient of variation across the laps; PO = Power output; CA = Cadence.*
Source: *Authors*

Pacing profile, power output and cadence distribution

During XCC, cyclists significantly oscillated average lap speed during the race, which is representative of a variable pacing profile, with two speed peaks, in the second and last laps. In contrast, during XCO competition, athletes adopted a fast start race, decrease speed from SL for Lap 1, and were able to maintain similar speed from lap 1 until lap 6, which is representative of a positive pacing (with only one speed peak in SL) (Figure 2).

PO across laps did not change during XCC. However, during XCO, PO decreased from SL for Lap 1 ($p<0.05$) and it was similar from lap 1 until lap 6 ($p>0.05$) (Figure 2). For CA, no significant difference was observed across laps ($p = 0.403$) during XCC. However, during XCO, a significant decrease was observed in lap 6 compared with lap 1 ($p = 0.022$) (Figure 2). No significant correlation was found between average speed and average PO across laps for XCC ($r = 0.462$; $p = 0.249$), but a significant positive correlation was found for XCO competition ($r = 0.991$; $p < 0.01$).

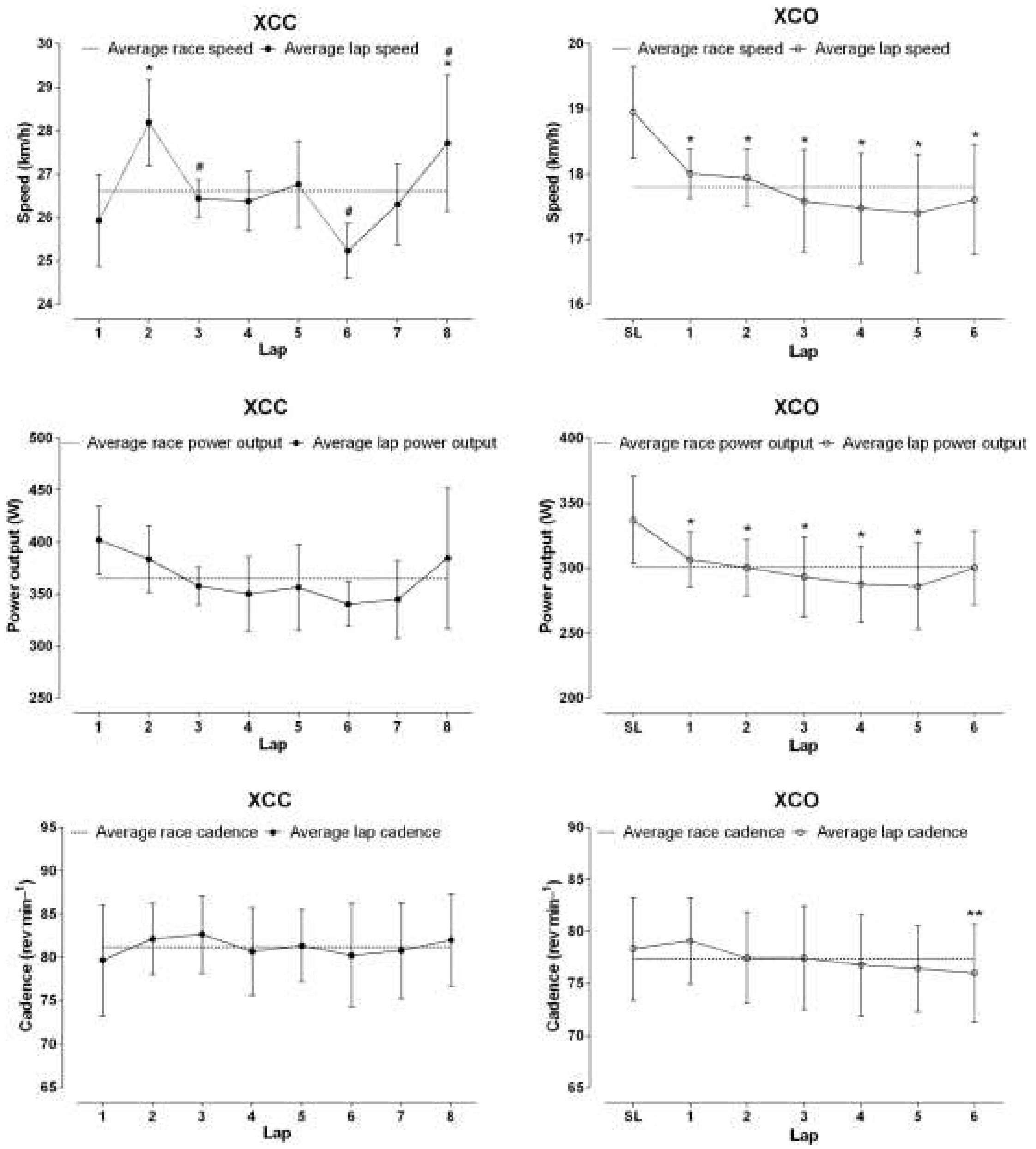

Figure 1. Average speed, PO and CA during XCC and XCO races
Note: Data are mean ± SD. SL, start loop. * $p < 0.05$ compared with Lap 1 or SL; $^{\#}$ $p < 0.05$ compared with previous lap; ** $p = 0.022$ compared with lap 1
Source: Authors

Discussion

The aim of this study was to report how elite mountain bikers respond on different cross-country events performed during a stage of the mountain biking world cup. Our main findings were that during XCC athletes adopted a variable pacing profile with a conservative starting pace (below average race speed), but a positive pacing profile with a faster starting pace during XCO (above average race speed). In addition, as the duration of the XCC is shorter than the XCO, the athletes adopted higher speed, PO and CA during XCC. Lastly, PO and CA across laps were significantly similar over the entire XCC. However, during

XCO, the cyclists decreased PO after SL but maintained a similar PO from Lap 1 to Lap 6 and decreased average CA only at the last lap.

This is the first study to analyze pacing profile and mechanical responses during XCC and between two mountain biking race formats. Race durations (XCC = 21 ± 0.5 and XCO = 84 ± 3.0 min), distance of the course and elevation gain reported in the present study (Table 1) are in line with actual Union Cycliste Internationale regulation (Union Cycliste Internationale regulations, Part 4 mountain bike, version from January 2022). These recommendations demonstrate that, in addition to a less technical circuit, XCC has a lower race duration, total distance and elevation gain when compared to XCO. Such differences can influence the choice of pacing profile[11] and mechanical demands[12], which was coherent with our findings.

According to our data, while cyclists adopted a variable pacing during XCC, a positive pacing was adopted during XCO, showing that the XCC competition was composed by higher speed variations. It is probable that such accelerations were more apparent in XCC due to constant attempts to overtake opponents during competition, which does not occur during XCO. This interaction with an opponent (an external factor) evoked reactions of the cyclist to accelerate, to decelerate or to maintain current pacing, which resulted in a variable pacing profile. In fact, previous study suggests that this interaction with opponents (an external factor) provide new insights that can affect the decision-making of the athlete and consequently alter its pacing[13] in order to achieve the first place. As XCC is a short time competition, a decision to remain at current pace while opponent accelerates could affect the chances of winning, once the winner of the event is the cyclist who passes the finish line first. These findings are interesting, because they may indicate that the athletes are more required to continually make decisions during XCC than XCO as a result of a direct influence of an opponent. Therefore, since decision-making environments is part of competition and important for effort regulation[4,5,13], we suggest that, mainly for XCC competition, athletes simulate this interaction with opponents during training process in order to better prepare them for achieve maximal performance level.

Interestingly, it is important to note that the pace adopted in the initial phase of the race was different between competitions. While athletes adopted a faster start during XCO (above average race speed), which is in line with previous study[3], during XCC, they adopted a more conservative starting pace (below average race speed) (Figure 2). This decision-making can be due to number of competitors competing within a race[7], where XCC was performed with 40, and XCO was performed with 154 participants. That is, with a high number of competitors, as in XCO, athletes tend to adopt an aggressive starting. During XCO, cyclists accelerate in the initial phase in order to place themselves in the front positions for avoid crashes and congestion[3,14] caused by single track and turns in tight areas that could impair their overall performance, which probably did not happen during XCC. This suggestion of effect of the number of participants in the initial phase of the race appears to be supported by the work of Konings and Hettinga[7]. The authors demonstrated that the number of participants within a race affected the pacing behavior in the initial phase of the short-track speed skating competitions. Thus, considering the race format, it appears that a faster starting required in XCO is not required in XCC. However, futures studies are encouraged to better investigate this aspect.

Although pacing refers to time and/or speed, its regulation is also dictate by the ability to resist fatigue[11]. Thus, examine the PO produced by the cyclists during competition is of important for better understanding the physical requirements[3]. During XCO, it was observed that there was a decline in the average speed after SL, which was associated with a reduction in the PO. In addition, a significant positive correlation was found for XCO competition between average speed and average PO across laps ($r = 0.991$; $p < 0.01$). This decline in PO after SL also was observed by Granier et al.[3] during XCO competition. Following their hypothesis, such decline could be an indication of fatigue development due to high produce PO in the initial phase of the race, where athletes tend to adopt a faster starting to place themselves in the front positions. In contrast with XCO, our results showed that the accelerations observed during XCC were not significantly correlated with PO responses ($r = 0.462$; $p = 0.249$). Perhaps a higher speed generates a smaller change in PO. Moreover, no decline in PO was observed after Lap 1. These results indicate that cyclists adopted a speed and PO distribution different between XCC and XCO race, and that physical demands are specific for each competition.

The importance of sustaining a high PO and speed to be competitive in mountain biking has been confirmed[14,15]. Nevertheless, these mechanical variables can be affected by race format[12]. Our findings showed that athletes completed XCC with average PO and speed higher compared to XCO (Table 2), but no difference between races was found in CV of PO and speed. It has previously been shown that the PO and speed average were substantially higher during a circuit composed by lower elevation gain, total race time and total distance[12]. Therefore, our results indicate that XCC is the most physically demanding event in elite mountain biking in terms of speed and PO when compared with the most popular mountain biking event (i.e., XCO). Given such differences, we suggest that the cyclists should incorporate specific training to prepare for each race demands.

We would like to emphasize that the average PO value found in XCO was higher than the reported in previous research [301.0 ± 26.2 (in our study) versus 283 ± 22 watts[3]]. However, cyclists of the current study had a better World ranking [listed in the first 40 positions versus world ranking of 49 with the range 7-184 positions], which could indicate a higher performance level[16]. In relation to XCC, no study assessed PO during race. Therefore, more research is necessary to confirm our findings. Although reporting average PO is a more basic methodology[17], this method is widely adopted to describing the mechanical responses of mountain biking events[3,15,18].

CA is an important factor for cycling performance that has been widely investigated in recent years[19,20]. Although CA of ~60 $rev \cdot min^{-1}$ has been shown to minimize metabolic cost under laboratory conditions, cyclists chose a relatively higher CA during both competitions (XCC = 81.2 ± 4.7 and XCO = 77.4 ± 4.3 $rev \cdot min^{-1}$), as has been previously reported[19]. Nevertheless, we observed that cyclists adopted a CA higher during XCC. Probably, this preferred higher CA selected by the cyclists can be associated to specific demands of this competition. There is a trend of increases in CA as PO and speed increased[21]. As XCC was performed with higher PO and speed, can be that a higher CA was necessary to ensure that the muscle power capacity remains high[19]. Moreover, it is suggest that the CA selection coincides with the CA at which perception of effort is minimized or at which they are habituated[22]. That is, cyclists adopted specific CA in response to their perceived level of comfort. Another important finding in our study was the significant decrease in CA at the last lap of the XCO. This decrease in CA has also been observed in 2 hours cycling endurance[23]. Perhaps such decrease may be due to decrease force production and fatigue development[21].

Lastly, we would like to highlight that the study was conducted only on a single XCO and XCC course. In this way, the track settings (as difficult technical) and race dynamics of other events could influence the pacing profile. Moreover, we did not exclude the time spent not pedaling for CA, which could influence overall response for both XCC and XCO competition [3]. Therefore, we suggest that future research take this into account.

Conclusion

Elite mountain bikers adopted a different pace during XCC and XCO, mainly in the initial phase of the competition, where the athletes adopted a more conservative pace during XCC and a faster pace during XCO. Moreover, as the duration of the XCC is shorter, the athletes adopted an average speed, PO and CA higher than the XCO. In this respect, we have shown that the competitive environment influences the decision-making of the athletes during race and that the mechanical parameters required for success in XCC are different for those required in XCO. Athletes therefore must incorporate in their training routine, strategies and specifics training methods that consider the physical demands and the environment of each event to improve their performance in each competition.

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Acknowledgements: Moacir Marocolo is supported by Conselho Nacional de Desenvolvimento Científico e Tecnologico – CNPq (process no. 308138/2022-8) and Rhaí André Arriel by Fundação de Amparo à Pesquisa de Minas Gerais – FAPEMIG and Conselho Nacional de Desenvolvimento Científico e Tecnologico – CNPq (process no. BPD-00905-22).

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Editor: Ademar Avelar.
Received on Apr 19,2023.
Reviewed on May 19, 2023.
Accepted on May 25, 2023.

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