UNIVERSIDADE FEDERAL DE JUIZ DE FORA
FACULDADE DE EDUCAÇÃO FÍSICA E DESPORTOS
PROGRAMA DE PÓS-GRADUAÇÃO EM EDUCAÇÃO FÍSICA

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A general approach for analysis and enhancement performance in mountain biking modality

Juiz de Fora
2022

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Thesis presented to the Postgraduate Program of Physical Education, doctoral level, from the Federal University of Juiz de Fora as a partial requirement to obtaining the doctoral degree in Physical Education.
Area: Exercise and sport.
Research line: Studies of sport and its manifestations.

Supervisor: Moacir Marocolo Júnior

Juiz de Fora
2022

Ficha catalográfica elaborada através do programa de geração
automática da Biblioteca Universitária da UFJF,
com os dados fornecidos pelo(a) autor(a)

Oliveira, Rhaí André Arriel e.
A general approach for analysis and enhancement performance in mountain biking modality / Rhaí André Arriel e Oliveira. -- 2022.
118 p. : il.

Orientador: Moacir Marocolo Júnior
Tese (doutorado) - Universidade Federal de Juiz de Fora, Universidade Federal de Viçosa, Faculdade de Educação Física. Programa de Pós-Graduação em Educação Física, 2022.

1. Ciclismo de montanha. 2. Cross-country. 3. Ritmo. 4. Potência. 5. Composição Corporal. I. Júnior, Moacir Marocolo, orient. II. Título.

Rhaí André Arriel e Oliveira

A general approach for analysis and enhancement performance in mountain biking modality

Tese apresentada ao Programa de Pós-graduação em Educação Física da Universidade Federal de Juiz de Fora como requisito parcial à obtenção do título de Doutor em Educação Física. Área de concentração: Exercício e Esporte

Aprovada em 11 de outubro de 2022.

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I dedicate this work to my mother, Eliane, my brother, Matheus, and my wife, Jéssica, for the support, love and attention during these four years.

AGRADECIMENTOS

Ao longo destes seis anos eu tenho aprendido e vivido o mountain biking. Apesar de estar envolvido em outras atividades e esportes ao longo da minha vida e carreira, este esporte me ensinou muito, sendo crucial no mestrado e, principalmente, no processo de doutoramento. Portanto, espero que esta tese seja de grande valia para todos que admiram, gostam e vivem o mountain biking.

Primeiramente, eu gostaria de agradecer ao Criador pela oportunidade de vivenciar este momento que é tão restrito a tantas pessoas.

Agradecer os meus familiares, em especial a minha Mãe, irmão e esposa, por tanto carinho, apoio e cuidado. Nos piores momentos, são eles que nos guiam e nos amparam. Pessoas incríveis, que admiro muito e tenho um nobre respeito.

Agradeço aos meus amigos do Núcleo de Estudos em Prescrição de Exercícios Físicos (NEPEF - UFLA), ao Prof. Dr. Fernando de Oliveira (em memória), aos colegas do mestrado, doutorado, e à todos os funcionários dos programas de Pós-graduação da Universidade Federal do Triângulo Mineiro (UFTM) e da Universidade Federal de Juiz de Fora (UFJF). Em especial, gostaria de agradecer o apoio dos amigos do Grupo de Pesquisa em Fisiologia e Desempenho Humano da UFJF. O amparo dos nossos amigos e colegas é fundamental para alcançar nossos objetivos e realizar nossos sonhos.

Ao professor, orientador e amigo, Moacir Marocolo. Um grande profissional que transformou este sonho em realidade, me incentivando e orientando ao longo desses seis anos. Sou muito grato por toda sua dedicação e confiança comigo.

À Fundação de Amparo à Pesquisa de Minas Gerais – FAPEMIG pelo apoio financeiro; e à todos os voluntários, atletas profissionais e amadores do mountain biking, por acreditarem no trabalho e na evolução deste esporte.

Enfim, à todos os familiares e amigos que estiveram comigo durante este período, me dando suporte para que eu pudesse chegar até aqui. Muito obrigado!

ACKNOWLEDGEMENTS

Along these six years, I have learned and lived for mountain biking. Despite being involved in other activities and sports throughout my life and career, this sport has taught me a lot, being crucial in my master's, and especially in the PhD process. Therefore, I hope that this thesis will be of great value to everyone who admires, enjoys and lives mountain biking.

First, I would like to thank the Creator for the opportunity to experience this moment that is so restricted to so many people.

I Thank my family, especially my mother, brother and wife, for so much love, support and care. In the worst moments, they are the ones who guide and support us. They are incredible people, whom I greatly admire and for whom I have a noble respect.

I thank my friends of the Núcleo de Estudos em Prescrição de Exercícios Físicos (NEPEF - UFLA), Prof. Dr. Fernando de Oliveira (in memory), my master's and Doctoral colleagues, and all the employees of the Postgraduate programs of the Universidade Federal do Triângulo Mineiro (UFTM) and Universidade Federal de Juiz de Fora (UFJF). In particular, I would like to thank my friends from the Research Group on Physiology and Human Performance at UFJF for their support. The support of our friends and colleagues is fundamental to achieving our goals and realizing our dreams.

I thank my teacher, advisor and friend, Moacir Marocolo. A great professional who turned this dream into reality, encouraging and guiding me throughout these six years. I am very grateful for all your dedication and trust.

I thank the Fundação de Amparo à Pesquisa de Minas Gerais – FAPEMIG for the financial support; and all the volunteers, professional and amateur mountain biking athletes, for believing in the work and in the sport evolution.

Finally, I thank all the family and friends who were with me during this period, supporting me so that I could get here. Thank you very much!

RESUMO

O ciclismo de montanha (do termo em inglês *mountain biking* – MTB) é uma modalidade do ciclismo fora de estrada (do termo em inglês *off-road*) o qual é praticado sob uma variedade de terrenos não pavimentados que normalmente incluem obstáculos naturais ou artificiais, como trilhas em florestas, cascalho e lama, envolvendo várias seções de subidas e descidas. O *cross-country* (XC) é o formato de competição mais popular no MTB, envolvendo 8 eventos ao todo, sendo cross-country Olímpico (XCO) o mais conhecido entre eles. Além do XCO, outros eventos do XC têm ganhado popularidade, mas existem poucos estudos sobre o tema. O regulamento do *cross-country mountain biking* (XC-MTB) e as bicicletas sofreram várias modificações ao longo dos anos, gerando discussões e incertezas entre os praticantes. Portanto, o principal objetivo desta tese foi fornecer um panorama atualizado sobre o tópico, e contribuir com o avanço do conhecimento sobre os eventos do XC-MTB. Para isso, foram desenvolvidos quatro estudos. O estudo um é uma revisão de literatura que apresenta e discute as evidências científicas mais relevantes sobre o XC-MTB, com foco nas características dos principais eventos do XC e dos ciclistas, bem como no desenvolvimento das bicicletas, acidentes e lesões neste esporte. As evidências sugerem que as respostas fisiológicas e as demandas mecânicas mudam de acordo com o evento do XC. Além disso, nós identificamos que as características dos ciclistas diferem de acordo com o nível de desempenho, além de destacar a importância do pacing e da capacidade de desempenhar seções técnicas do circuito para ser competitivo no XC-MTB. Sobre as bicicletas, é possível sugerir que a bicicleta equipada com aro de 29” e com um sistema de amortecimento *full suspension* (quadro com suspensão frontal e traseira) tem potencial para alcançar um desempenho superior nos circuitos de XC-MTB. Por fim, parece que adotar estratégias como equipamentos de proteção, *bike fit*, treinamento resistido e medidas de prevenção de acidentes podem reduzir a gravidade e o número de lesões. A proposta do estudo dois foi investigar o perfil de *pacing* e o nível de desempenho de ciclistas do XC sob diferentes seções técnicas e não técnicas do circuito durante um evento de *cross-country short track* (XCC). Vinte ciclistas profissionais (sub-23 e elite) realizaram seis voltas no circuito de XCC durante a Copa Internacional de MTB. Em geral, os ciclistas adotaram um perfil de *pacing* positivo, o mesmo perfil adotado pela categoria elite e sub-23. Os ciclistas mais rápidos adotaram um perfil de *pacing* mais uniforme, enquanto os ciclistas mais lentos adotaram um perfil de *pacing* em "J" inverso. Inclusive, os ciclistas mais rápidos gastaram menos tempo que os ciclistas mais lentos durante a seção de subida sustentada não técnica. Portanto, nós concluímos que o melhor desempenho no XCC foi associado com um perfil de *pacing* mais uniforme e com um desempenho mais alto na seção de subida sustentada não técnica. A proposta do estudo três foi avaliar parâmetros mecânicos e o perfil de *pacing* adotado por doze ciclistas profissionais do XC da categoria elite durante o XCC e XCO da Copa do Mundo de MTB. Durante ambas as competições, o tempo total, velocidade, potência (PO) e cadência (CA) foram gravadas. Enquanto o tempo total de prova foi maior no XCO, a velocidade, PO e CA foram significativamente maiores no XCC. No XCC o perfil de *pacing* adotado pelos ciclistas foi variável e no XCO foi um perfil de *pacing* positivo. Além disso, os atletas adotaram um ritmo mais conservador no início do XCC (abaixo da velocidade média da corrida), mas um início mais agressivo durante o XCO (acima da velocidade média da corrida). Portanto, uma vez que os parâmetros avaliados são diferentes entre XCC e XCO, as estratégias e os métodos de treinamento desenvolvidos para alcançar um desempenho superior devem ser específicos para cada formato de competição. Por fim, a proposta do estudo quatro foi avaliar se a massa corporal e a composição corporal podem ter alguma relação com medidas de desempenho no XC-MTB, tal como PO e tempo até exaustão. Quarenta ciclistas amadores do XC foram submetidos a realização de medidas antropométricas e de um teste incremental em cicloergômetro. Nossos achados mostram que a massa corporal e a massa de gordura estão associadas com as medidas de desempenho do XC-MTB, mas a massa livre de gordura, não.

Palavras-chave: Bicicleta de montanha. *Cross-country*. Suspensão. Ritmo. Potência. Velocidade. Cadência. Composição corporal.

ABSTRACT

Mountain biking (MTB) is an off-road cycling modality which is performed on a variety of unpaved terrains that normally include natural and/or artificial obstacles, such as trails in forests, rock garden and mud, involving successive uphill and downhill sections. Cross-country (XC) is the most popular competition format in MTB, which is composed by eight events, being Olympic cross-country (XCO) the best known among them. In addition to XCO, other XC events have gained popularity, but there are few studies on the topic. The cross-country mountain biking (XC-MTB) regulations and bicycles have been changed along the years, generating debates and uncertainties among cyclists. In this sense, the general aim of this thesis was to provide an up-to-date overview of the topic, and to contribute to the advancement of knowledge on the XC-MTB events. For this, four studies were developed. Study one is a literature review that presents and discusses the most relevant scientific evidence on the XC-MTB, focusing on the characteristics of the main XC events and cyclists, as well as the development of bicycles, accidents and injuries in this sport. Evidence suggests that the physiological responses and mechanical demands change according to XC event. Moreover, we identified that the characteristics of cyclists differ according to the level of performance, and we highlighted the importance of pacing and the ability to perform technical sections of the circuit to be competitive in XC-MTB. Regarding bicycles, it is possibly to suggest that the bicycle equipped with 29” wheel and full suspension (frame with front and rear suspension) has the potential to achieve superior performance on XC-MTB circuits. The purpose of the study two was to investigate the pacing profile and performance level of XC cyclists on different technical and non-technical sections during a cross-country short track (XCC) event. Twenty professional cyclists (under-23 and elite) performed six laps on a XCC circuit during the International MTB Cup. In general, the cyclists adopted a positive pacing profile, the same profile adopted by the elite and under-23. Faster cyclists adopted a more even pacing profile, while slower cyclists adopted a reverse J-shaped pacing profile. In addition, faster cyclists spent less time than slower cyclists during a non-technical sustained uphill section. Therefore, we conclude that superior XCC performance was associated with a more even pacing profile and a higher performance on a non-technical sustained climb section. The purpose of the study three was to evaluate mechanical parameters and pacing profile adopted by twelve professional male elite XC cyclists during XCC and

XCO events in MTB World Cup. During both competitions, total time, speed, power output (PO) and cadence (CA) were recorded. While total race time was higher in XCO, speed, PO and CA were significantly higher in XCC. The pacing profile adopted by the cyclists in XCC was variable, while in XCO was positive. In addition, cyclists adopted a more conservative starting pace in XCC (below average race speed) but a more aggressive start in XCO (above average race speed). Therefore, since the parameters evaluated are different between XCC and XCO, the strategies and training methods developed to achieve superior performance must be specific to each competition format. Finally, the purpose of the study four was to assess whether body mass and body composition may be related to performance measures in XC-MTB, such as PO and time to exhaustion. Forty amateur XC cyclists were recruited to participate in this study. Anthropometric measurements were take and an incremental test on a cycle ergometer was performed. Our findings show that body mass and fat mass are associated with XC-MTB performance measures, but fat-free mass did not.

Keywords: Mountain bike. Cross-country. Suspension. Pace. Power output. Speed. Cadence. Body composition.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BC	Body Composition
BF	Body Fat
BM	Body Mass
BMI	Body Mass Index
CA	Cadence
CV	Coefficient of Variation
FFM	Fat-Free Mass
FS	Full Suspension
HR	Heart Rate
HT	Hardtail
MOP	Maximal Oxidative Power
MTB	Mountain Biking
PO	Power Output
PPO	Peak Power Output
PPO-BM	Peak Power Output Relative to Body Mass
RCP	Respiratory Compensation Point
TE	Time to Exhaustion
U23	Under 23
UCI	Union Cycliste Internationale
VO_{2Max}	Maximal Oxygen Uptake
XC	Cross-county
XCC	Cross-country Short Track
XCE	Cross-country Eliminator
XCM	Cross-country Marathon
XC-MTB	Cross-country Mountain Biking
XCO	Cross-Country Olympic
XCP	Cross-country point-to-point
XCS	Cross-country Stage Race
XCT	Cross-country Time Trial

CONTENTS

1 INTRODUCTION

Mountain Biking (MTB), an off-road cycling modality, emerged in the 70s in California - USA, but became more popular after its insertion in the Atlanta Olympic Games in 1996, through one of its events known as Cross-Country Olympic (XCO). Unlike road cycling, this modality is practiced on a variety of terrains, which normally include successive uphill and downhill sections, forest tracks, fields and paths made up of dirt and gravel. Paved roads, such as asphalt, are allowed but cannot exceed 15% of the total course (Union Cycliste Internationale [UCI] regulations, Part 4 mountain bike, version from 11 February 2020). Therefore, based on these differences, bikes were developed and equipped with wider tires composed of shorter knobs, front (named hardtail) or front and rear suspension (named full suspension), and more accurate gear systems aiming to improving performance in MTB competitions. Finally, in recent years, there was a transition from 26” to 29” wheel bike, which has brought benefits in general performance (STEINER et al., 2016). Although relevant, this MTB evolution has generated discussions and uncertainties among cyclists.

Cross-country (XC) is the most popular format of MTB competition, being XCO its main event. In this event, approximately 150 athletes start together and perform several laps on a closed-loop ranging from 4 to 6 km, with an average race total duration of 90 ± 10 minutes (GRANIER et al., 2018). The circuit is composed by several technical and non-technical uphill and downhill sections with natural and/or artificial obstacles, demanding physical (PRINZ et al., 2021) and technique (ABBISS et al., 2013) ability of the athletes. In addition to XCO, other events have become more popular in recent years, as cross-country stage race (XCS) (ENGELBRECHT; TERBLANCHE, 2017), cross-country marathon (XCM) (MOSS et al., 2019) and cross-country short track (XCC). XCS is performed on four to nine consecutive days, where cyclists can cycle between 24 to 134 km, spending an average of 3 to 10 hours per day of competition (ENGELBRECHT; TERBLANCHE, 2017). XCM is performed on a single or repeated lap circuit consisting of a minimum of 60 and a maximum of 160 km (UCI regulations, Part 4 mountain bike, version from 11 February 2020). On the other hand, XCC is performed on a smaller circuit (approximately 2 km) with a total race duration between 20 to 60 minutes (UCI regulations, Part 4 mountain bike, version from 11 February 2020).

The XCC course is similar to the XCO, but the technical sections have a low degree of difficulty and only 40 riders start together. Such differences could influence important factors for the overall race performance, such as mechanical responses (such as power output and cadence), pacing profile and performance in technical and non-technical track sections. However, although evaluated in XCO (ABBISS et al., 2013; GRANIER et al., 2018), no researchers analyzed these responses in XCC or compared with XCO. Knowing and understanding these responses is important for coaches and athletes to determine training and competition strategies to improve overall performance at each event.

Both XCO and XCC are competitions performed in an extremely complex environment, exposing cyclists to a large amount of information, both before and during the competition, which could influence decision-making (RENFREE et al., 2014) and, consequently, the choice of pacing. Pacing is generally defined as the regulation of speed (or intensity) throughout a physical task and is widely considered an important factor in performance (ABBISS; LAURSEN, 2008; EDWARDS; POLMAN, 2013). There are many models/theories about pacing regulation mechanisms during self-selected exercise. Among them are the teloanticipatory theory (ST CLAIR GIBSON et al., 2006a), the central governor model (NOAKES; PELTONEN; RUSKO, 2001) and the psychobiological model (PAGEAUX, 2014).

One of the first models of the control of intensity was described by Ulmer (1996), incorporating the concept of “teleanticipation”. According to the author, through knowledge of the endpoint of the exercise, the brain creates a mathematical algorithm that interprets the afferent feedback from the peripheral physiological system, and then generates an appropriate response through an efferent neural command, regulating intensity throughout the exercise. If the algorithm indicates that the current effort is inappropriate, the brain then sends an efferent response to properly adjust intensity and speed would therefore also adjust. In this way, the athlete establishes an “ideal” effort over entire race, avoiding early exhaustion before the endpoint, which could impair overall performance. Along the years this model has been improved (PAGEAUX, 2014; RENFREE et al., 2014; ST CLAIR GIBSON et al., 2006a), and several factors have been revealed to influence the regulation of intensity, such as motivation, previous experience with exercise (PAGEAUX, 2014), interaction between athlete and competition environment (KONINGS; HETTINGA, 2018a, 2018b). In fact, when a virtual opponent was included during a time trial, the distribution of speed and performance were influenced (KONINGS et al., 2016). Therefore, both internal and external information are incorporated in the regulation of intensity.

Different pacing profiles were observed across different physical tasks (ABBISS; LAURSEN, 2008; EDWARDS; POLMAN, 2013) (Table 1). Moreover, it is interesting to note that individuals who achieve different exercise time display different pacing profile (ABBISS et al., 2013). However, the optimal pacing profile that ensure the best performance for each task is still not well defined. Perhaps, because speed regulation is influenced by several external factors, such as direct confrontation with the opponent (KONINGS; HETTINGA, 2018b), total number of opponents (KONINGS; HETTINGA, 2018a), environmental conditions, race and circuit format (ABBISS; LAURSEN, 2008). Nevertheless, due to competition regulations and format of some events, many athletes adopt the similar profile in order to avoid losses in critical parts of the circuit. For example, during XCO, athletes tend to adopt a faster start, but decrease speed after the start loop followed by a more even pace, which is representative of positive pacing (GRANIER et al., 2018). As this competition is a mass-start event, riders adopt this faster start in order to place themselves in the front positions for avoid congestion and accidents on sections composed of single track (narrow paths) and curves in tight areas, which could impair their overall performance during such event. This strategy is adopt mainly by cyclists who start at the middle and end of the starting grid. Although the XCC is also a mass-start event, the race format is different and the number of participants is smaller (40 athletes) when compared with XCO, which could influence the choice of the pacing profile, including the power output (PO) and cadence (CA) responses during the competition.

Table 1 - Pacing profile characteristic

Pacing Profile	Characteristic
Positive	It is observed when the athlete gradually reduces speed over the race, without significant oscillations during the event.
Negative	It is observed when the athlete increases speed over the competition, without significant oscillations during the event.
All-out	It is observed in competitions where the athlete starts and continue the competition in a greatest possible speed.
Even	Athlete tends to maintain a more even speed, or with few oscillations, throughout the competition.

Variable	This profile is characterized by the high oscillation of speed throughout the competition.
Parabolic-Shaped	It is observed when the athlete reduces speed in the first part of the competition, but increases in the second part of the event. They can be classified as U-shaped, J-shaped or reverse J-shaped.

Source: elaborated by the author (2022).

Although pacing refers to the distribution of speed across competition, it is suggested that its regulation is dependent on the ability to resist fatigue (ABBISS; LAURSEN, 2008). That is, in order to achieve a higher and more uniform speed, cyclist must be able to increase or maintain PO during periods of high external resistance (e.g. climbs), resisting fatigue, and reduce PO during periods of low external resistance (e.g. downhill). In this sense, examining the PO produced by cyclists would be essential to better understand the physical demands of a given competition (PASSFIELD et al., 2017). Furthermore, changes in PO and speed may be accompanied by changes in CA, which can modify metabolic demand during pedaling (HANSEN; SMITH, 2009). Although an optimal CA has been shown to minimize energy cost, cyclists choose a higher CA (BRENNAN et al., 2019), likely influenced by the specific demands of each competition (LUCÍA; HOYOS; CHICHARRO, 2001). Therefore, mechanical responses can be different among MTB competitions, such as between XCC and XCO, but there is limited research.

Given the track characteristics where MTB competitions are performed, in addition to physical ability, a high degree of technical ability is required in order to obtain success in these events. Thus, in addition to evaluating the pacing profile, some studies evaluated the XC cyclists’ performance in sections composed of technical and non-technical flat, uphill and downhill (ABBISS et al., 2013; MOSS et al., 2019). This analysis is important to verify in which part of the track the cyclists who finished in the first positions had an advantage on their opponents who finished in the lower positions. For instance, during an XCO competition, cyclists who finished in the lower positions were found to spend more time on a technical climb section, compared with those who finished in the first positions, but did not happen in the flat sections (ABBISS et al., 2013). This could explain, at least in part, the differences in overall performance of the cyclists. Thus, it can be assumed that the overall performance in XCO could be improved by improving technical climbs performance. These analyzes were performed in XCO (ABBISS et al., 2013) and XCM (MOSS et al., 2019), but not in XCC event.

Another important factor that can influence cycling performance is body composition (BC) of the XC cyclists. In fact, the results of the relationship between race time and indicators of physical ability in MTB, such as maximum and peak PO and maximal oxygen uptake (VO_{2max}), have a higher correlation coefficient value when normalized for body mass (BM) (PRINS; TERBLANCHE; MYBURGH, 2007). Therefore, the BC, which includes fat mass and fat-free mass, of the cyclists may have a direct relationship with measures related to cross-country mountain biking (XC-MTB) performance, such as maximal aerobic power and time to exhaustion. Although BC has been related to measures of cycling performance in elite MTB athletes (BEJDER et al., 2019), there is limited research about the BC and performance of amateur athletes (SIEGEL-TIKE et al., 2015).

1.1 AIMS

The aims of this thesis were: to provide a current perspective of XC-MTB, involving physiological and mechanical aspects, evolution of bikes, accidents and injuries in this modality; to assess pacing profile, PO, CA and performance of off-road athletes on different XC events; and to evaluate the relationship between BC and performance measures in XC-MTB amateur athletes. For this, four studies were developed:

- *Study 1:* The purpose of this study was to provide an up-to-date overview of scientific investigations on the XC-MTB, focusing on characteristics of the main events and athletes, the development of bicycles as well as the accidents and injuries, highlighting gaps and providing directions for future research.
- *Study 2:* The aim of this study was to investigate the pacing profile adopted by professional cyclists and evaluate their performance in different technical and non-technical sections during an XCC event.
- *Study 3:* The purpose of this study was to evaluate the PO, CA responses and the pacing profile adopted by elite cyclists during an XCC and XCO MTB World Cup competition.
- *Study 4:* The aim of this study was to assess whether there are correlations between BC and performance measures in amateur MTB athletes.

2 STUDY 1 - CURRENT PERSPECTIVES OF CROSS-COUNTRY MOUNTAIN BIKING: PHYSIOLOGICAL AND MECHANICAL ASPECTS, EVOLUTION OF BIKES, ACCIDENTS AND INJURIES

This study was published following peer-review.

ARRIEL, R. A. et al. Current Perspectives of Cross-Country Mountain Biking: Physiological and Mechanical Aspects, Evolution of Bikes, Accidents and Injuries. **International Journal of Environmental Research and Public Health**, v. 19, n. 19, p. 12552, jan. 2022.

2.1 ABSTRACT

Mountain biking (MTB) is a cycling modality performed on a variety of unpaved terrain. Although the cross-country Olympic race is the most popular cross-country (XC) format, other XC events have gained increased attention. XC-MTB has repeatedly modified its rules and race format. Moreover, bikes have been modified throughout the years in order to improve riding performance. Therefore, the aim of this review was to present the most relevant studies and discuss the main results on the XC-MTB. Limited evidence on the topic suggests that the XC-MTB events present a variation in exercise intensity, demanding cardiovascular fitness and high power output. Nonetheless, these responses and demands seem to change according to each event. The characteristics of the cyclists differ according to the performance level, suggesting that these parameters may be important to achieve superior performance in XC-MTB. Moreover, factors such as pacing and ability to perform technical sections of the circuit might influence general performance. Bicycles equipped with front and rear suspension (i.e., full suspension) and 29” wheels have been shown to be effective on the XC circuit. Lastly, strategies such as protective equipment, bike fit, resistance training and accident prevention measures can reduce the severity and the number of injuries.

Keywords: power output; intensity; anthropometry; pacing; suspension, off-road cycling.

2.2 INTRODUCTION

The bicycle was invented in the 19th century, with the purpose of improving movement and being more efficient than walk (BOPP; SIMS; PIATKOWSKI, 2018). Many types of mechanical system were tested until a chain and ratchet system was implemented and optimized to current standards. There are several social and cultural aspects related to the creation, development and use of the bicycle, such as the fact that it was a means of transport that preceded the automobile, generated an impact on public transport and made access to low-cost mobility possible for all and contributed for women freedom in dress, mobility and engagement on public sphere (BOPP; SIMS; PIATKOWSKI, 2018). However, the use of bicycle as a sport modality was literally a game changer in the bike and cycling world.

Although the first cycling competitions were already carried out in the 19th century, the popularization of this modality was consolidated with the Tour de France in 1903, becoming the most popular event in road cycling (MIGNOT, 2016). In this context, almost 70 years later and thousands of competitions using the bicycle on the road, there was another turning point event with the first competition on hostile terrain.

Mountain biking (MTB) emerged in the 1970s in California – USA and had the first official competition in the 1980s and the first world championship in the 1990s, organized by Union Cycliste Internationale (UCI), the main association that promotes and develops cycling in the world. Although there are a variety of MTB sub modalities (e.g., Downhill, Dual slalom, Trials, Enduro, Trip trail), the cross-country (XC) MTB (XC-MTB) modality became more popular after its inclusion in the 1996 Olympic Games, named in this first appearance as Olympic cross-country (XCO). This fact created greater visibility for the modality and attracted new fans all over the world. Despite XCO being the premier XC-MTB event, other XC competitions have been added to the racing calendar along the years (UCI regulations, Part 4 mountain bike, version on 11.02.2020).

In more than 50 years, MTB has undergone numerous changes to adjust to both sporting and technological evolution. In this context, new races and events were created, the technical and physical level required by the races increased substantially, with increments of sections with steep slopes, jumps, inclusion of obstacles and more judicious rules. To keep up with these developments, both athletes have improved their physical and technical level, as well as equipment (helmets, clothes, shoes, among others) and bicycles incorporate the highest technological level in their construction.

Nowadays, athletes and their technical team can define training and competition strategies as well as choice of the best suitable bike (and setup) to achieve a higher performance in each MTB event, carefully analyzing each detail regarding performance enhancement.

Considering that XC-MTB has constantly modified its rules, race format and created new types of events, this study aiming at providing an up-to-date overview of scientific investigations on the topic, focusing on characteristics of the main events and of the athletes, the development of bicycles as well as the accidents and injuries in MTB. Moreover, we highlight gaps and provide directions for future research.

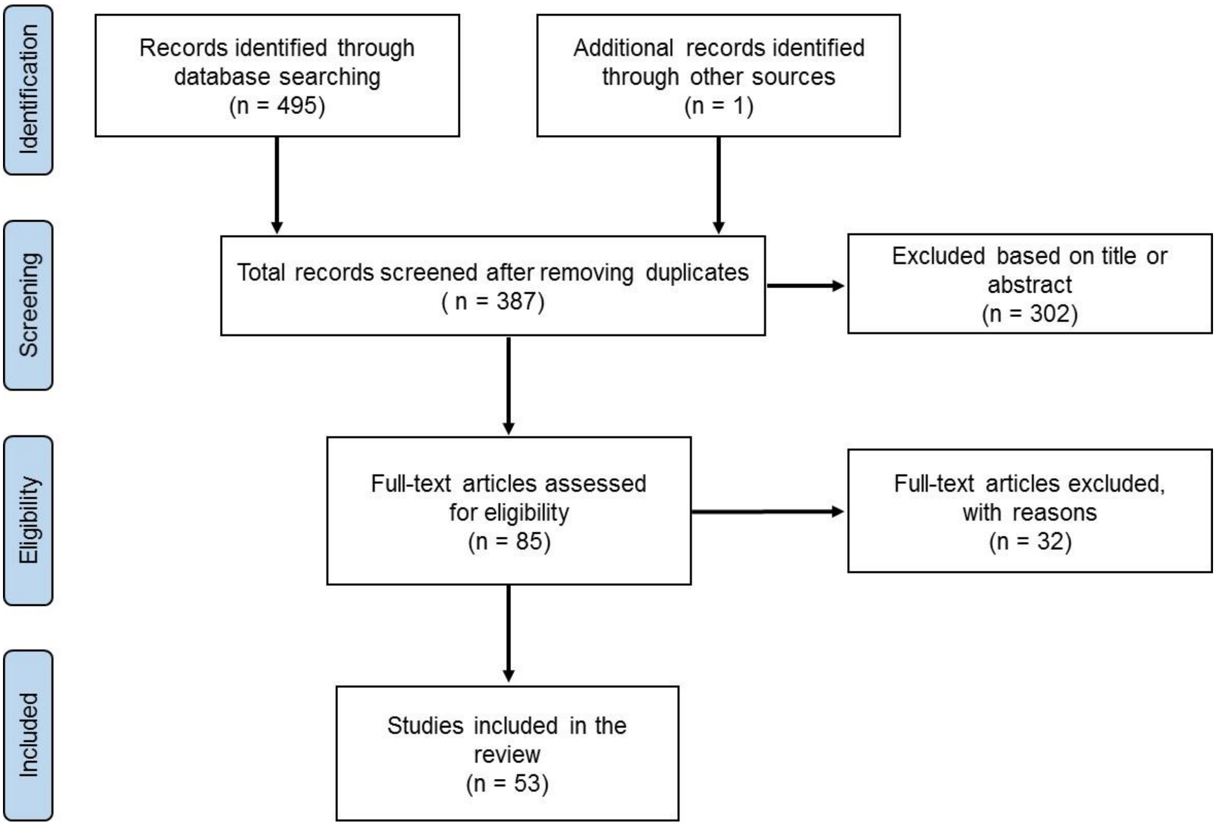
2.3 MATERIALS AND METHODS

The systematic search process was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline to find the maximal number of studies on the XC-MTB. By searching in PubMed and SPORTDiscus databases, two independent reviewers identified potential studies that combined the following specific keywords: “off-road cycling OR mountain bike OR mountain biking” AND “cross-country OR physiological OR mechanical OR performance”. When a disagreement occurred, a third reviewer was consulted.

The literature search was completed on 15 September 2022, selecting only original studies written in English, based on the following strict criteria: (a) studies involved XC-MTB cyclists aged 17 or over, and (b) XC races or exercise models correlated to performance in the XC format; (c) directly evaluated aspects related on the topics of the current study; and (d) studies published in peer-review journals. Studies with animal models, case reports, systematic reviews and meta-analysis were not included. Restrictions such as year of publication and fitness level were not applied.

The Figure 1 shows the study selection process. The search revealed a total of 495 studies. Primarily, the duplicates were removed and the title or abstracts were checked. If the study appeared to respect the criteria of eligibility, the full text was read and assessed. Finally, 53 studies were used in this study.

Figure 1 - Flow diagram of search process



Source: elaborated by the author (2022).

2.4 DEFINITION OF 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 in technique circuits usually composed of obstacles. For this, unlike road cycling, the bike was 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 disputed in pairs).

2.5 FORMAT OF COMPETITION IN THE MOUNTAIN BIKING

Currently, the UCI considers 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 2), 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 2 - 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	-	-
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.
Source: elaborated by the author (2022).

2.6 GENERAL AND MECHANIC-PHYSIOLOGICAL CHARACTERISTICS OF THE MAIN XC-MTB COMPETITIONS

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.

2.6.1 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 3). Total race distance and the total elevation gain were also reduced from 34 ± 3 km and 1430 ± 378 m (IMPELLIZZERI et al., 2002) to 28 ± 5 km and 1248 ± 197 m (GRANIER et al., 2018), respectively. 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 (PRINZ et al., 2021).

Since XCO is a mass start competition, the position of the athlete on the starting grid is an important factor to general performance (MACDERMID; MORTON, 2012; VIANA; INOUE; SANTOS, 2013). Previously, the definition of the starting grid in XCO for international events was decided according to the UCI points system and for national events, it was decided according to the national point system (IMPELLIZZERI; MARCORA, 2007a). However, in 2018, some competitions, such as the XC-MTB World Cup and the XC-MTB International Cup, 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.

Table 3 - 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)	147 ± 15	90	-	-	-	-	-	-
(STAPELFELDT et al., 2004)	128 ± 17	91	246 ± 12	3.6 ± 0.2	66.9	-	-	-
(GRANIER et al., 2018)	90 ± 9	91	283 ± 22	4.3 ± 0.3	68.0	68 ± 8	83 ± 7	19.7 ± 2.1
(PRINZ et al., 2021)	82 ± 13	91	255 ± 37	3.9 ± 0.4	68.9	64 ± 6	-	-
Study (Female)								
(STAPELFELDT et al., 2004)	108 ± 4	92	193 ± 1	3.1 ± 0.2	64.3	-	-	-
(PRINZ et al., 2021)	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 spent not pedaling; -: not evaluated.
Source: elaborated by the author (2022).

2.6.1.1 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 (GRANIER et al., 2018; IMPELLIZZERI et al., 2002; PRINZ et al., 2021; STAPELFELDT et al., 2004). Although few studies have described these responses and demands in the XCO, it is possible to summarize its requirements (table 3). For men, a slight increase in mean heart rate (HR) (expressed as %HR maximal), mean absolute power output (PO) (W), relative PO ($W{\cdot}kg^{-1}$) and expressed as %PO maximal were identified along the years. For women, a slight increase in mean HR (expressed as %HR maximal), relative PO ($W{\cdot}kg^{-1}$) 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 (GRANIER et al., 2018; PRINZ et al., 2021) (Table 3). The results showed that the CA selected by the riders was higher than these reported in the laboratory tests considered most effective (BRENNAN et al., 2019; D JACOBS et al., 2013), 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 (ANSLEY; CANGLEY, 2009). 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 (ANSLEY; CANGLEY, 2009). In fact, during a cycling Gran Tour, professional riders selected different CA at different stages of the competition (LUCÍA; HOYOS; CHICHARRO, 2001). Therefore, it is probable that this higher CA selected by the riders during XCO resulted from a specific competition demand. Lastly, there seems to be no effect of sex on CA selection (PRINZ et al., 2021).

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 (IMPELLIZZERI et al., 2002). Another study used the PO that corresponded to maximal oxidative power (MOP) for the first and second threshold, separating these into four zones (STAPELFELDT et al., 2004), 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 (GRANIER et al., 2018; PRINZ et al., 2021). The percentage of time spent in the intensity zones during XCO is summarized in table 4. It was observed that the time spent in different intensity zones during XCO was modified throughout the years. Considering more recent studies (GRANIER et al., 2018; PRINZ et al., 2021), ~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 4 - 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) (HR)		18 ± 10	51 ± 9	31 ± 16	
(STAPELFELDT et al., 2004) (PO)		39 ± 6	19 ± 6	20 ± 3	22 ± 6
(GRANIER et al., 2018) (PO)	25 ± 5	21 ± 4	13 ± 3	16 ± 3	26 ± 5
(PRINZ et al., 2021) (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.
Source: elaborated by the author (2022).

XCO is performed with a coefficient of variation of PO of 75.8 ± 5.2% (GRANIER et al., 2018), 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 (PRINZ et al., 2021).

Recently, the number of efforts put in above the MOP was also measured (PRINZ et al., 2021). Cyclists performed an average of 334 ± 84 efforts, with an average duration of 4.3 ± 1.1 seconds, and an average interval between efforts of 10.9

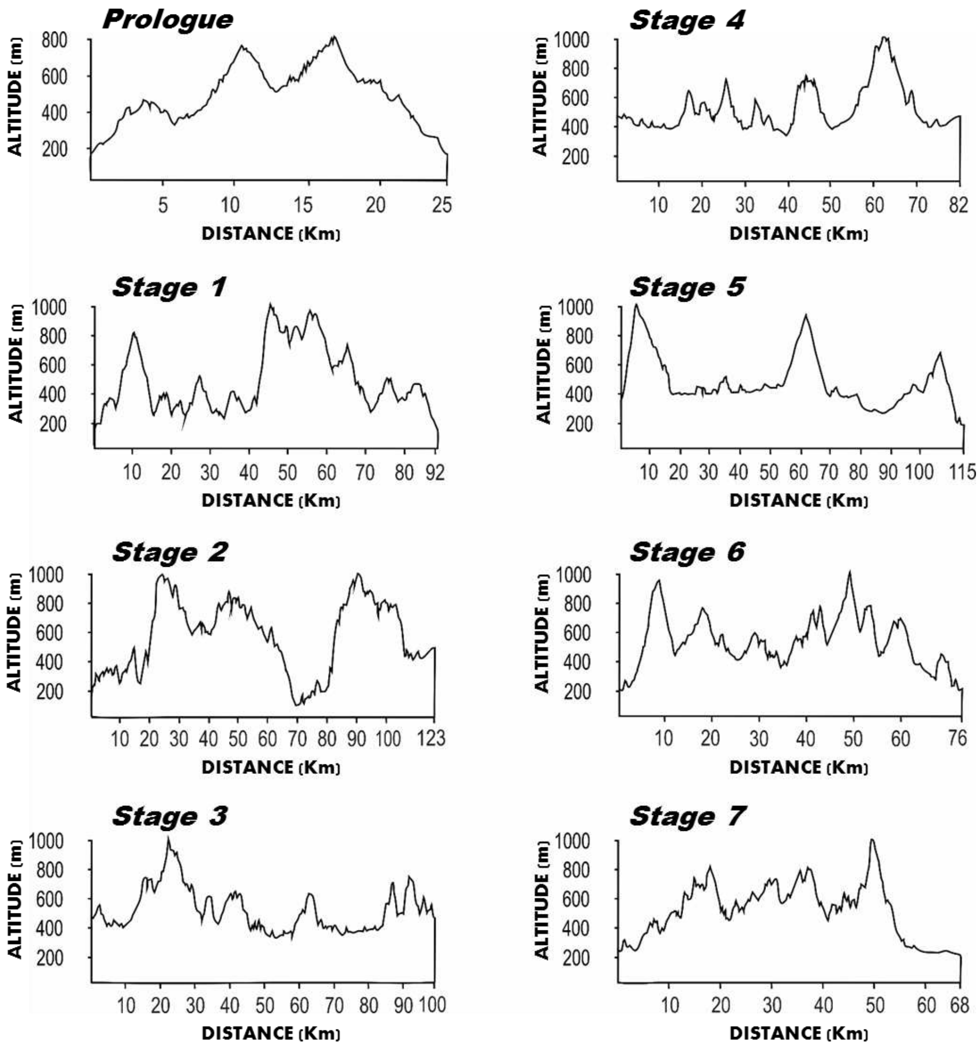
± 3.0 seconds. The average PO of the efforts was of 7.3 ± 0.6 $W \cdot kg^{-1}$, which corresponds to 135 ± 9% of MOP. When the efforts were separated into five duration-based categories [(1 to 5 s); (6 to 10 s); (11 to 15 s); (16 to 20 s); and (> 20 s)], the higher number of efforts was performed between 1 to 5 s (261 ± 73 efforts), while the lower number of efforts was performed between 16 to 20 s (6 ± 3 efforts). Therefore, the ability to perform multiple efforts of high-intensity, short-duration and with low recovery intervals could be a decisive parameter for achieving success in the XCO competition.

2.6.2 XCS

XCS is a stage race competition that includes several XC-MTB events modalities along 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 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 to 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 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 in individual dispute or teams of up six riders can be carried out. The XCS winner will be the rider or team that completes all stages in the lower accumulated time.

South Africa Cape Epic is considered one of the main XCS event. Consists of eight stages carried out in eight consecutive days. In 2022, athletes covered a total distance of 681 kilometers with 16,900 meters of elevation gain. The characteristics of the event are presented in figure 2. It is interesting to note that there is a high variation in total distance, altitude and elevation gain among stages, which could influence the physiological responses and mechanical demands among them. The winning race time was 27:44h.

Figure 2 - Characteristics of the Cape Epic event



Source: epic-series.com/capeepic (2022).

2.6.2.1 Physiological responses and mechanical demands of the XCS

Interestingly, there are few studies examining the exercise intensity during XCS competition (REINPÕLD; BOSSI; HOPKER, 2021; WIRNITZER; KORNEXL, 2008). In 2008, Wirnitzer and Kornexl (2008) examined exercise intensity during the Transalp Challenge, a competition comprised of eight day stage race, total distance covered of 662 kilometers (average of 83 ± 25 km/stage) and total elevation gain of 22,500 meters (average of 2,810 meters/stage.), respectively. The authors used the HR corresponding to the lactate thresholds 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 the LT6. In general, the average HR (expressed as %HR maximal), considering all stages was of 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 (2021) examined the mechanical demands of the Cape Epic event. The authors defined the intensity zones using PO and HR corresponding to the percentage of 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 only, but stage 6 was 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 $W{\cdot}kg^{-1}$). Coefficient of variation of the PO in prologue, stage 1, 2 and 6 was of 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 the Reinpõld; Bossi and Hopker (2021) study should be interpreted with caution, because the analyses were performed with only 6 cyclists of different performance levels, which could reveal a low statistical power (statistical power < 0.8), increasing the probability of a type II error (FAUL et al., 2007). 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 oxidative and non-oxidative energy system. Furthermore, cyclists tend to spend more time at high intensity (above second threshold) in the first stage, reducing throughout the competition.

2.6.3 XCM

XCM is a mass start event, composed by a course of 60 to 160 km of distance, without 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 3 laps. For single lap, the start and finish lines of the circuit may be located at the same place. Paved or unpaved sections, and technical section, such as 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 who 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) measured PO and oxygen uptake during a 4-hour MTB competition. However, the aim of the study 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.

2.6.4 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 to 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, 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 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, 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).

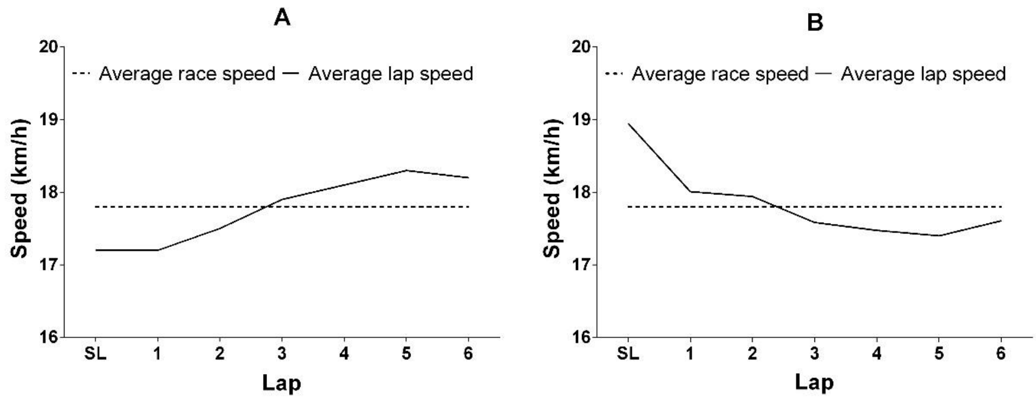
Despite the XCO being the premier XC-MTB event, the XCC has become popular in recent years. Indeed, in addition to the prizes, the results of this event add points to the UCI individual ranking and define the top 24 position of the XCO start grid (read item 2.6.1). Moreover, in the year 2021, a world championship was developed for this event. However, important factors to overall performance, such as mechanical and physiological aspects of this competition are currently lacking.

2.7 PACING PROFILE IN XC-MTB

The XC-MTB competitions are performed in complex environments, where athletes are confronted with a vast amount of information, requiring successive decisions about how to distribute speed or energy expenditure throughout the exercise (RENFREE et al., 2014). This process is known as pacing, and is widely considered a determining factor in overall competition performance (ABBISS; LAURSEN, 2008). Although several theoretical models have been proposed to explain the regulation of speed during exercise (ABBISS et al., 2015; NOAKES; PELTONEN; RUSKO, 2001; PAGEAUX, 2014; ST CLAIR GIBSON et al., 2006a; ULMER, 1996), most of them indicate the existence of a complex relationship between the brain and physiological systems, taking into account both internal (such as physiological responses) and external (such as opponent and environment) factors. That is, the brain must continuously process this vast amount of information to establish the more appropriate speed in order to reach the end of the exercise in the shorter time possible, without inducing premature fatigue.

Although complex and less understood, the pacing profile adopted by cyclists during some XC-MTB competitions has been examined (GRANIER et al., 2018; MOSS et al., 2019). In the XCO competition, it was observed that cyclists adopted a higher speed at the beginning of the competition (start loop), followed by a reduction of the speed after the start loop (GRANIER et al., 2018), which is representative of a positive pacing (See figure 3B). This result has been confirmed by Viana et al. (2018) during a laboratory-simulated XCO performance test. In mass start competitions, such as XCO, the cyclists tend to adopt an aggressive start in order to place themselves in better positions to ride, avoiding accident and congestion in sections composed of a single track or very tight curve, which may influence the overall performance. This confirms the impact of the competition environment on the decision-making regarding pacing profile (KONINGS; HETTINGA, 2018a). On the other hand, during an XCM competition, cyclists increased speed at the final of the competition, which is representative of negative pacing (MOSS et al., 2019). However, it is important to note that the final section of the XCM circuit consisted of a sustained descent, which may have influenced the distribution of speed. Therefore, this result should be interpreted with caution. Despite these pacing profile studies in XC-MTB, evidence in other events, such as XCC and XCS, remains scarce.

Figure 3 - Example of a negative (A) and of a positive (B) pacing profile adopted by cyclists during an XCO competition



SL: Start Loop
Source: elaborated by the author (2022).

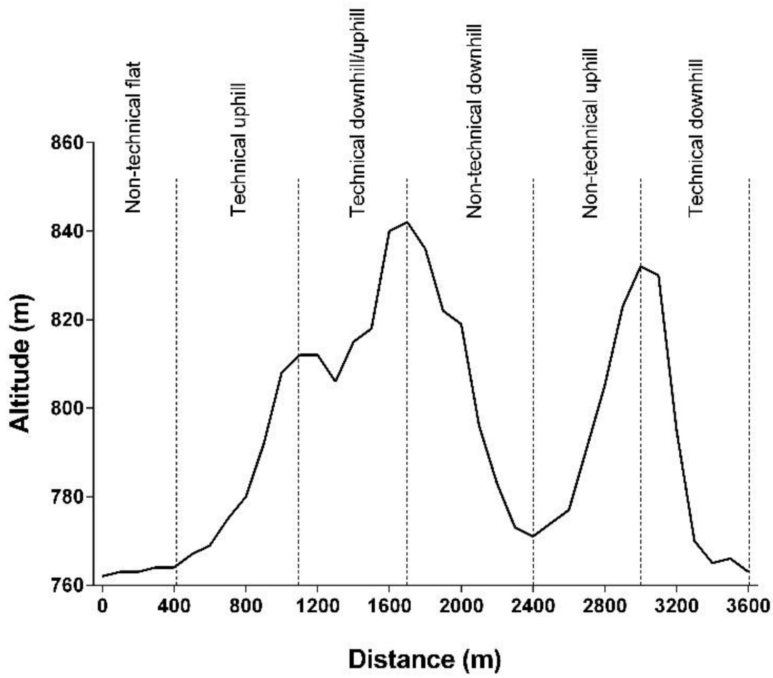
Previous study has showed that, during a XC-MTB competition, faster cyclists display a pacing profile different of slower cyclists (ABBISS et al., 2013). For instance, while faster cycling adopt a negative pacing, slower cyclists adopt a positive pacing (See figure 3). Moreover, compared with bottom placed cyclists, top cyclists maintain a more even distribution of speed over the entire competition, which is indicated by a lower standard deviation in speed (ABBISS et al., 2013; MOSS et al., 2019). Considering the models proposed to explain the pacing regulation (RENFREE et al., 2014; ST CLAIR GIBSON et al., 2006a), we can suggest that faster cyclists are likely to be more efficient at processing information and making decisions, resulting in less variation in cycling speed and superior performance. Therefore, in addition to other factors, it is likely that the performance of slower cyclists may be improved by enhancing information processing and decision making.

2.8 TECHNICAL AND NON-TECHNICAL ABILITY

The circuits of XC-MTB events are composed of successive uphill, downhill and flat sections that, when considered technical, may require a high technical ability of the cyclists. In this context, in addition to a high physical and cognitive ability, a high degree of technical ability to perform technical sections is required in order to improve performance on XC-MTB circuits and gain advantage over the opponent throughout the competition. To confirm this, previous research was developed to evaluate the performance of cyclists with different race times in different technical and non-technical sections of the XC-MTB circuit (ABBISS et al., 2013; MOSS et al., 2019).

Abbiss et al. (2013) evaluated the performance of elite cyclists on different sections of an XCO circuit. The figure 4 shows an example of an XCO circuit divided into six sections according to the characteristics of each one. In addition to topography (uphill, downhill and flat), the sections were classified in technical and non-technical. To be considered technical, the section should be composed of natural or artificial obstacles, narrow curves and/or a single track. Otherwise, the section was classified as non-technical. The authors observed that the top placed finishers spent less time than bottom placed finishers on the technical uphill section of the circuit, but not on the technical downhill and flat sections. Moss et al. (2019) also found similar results during XCM, but on a non-technical uphill section. That is, top placed finishers were faster (i.e., spent less time) than their bottom opponents on a non-technical uphill section. Moreover, the authors reported that the top cyclists were faster than their bottom opponents during a section composed of a series of short climbs and descents, with a gain of 246 m.

Figure 4 - Example of an XCO circuit profile with the location of each track section for an individual lap



Source: elaborated by the author (2022).

Considering the results of the studies cited earlier, it appears that improving the ability on both technical and non-technical climbs could improve XC-MTB performance. However, the XC-MTB circuits differ in terms of distance, topography and degree of difficulty of the technical sections, which could influence the performance responses in each section of the circuit and, consequently, in overall performance. Therefore, future studies that evaluate the performance on the sections of other XC-MTB circuits, such as XCC and XCS, are warranted.

2.9 CHARACTERISTICS OF CROSS-COUNTRY CYCLISTS

Anthropometric and physiological data from different groups of individuals are widely used as a parameter to assist coaches and athletes in the selection and sports development of amateur and professional athletes. In this sense, we analyze, in this section, the height, body mass (BM), body composition (BC), maximal oxygen uptake (VO_{2Max}) and MOP data of the cyclists according to sex and performance level (Table 5).

Table 5 - Anthropometric and physiological profile of the cyclists according to performance level and sex

Study	Performance level	Sample (n)	Height (cm)	BM (kg)	VO_{2Max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	MOP ($W \cdot kg^{-1}$)
MALE						
(MACRAE HS-H; HISE; ALLEN, 2000)	Trained	6	179.5 ± 6.7	76.9 ± 3.6	58.4 ± 2.3	5.1 ± 0.3
(CRAMP et al., 2004)	Trained	8	179.0 ± 6.4	69.0 ± 7.6	60.0 ± 3.7	-
(PRINS; TERBLANCHE; MYBURGH, 2007)	Trained	8	-	72.9 ± 5.6	63.6 ± 5.7	5.1 ± 0.4
(GREGORY; JOHNS; WALLS, 2007)	Trained	11	180.2 ± 3.5	71.6 ± 6.3	64.8 ± 8.2	5.1 ± 0.4
(WIRNITZER; KORNEXL, 2008)	Trained	5	171 ± 4.0	63.3 ± 10.0	-	4.8 ± 0.3
(ZARZECZNY; PODLEŚNY; POLAK, 2013)	Trained	8	174.6 ± 1.1	70.3 ± 2.9	60.0 ± 1.7	-
(INOUE et al., 2016)	Trained	9	176.8 ± 6.7	69.6 ± 6.9	60.6 ± 4.3	4.2 ± 0.4
(HEBISZ et al., 2017)	Trained	19	181.1 ± 9.5	73.2 ± 7.6	58.1 ± 5.8	-
(ENGELBRECHT; TERBLANCHE, 2017)	Trained	22	180.1 ± 7.9	76.4 ± 7.8	54.3 ± 7.4	4.7 ± 0.4
(COSTA et al., 2019)	Trained	26	177.0 ± 5.0	76.0 ± 9.0	58.0 ± 7.0	-
(ARRIEL et al., 2020)	Trained	40	175 ± 4.0	77.8 ± 9.7	-	4.2 ± 0.7
(BAZAŃSKA-JANAS; JANAS, 2020)	Trained	36	176.0 ± 17	75.8 ± 10.0	60.0 ± 6.0	5.3 ± 0.7
(INOUE et al., 2021)	Trained	16	175.0 ± 5.7	68.7 ± 5.6	65.4 ± 4.9	4.3 ± 0.4
(SEWALL; FERNHALL, 1995)	Well-trained	10	176.7 ± 4.9	70.5 ± 8.0	68.9 ± 2.6	-
(BARON, 2001)	Well-trained	25	179.0 ± 5.1	69.4 ± 6.5	68.4 ± 3.8	5.5 ± 0.4
(STAPELFELDT et al., 2004)	Well-trained	9	179.9 ± 5.9	69.4 ± 4.7	66.5 ± 2.6	5.3 ± 0.3

(INOUE et al., 2012)	Well-trained	10	177.9 ± 7.4	68.7 ± 7.6	68.4 ± 5.7	5.4 ± 0.5
(MACDERMID; STANNARD, 2012)	Well-trained	7	176.0 ± 4.0	66.9 ± 7.7	67.6 ± 5.3	-
(SMEKAL et al., 2015)	Well-trained	24	179.0 ± 5.0	70.0 ± 4.9	64.9 ± 7.5	5.6 ± 0.6
(HEBISZ et al., 2020)	Well-trained	20	178.4 ± 5.6	69.9 ± 9.0	67.9 ± 6.3	-
(WILBER et al., 1997)	Professional	10	176.0 ± 7.0	71.5 ± 7.8	70.0 ± 3.7	5.9 ± 0.3
(LEE et al., 2002)	Professional	7	178 ± 7.0	65.3 ± 6.5	78.3 ± 4.4	6.3 ± 0.5
(IMPELLIZZERI et al., 2002)	Professional	5	174.6 ± 3.4	64.9 ± 4.6	75.2 ± 7.4	5.7 ±0.6
(IMPELLIZZERI et al., 2005a)	Professional	13	177 ± 8	65 ± 6	72.1 ± 7.4	-
(IMPELLIZZERI et al., 2005b)	Professional	12	176.0 ± 7.0	66.4 ± 5.7	76.9 ± 5.3	6.4 ± 0.6
(GRANIER et al., 2018)	Professional	8	179.0 ± 3.0	65.4 ± 3.5	79.9 ± 5.2	6.3 ± 0.4
(BEJDER et al., 2019)	Professional	11	182.0 ± 6.0	70.2 ± 7.2	71.1 ± 7.4	-
(PRINZ et al., 2021)	Professional	7	179.6 ± 6.7	65.3 ± 8.0	73.8 ± 2.6	5.7 ± 0.4
FEMALE						
Study	**Performance level**	**Sample (n)**	**Height (cm)**	**BM (kg)**	**VO_{2Max} ($ml.kg^{-1}.min^{-1}$)**	**MOP ($W.kg^{-1}$)**
(WIRNITZER; KORNEXL, 2008)	Trained	2	163.0 ± 2.1	51.0 ± 1.4	-	4.1 ± 0.6
(ENGELBRECHT; TERBLANCHE, 2017)	Trained	2	168.5 ± 4.9	59.1 ± 0.9	53.0 ± 2.8	4.4 ± 0.3
(WILBER et al., 1997)	Professional	10	162.0 ± 5.0	57.5 ± 4.7	57.9 ± 2.8	5.4 ± 0.4
(STAPELFELDT et al., 2004)	Professional	2	170.5 ± 2.1	63.0 ± 1.4	59.4 ± 1.7	4.8 ± 0.4
(PRINZ et al., 2021)	Professional	5	164.6 ± 3.9	52.1 ± 3.1	67.3 ± 2.9	5.0 ± 0.1

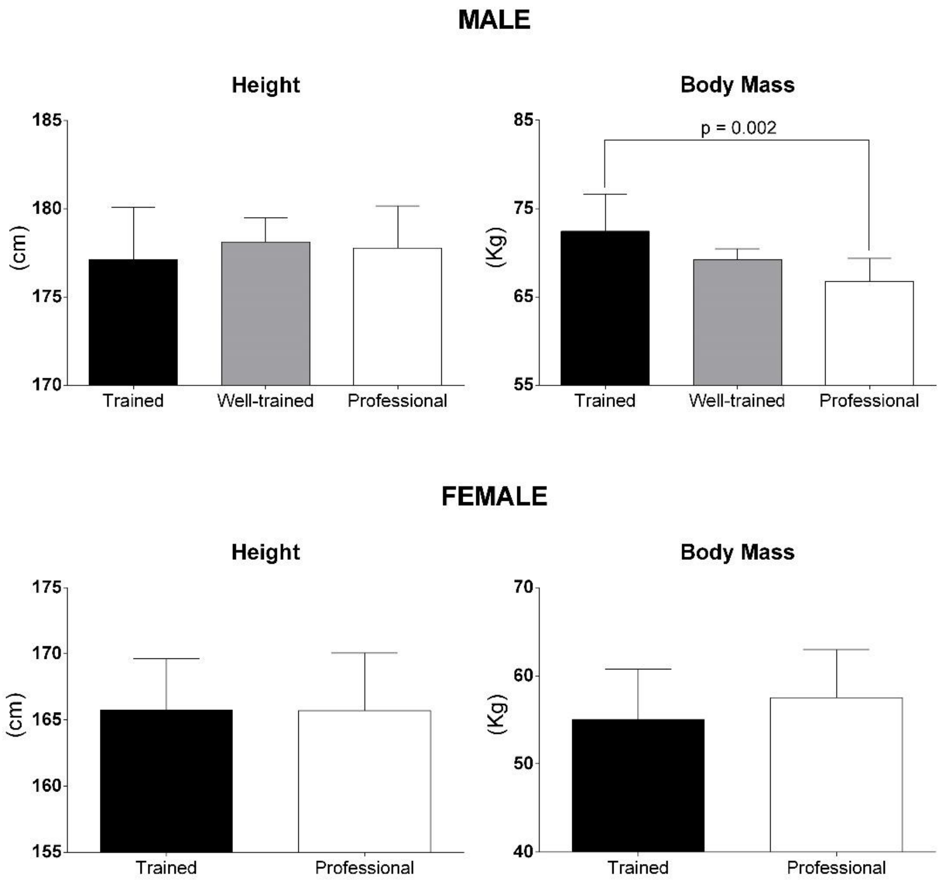
Data are mean ± SD. VO_{2Max}: maximal oxygen uptake; MOP: maximal oxidative power; BM: body mass; -: not evaluated.
Source: elaborated by the author (2022).

2.9.1 Anthropometric profile

Both MOP and VO_{2Max} have a strong correlation with total race time in XC-MTB competitions (ENGELBRECHT; TERBLANCHE, 2017; PRINS; TERBLANCHE; MYBURGH, 2007). However, when these performance measures are normalized to BM, the correlation coefficient is higher, suggesting that BM is an important factor for XC-MTB performance. In addition, there is a relationship between MOP normalized to BM and body fat (BF), but not with fat-free mass (FFM) and body mass index (BMI) (ARRIEL et al., 2020). Therefore, the anthropometric profile of the cyclists seems to be a relevant factor for achieving success in competitions.

The average height and BM of the cyclists according to sex and performance level are presented figure 5. Regardless of performance level, male and female cyclists have, respectively, an average height of 177.6 ± 2.4 cm (range: 171.0 to 182.0 cm) and 165.7 ± 3.6 cm (range: 162.0 to 170.5 cm), and a BM of 70.0 ± 4.0 kg (range: 63.3 to 77.8 kg) and 56.5 ± 5.0 kg (range: 51 to 63 kg). Considering performance level, no significant difference in height was found for male cyclists (One-way ANOVA; $p = 0.668$), but the BM was significantly lower in professional cyclists when compared with trained cyclists (One-way ANOVA: $p = 0.002$; Bonferroni: $p = 0.002$), suggesting a relationship between performance level and BM. For female cyclist, there seems to be no difference in height, but the BM of the professionals is higher when compared to the trained ones. However, there are few XC-MTB studies involving female cyclists. Therefore, the results are unclear. Interestingly, in 1997 (WILBER et al., 1997), male and female professional cyclists had a BM with 6.2 and 5.4 kg more than in 2021 (PRINZ et al., 2021), respectively.

Figure 5 - Anthropometric profile of the XC-MTB cyclists according to performance level and sex



Data are mean ± SD
Source: elaborated by the author (2022).

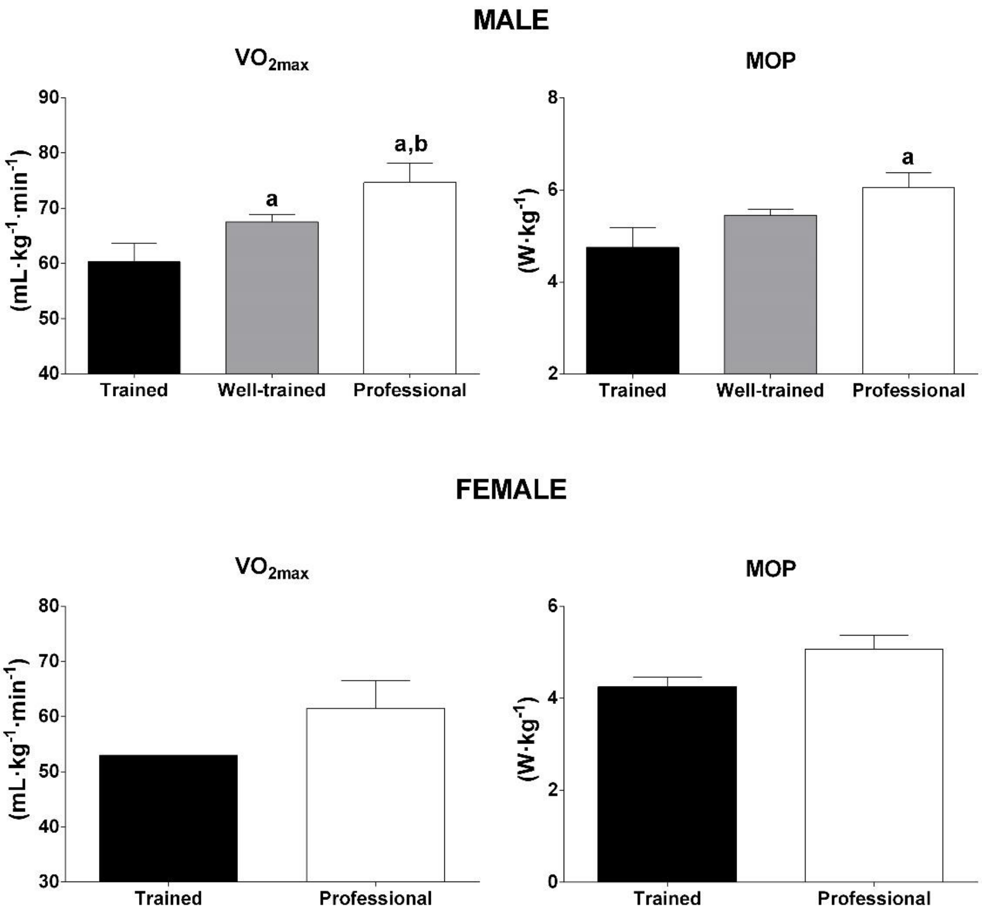
In general, studies have reported that male cyclists have an average BF of 8.1 ± 3.5% (range: 5.1 to 15.6%) (ARRIEL et al., 2020; BEJDER et al., 2019; IMPELLIZZERI et al., 2002, 2005a; INOUE et al., 2012, 2021; LEE et al., 2002; MACRAE HS-H; HISE; ALLEN, 2000; SEWALL; FERNHALL, 1995; WILBER et al., 1997), while female cyclists have an average BF of 13.2 ± 2.0% (WILBER et al., 1997). When verified according to performance level, the average BF reported in male cyclists was of 10.5 ± 4.5% in trained cyclists (ARRIEL et al., 2020; INOUE et al., 2021; MACRAE HS-H; HISE; ALLEN, 2000), 7.3 ± 2.3% in well-trained (INOUE et al., 2012; SEWALL; FERNHALL, 1995) and 7.0 ± 3.2% in professionals (BEJDER et al., 2019; IMPELLIZZERI et al., 2002, 2005a; LEE et al., 2002; WILBER et al., 1997). These observations are in line with those reported by Sánchez-Muñoz; Muros and Zabala (2018), who found that the cyclists with higher performance level had a lower BF. For male cyclists, we can therefore suggest that having a low BF can be an advantage for riding high-level XC-MTB circuits.

2.9.2 Physiological profile

2.9.2.1 Maximal oxidative capacity and power

Since the VO_{2Max} and MOP related to BM are considered important predictors of performance in cycling as well as in MTB, these variables have been used to classify the performance level of a group of cyclists (DE PAUW et al., 2013). Therefore, it is not surprising that, in our analysis, we found significant differences (One-way ANOVA or Kruskal-wallis, $p < 0.01$) among performance level groups for both VO_{2Max} and MOP related to BM in male cyclists (Figure 6). Unfortunately, a limited number of studies with female cyclists has been conducted. Therefore, data on that subject were not included in the statistical analysis. For male cyclists, the studies reported average values of VO_{2Max} between 54.3 to 65.4 $ml \cdot kg^{-1} \cdot min^{-1}$ for trained cyclists, 64.9 to 68.4 $ml \cdot kg^{-1} \cdot min^{-1}$ for well-trained cyclists and above 70 $ml \cdot kg^{-1} \cdot min^{-1}$ for professionals. The average values of MOP reported were between 4.2 to 5.3 $W \cdot kg^{-1}$ for trained cyclists, 5.3 to 5.6 $W \cdot kg^{-1}$ for well-trained cyclists and above 5.7 $W \cdot kg^{-1}$ for professionals. For female cyclists, the studies reported average values of VO_{2Max} between 53.0 a 67.3 $ml \cdot kg^{-1} \cdot min^{-1}$, and average values of MOP between 4.1 a 5.4 $W \cdot kg^{-1}$ for competitive cyclists with different performance levels.

Figure 6 - Physiological profile of the cyclists according to performance level and sex



Data are mean ± SD or only mean. One-way ANOVA test for VO_{2Max} and Kruskal-Wallis test for MOP presented *p* value: $p < 0.01$; a < 0.01 vs trained; b < 0,01 vs well-trained. VO_{2Max}: maximal oxygen uptake; MOP: maximal oxidative power.
Source: elaborated by the author (2022).

According to the current characteristics of XC-MTB competitions, the ability to maintain a high rate of energy production for a long time has been highlighted (PRINZ et al., 2021; REINPÕLD; BOSSI; HOPKER, 2021). Regardless performance level, the relative intensity at the second threshold between cyclists was of 78 to 86% of the MOP (ENGELBRECHT; TERBLANCHE, 2017; GRANIER et al., 2018; INOUE et al., 2016; LEE et al., 2002; PRINS; TERBLANCHE; MYBURGH, 2007; PRINZ et al., 2021; WIRNITZER; KORNEXL, 2008). However, professional cyclists reached an absolute intensity at the second threshold (5.2 $W \cdot kg^{-1}$) (GRANIER et al., 2018) that was higher than trained cyclists (3.7 $W \cdot kg^{-1}$) (INOUE et al., 2016).

2.9.2.2 Non-oxidative capacity and power

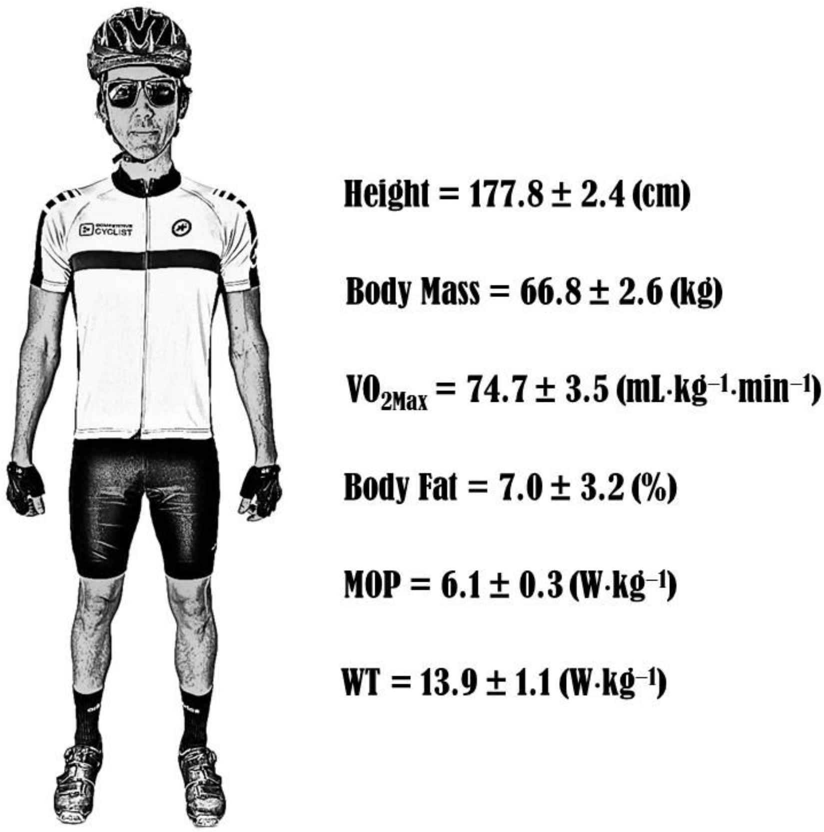
In addition to high oxidative metabolism involvement, non-oxidative contribution, such as ATP-CP and fast glycolysis, is crucial to achieving superior performance in XC-MTB competition (PRINZ et al., 2021). In fact, the literature show that the ability to produce high PO within a short time is associated with the race time in mountain bikers (INOUE et al., 2012). Therefore, it is not surprising that, during a Wingate test (30s all out), male trained cyclists achieved a peak PO of 11.5 ± 1.1 $W \cdot kg^{-1}$ (MACRAE HS-H; HISE; ALLEN, 2000) and 11.8 ± 0.2 $W \cdot kg^{-1}$ (ZARZECZNY; PODLEŚNY; POLAK, 2013), while the professional cyclists achieved 13.9 ± 1.1 $W \cdot kg^{-1}$ (PRINZ et al., 2021). To date, only one study has described the peak PO of the female cyclists during Wingate test (PRINZ et al., 2021). The professional female cyclists achieved a peak PO of 11.4 ± 1.9 $W \cdot kg^{-1}$.

Moreover, a previous study has highlighted the importance of maintaining successive high-intensity efforts, with short recovery intervals, throughout the competition (PRINZ et al., 2021). The authors showed that, during a XCO competition, the athletes performed more than 300 efforts at the intensity above the MOP, which had a mean duration of 4.3 seconds, separated by a mean of 10.9 seconds. Thus, we suggest that athletes and coaches should apply specific training strategies to develop athletes' ability to produce repeated high-intensity efforts (above MOP) throughout competition, such as high intensity interval training and/or sprint interval training (INOUE et al., 2016).

2.9.3 Anthropometric and demographic characteristics of cross-country cyclists

Considering the reviewed studies, it was noted that the anthropometric, physiological and mechanical characteristics differ according to the performance level of cyclists. Figure 7 shows the average values of general characteristics of a professional cyclist. The values were obtained through the data described in table 5 and item 2.9.1. We believe that these data can be relevant to the development of the cyclist’s profile who intends to compete at the professional level in XC-MTB.

Figure 7 - General profile of a male professional cyclist



Values are the mean ± SD of the professional cyclists data described in table 5 and item 2.9.1. VO_{2Max}: maximal oxygen uptake; MOP: maximal oxidative power; WT: Wingate test.
Source: elaborated by the author (2022).

2.10 MOUNTAIN BIKE SETTINGS

In addition to being used as a means of transport, as well as a rehabilitation process, more recently, the bicycle has become a popular type of equipment for outdoor recreational and professional activity. Nonetheless, bicycles have undergone important modifications to meet the specific needs of each activity, seeking higher safety, comfort and greater efficiency, especially in the sports environment (MACDERMID et al., 2017; NIELENS; LEJEUNE, 2004). The use of different materials in an attempt to build lighter and more resistant frames included iron, aluminum, chromium molybdenum and, more recently, the use of carbon fiber. This allows for very high rigidity combined with a low weight, in addition to high impact resistance

(FRANK; HERMANUTZ; BUCHMEISER, 2012). This allows the increasingly dangerous use of bikes in XC-MTB with drops of more than 2 m and descents with obstacles at speeds above 50 km/h, maintaining high safety for the athletes.

Unlike road cycling, XC-MTB is displayed on circuits with different types of terrain that are composed by natural or artificial obstacles. On the basis of such conditions, the bikes were then equipped with tires composed of shorter knobs, shock absorption systems (i.e., suspension system) and gear systems. Moreover, more recently there was a transition from 26-inch-wheel to 29-inch-whell bikes.

In the 1980s mountain bikes were made of iron, weighing around 18-20 kg and in the 1990s, other metal alloys were used, such as aluminum and chrome molybdenum, allowing the weight of the bikes to decrease to around 15 kg for hardtail bikes. Currently, using carbon compounds, it is possible to obtain full suspension bikes with 29” wheelset under 10 kg.

2.10.1 Bicycle Shock Absorption Systems

During XC-MTB, cyclists are exposed to continuous mechanical vibrations induced by terrain irregularities that are transmitted along the body segments, causing an increase in muscle contraction (VIELLEHNER; POTTHAST, 2021). When exposure to these vibrations is prolonged, it can increase muscle fatigue and decrease strength (ADAMO; MARTIN; JOHNSON, 2002), affecting the cycling performance. In this sense, the bicycles were then equipped with shock absorption systems, simply known as suspension, in order to generate low vibrations frequency and to improve bicycle comfort and performance (FAISS et al., 2007).

In the beginning, the bikes had no suspension systems and were named “rigid bike” (Figure 8A). However, throughout the years, bikes were increasingly equipped with a front suspension and were named hardtail bikes (HT) (Figure 8B), followed by a bike equipped with front and rear suspension, named the full suspension bike (FS) (Figure 8C). In fact, both HT and FS absorb more high frequency vibrations (NIELENS; LEJEUNE, 2004), reducing muscle stress, when compared to a rigid bike (SEIFERT et al., 1997). However, when compared to HT, the FS seems to absorb more terrain-induced vibrations at the saddle level, presenting greater comfort (FAISS et al., 2007; TITLESTAD et al., 2006) and less exercise-induced muscle damage (NISHII; UMEMURA; KITAGAWA, 2004).

Figure 8 - Rigid (A), hardtail (B) and full suspension (C) bike models for the XC-MTB events

Source: elaborated by the author (2022).

Suspension is widely used within MTB, but the best suspension mode to achieve superior performance during off-road cycling has prompted a debate among athletes and coaches. Most of the athletes who still prefer the HT, claiming that FS may be related to a possible energy loss due to small oscillatory movements during pedaling movements, mainly at higher PO and during climbing (NIELENS; LEJEUNE, 2004, 2001). However, studies comparing both HT and FS showed controversial results regarding perceptive, physiological and performance responses (FAISS et al., 2007; HERRICK et al., 2011; NISHII; UMEMURA; KITAGAWA, 2004; SEIFERT et al., 1997). Exploring the metabolic and performance responses between HT and FS on a circuit that simulated the XC-MTB race conditions, Herrick et al. (2011) showed that, with similar oxygen consumption, the HT bike was faster than the FS during climbing, resulting in better overall performance. Nonetheless, the FS bike had 2.2 kg more than the HT, which may explain the difference in performance between them, since the total mass is an important factor in performance. When the bike weights were equalized, neither advantages during the climb section nor changes in physiological and perceptual variables between HT and FS were found (FAISS et al., 2007). Moreover, FS was found to absorb more terrain-induced vibrations, leading to a greater comfort (FAISS et al., 2007), and it has better grip in steep-unpaved climbs due to the better (or more time of) contact of the tire with the terrain. In relation to performance, other studies also reported no differences between HT and FS (MACDERMID et al., 2017; MACRAE HS-H; HISE; ALLEN, 2000; NISHII; UMEMURA; KITAGAWA, 2004). Considering the characteristics of the XCS event, the FS bike could be the better choice, if the bike weight is similar to a HT bike.

Although suspensions have been shown to be effective for promoting comfort and attenuating muscle stress, competitive cyclists claim that these shock absorption systems may dissipate the energy generated by them through small oscillatory movements (NIELENS; LEJEUNE, 2004), especially during a sustained climb or sprinting. In this way, suspension manufacturers have improved this system, developing a preload and locking system in order to avoid these likely energy losses. The preload system provides cyclists with the option of compress or decompress springs, resulting in a more or less rigid suspension. Recently, this adjustment has been carried out by increasing or decreasing air pressure in air suspension, making it more modern and effective. With this air system, the cyclist can regulate the stiffness through calibrations relative to his/her BM. It is hypothesized that the preload is able to improve absorption efficiency and keep the tire in contact with the terrain on the more critical sections of the circuit, which could be crucial for performance on the irregular sections that require higher PO and/or higher speed. On the other hand, the locking system provides cyclists with the option of locking the absorption systems completely, resulting in a suspension that is fully rigid. With this system, the cyclist can avoid possible energy dissipation induced by the suspension through oscillatory movements generated by the pedaling movements during a sprint, increasing the PO as well as during a sustained uphill section, since the cyclist spends a considerable time climbing. However, to date, the possible effects of these devices on the mechanical, physiological, perceptual and performance responses have not been examined.

2.10.2 Crank systems, wheel diameter, dropper seatpost and frame size

Other bicycle components have been modified in order to improve performance, such as bicycle gear systems and wheel diameter. The first gear system was created in the 1940s by an Italian, Tulio Campagnolo, containing only four gears on the cassette, and one gear on the chain set. This system was named as Cambio Corsa de Campagnolo. With this system, the cyclist could choose the most adequate gear to adjust the speed and PO according to each section of the circuit. Over time, the system gained more gears, increasing the number of combinations. The most common among them was the 18-speed (3 gears on the chain set x 6 gears on the cassette, or 3 x 6) (Figure 9), but in 2015, it was created the system with 30-speed (3 gears on the chain set x 10 gears on the cassette, or 3 x 10). Although this system offered a greater number of combinations, the bike weight was increased, which could influence the cyclist's performance during a competition (HERRICK et al., 2011). Thus, bike manufacturers have developed a system with 20-speed (2 x 10) and more recently, the 12-speed system (1 x 12) (Figure 9). In these systems, cassette gears circumference and number of teeth have increased, making it possible to achieve adequate combinations to perform on the different sections of the off-road course. In this way, in addition to reducing the weight of the bike, it was possible to improve gear changes, as well as facilitating the transmission system, reducing friction.

Figure 9 - Most popular in the 1990s (18-speed) and more recent (12-speed) gear system models. Although the left allows more speed combinations, the right one is more accurate, lighter, stronger, more efficient and easier to handle

Source: elaborated by the author (2022).

The introduction of 27.5” and, more recently, a 29” wheel bike, where the standard was 26” wheel, has generated a debate about their true advantages (Figure 10). According to Macdermid; Fink and Stannard (2014), this debate was intensified, especially when the Czech Jaroslav Kuhlavy won XC-MTB World Cup on a 29” wheel bike, and after the London Olympics Games (2012), where of the top 10 men and women riders, 70% of them used the 29” wheel, 25% used 26” wheel and 5% used 27.5” wheel. The gold medal was won on a 29" wheel in the men's category, while in the women's category on a 26”-wheel bike. For both men and women, the silver and bronze medals were won on 27.5” and 29” wheel bike, respectively. Despite such subjective discussions, some studies were developed to clarify whether a 27.5” or 29” wheel has a beneficial impact on off-road cycling performance, when compared to a 26” wheel bike (HURST et al., 2017a; MACDERMID; FINK; STANNARD, 2014; MORENO MAÑAS et al., 2021; STEINER et al., 2016). However, controversial results were found.

Figure 10 - Example of the bike wheel diameters for XC along the years

Source: elaborated by the author (2022).

In 2014, Macdermid; Fink and Stannard (2014) examined terrain-induced vibrations, mechanical, physiological and performance responses of competitive athletes during a MTB course lap (~2 km) on a 26” wheel and 29” wheel mountain bike. The authors found that, even with an increase in vibrations, the time to complete the lap was shorter (~3% shorter) on the 29” wheel bike. Mean PO and HR were similar between conditions. Despite the results, the authors highlighted that the tests were performed on the same 29-inch frame and only the wheel size was changed, which would not represent reality, since the bike equipped with the 26” wheel involve different frame geometry, which may influence performance. However, when the specific components of each bike were kept the same, the 29” wheel bike was better than the 26” wheel bike during two laps on a MTB circuit (~1.2 km), even with higher weight (26" wheel = 9.2 kg; 29" wheel = 10.1 kg) (STEINER et al., 2016). The authors speculate that the better performance of the 29” wheel bike can be explained by a reduction in rolling resistance and a lower energy loss due to the larger wheel circumference and better traction, respectively. Moreover, the 29” wheel bike seems to promote more benefits in passing obstacles. More recently, additional evidence supports the idea that the 29” wheel increases vibrations, but results in better performance when compared with the 26” wheel bike (MORENO MAÑAS et al., 2021). Although the findings reported a superiority of the bicycle equipped with a 29” wheel bike, this benefit was not found in the study by Hurst et al. (2017a). The authors used the same components in the bicycle, with the exception of the wheel size, but they found no significant differences in total time or PO among the 26”, 27.5” and 29” wheel bike during only one lap (~3.5 km) on a MTB circuit. In addition, another study conducted by the same authors demonstrated that the wheel diameter (26”, 27.5” or 29”) had no influence on terrain-induced muscle vibrations during one lap on a purpose-built cross-country mountain bike course (HURST et al., 2017b).

It is important to highlight that XC-MTB races can have a significantly higher number of laps, total time and total distance than those reported in the previous studies (UCI regulations, Part 4 mountain bike, version from 11 February 2020). In addition, the characteristics among the XC-MTB competitions are different, which could influence the mechanical, physiological and performance responses, using different bike wheels. Therefore, based on the previous studies, we can consider that bikes equipped with 29” wheels can achieve superior results. However, future studies must be developed, taking into account the official characteristics of each XC-MTB competition. However, in addition to the better rolling ability of the 29 bikes, the recent use of boost hubs has also contributed to wheel stiffness. Boost wheels have a wider axle, which means that the spacing between your hub’s flanges can be increased. By increasing the width of the hub flanges, the bracing angles of the spokes in the wheel are improved, resulting in a stiffer, and ultimately more efficient, wheel.

Recently, XC-MTB bikes have been equipped with a hydraulic system in the seatpost. Known as a dropper seatpost (an example of this system is shown in Figure 11), this equipment provides the cyclist with the option of reducing the height of the seatpost and can return it to its original height remotely through a device attached to the handlebars during pedaling. It is suggested that reducing the seatpost height (or reducing the saddle height) gives the cyclist more maneuverability, more control and, consequently, more speed on descents, through turns and over jumps. Despite this, curiously, a number of cyclists do not actually use a dropper seatpost. The main reason is that cyclists are not certain about where and when it is best to use the dropper seatpost. Moreover, this kind of seatpost is heavier than rigid carbon ones, which could add weight to the bike. Therefore, although the MTB industry and off-road cyclists claim that the dropper seatpost significant enhances riding, no study that explores its real benefit has been developed.

Lastly but not least, it is important to highlight the size of the frames used (whether hardtail or full suspension) by XC-MTB athletes. We know that the size of the frame varies according to the stature, wingspan, length of the lower limbs and/or trunk of each athlete. This means that two athletes of similar heights can use different frames and fits. In this context, athletes often try to use a frame of the smallest size possible, in order to carry less weight during the race. However, it is worth noting the fact that a bike with a longer wheelbase (which depends not only on the frame, but also on its geometry) can offer greater stability on ascents and/or descents. Therefore, the adjustments of equipment, bike, tires and suspension can constantly vary throughout a season, always aiming to achieve combinations for the best possible performance.

Figure 11 - Example of a drop seatpost with original (left) and reduced (right) length/height

Source: elaborated by the author (2022).

2.11 ACCIDENTS AND INJURIES IN MTB: INCIDENCE AND PREVENTION

Given the characteristics of XC-MTB events, which involve a significant amount of natural or artificial obstacles along the circuit (UCI regulations, Part 4 mountain bike, version from 11 February 2020) and with athletes adopting increasingly risk-riding techniques, the risk of accidents with consequent acute injuries will always be present during training sessions, but especially during competitions (BUCHHOLTZ et al., 2021; CHOW; KRONISCH, 2002). The crashes more often occur in technical downhill sections (CHOW; KRONISCH, 2002; KRONISCH et al., 1996), where many cyclists fall forward over the handlebars, which is associated with more severe injuries (CHOW; KRONISCH, 2002). According to previous studies, the most acute injuries reported involves skin (as contusions, abrasions and lacerations), bone fracture, joint, soft tissue and head/neck (concussion) (BUCHHOLTZ et al., 2021; STOOP et al., 2019), without difference in number of acute injuries between trained and professional cyclists (STOOP et al., 2019). Spine fractures and spinal cord injuries caused by accidents were also reported (DODWELL et al., 2010). Loss of bike control is the main cause of fall, leading to acute injury, followed by collisions with other cyclists and mechanical failure (CHOW; KRONISCH, 2002).

In addition to the use of protective clothing and equipment, such as helmet, eyewear and gloves, accident prevention measures could be adopted. However, since the studies on the topic are scarce, we provided insights about these measures, such as: 1) the use of bicycle with high quality components to avoid mechanical failure, and the use of bicycle in accordance with the characteristics of the event (such as suspension, crank system, tires, wheel diameter and dropper seatpost). In this context, with a more technological bike, it is possible to undertake more difficult tracks, such as drops of about 2 m and rock garden obstacles and fast downhills. The suspension system provides high stability for the cyclist, while larger tires promote a better grip on different types of terrains; 2) the familiarization process with the circuit prior the competition. This process is required to reduce the influence of environmental aspects, such as obstacles, terrain and curves, improving motor control and performance, which could reduce the possibility of accidents; and 3) the improvement of the degree of technical ability of the cyclist. The addition of natural and/or artificial obstacles similar to those found on official XC-MTB circuits into training routines could improve performance and decrease cause of falls during competitions. It is necessary for the cyclist to simulate crossing these obstacles alone and in a group, as in the official competition. In addition to these insights, UCI recommends some accident prevention measures, such as the non-inclusion of obstacles in the start and finish zones of the circuit to avoid a crash or a collision; full course marking with panels and arrows, showing all potentially dangerous situations (UCI regulations, Part 4 mountain bike, version from 11 February 2020).

Despite the fact that acute injuries are more often associated with MTB, overuse injury syndromes should also be considered (KRONISCH; PFEIFFER, 2002). The main syndromes affect the neck, hand/wrist, low back and knees (LEBEC; COOK; BAUMGARTEL, 2014). It is speculated that these syndromes occur due to accumulative stress in these regions, induced by the repetitive nature of cycling, including terrain-induced vibrations combined with the need of the athlete to maintain position on the bicycle throughout the exercise (ANSARI; NOURIAN; KHODAEE, 2017). Bike fit (i.e., bike adjustment according to the cyclist's profile), correction of riding style, bicycle settings (such as suspension system) and resistance training seem to be an alternative to reduce such risks (ANSARI; NOURIAN; KHODAEE, 2017).

2.12 CONCLUSIONS

Despite the limited number of studies, the main XC-MTB events can be characterized as intermittent exercise, demanding cardiovascular fitness and high strength and power. Moreover, it is possible to suggest that the physiological responses and mechanical demands can be XC-MTB event dependent. The cyclist's profile and factors such as the distribution of speed over the competition (i.e., pacing) and ability to perform technical sections of the circuit differ according to the performance level, suggesting that these parameters are important for improving performance on high-level XC-MTB circuits. The scientific evidence suggests that the full suspension bike model equipped with 29" wheels seems to be more efficient on the XC-MTB circuit, especially with its low weight. Lastly, in addition to the use of protective equipment and alternatives, such as bike fit and resistance training, adopting accident prevention measures can be a good strategy to reduce the risk of injuries in MTB.

2.13 FUTURE RESEARCH PERSPECTIVES

In addition to the limited number of studies on the XC-MTB, most of these investigations explore the general characteristics and demands of the XCO competition. Since the format of the XC-MTB events is different, physiological responses, mechanical and technical demands, as well as the pacing profile adopted by the cyclists, may differ among races. In this way, the findings of scientific research on XCO should not be extrapolated to all the XC-MTB events and further investigations are necessary to better understand these competitions. Moreover, since the MTB performance parameters were better related to race time when normalized to BM, it is likely that the BC components of the cyclists could be relevant to XC-MTB performance.

As a future proposal, we would like to highlight the importance of an investigation that compares technological tools, mainly regarding the bicycles. For example, the comparisons between hard tail and full suspension bikes are still lacking, and the benefits of the 29” wheel bike still need to be explored in more depth, taking into account the characteristics of each XC-MTB competition. It is possible that there is a specific bike configuration according to each XC-MTB competition that cyclists must take into account in order to reach superior performance. Moreover, more studies on the risks of accidents and number of acute and chronic injuries in XC-MTB, including all categories, should be carried out. The majority of the current studies involve all formats of MTB competition, considering recreational, amateur and professional cyclists.

2.14 ACKNOWLEDGEMENTS

The authors would like to thank the Federal University of Juiz de Fora for the support given to the study, as well as the State Funding Agency of Minas Gerais, Brazil (FAPEMIG), for the scholarship of Rhaí André Arriel e Oliveira.

3 STUDY 2 – PACING PROFILE AND PERFORMANCE LEVEL OF PROFESSIONAL CROSS-COUNTRY CYCLISTS DURING AN INTERNATIONAL CROSS-COUNTRY SHORT TRACK MOUNTAIN BIKE EVENT.

3.1 ABSTRACT

While cross-country short track (XCC) mountain biking (MTB) became more popular in recent years, research detailing the pacing profile and performance of athletes are lacking. Thus, we investigated the pacing profile and performance level of professional cross-country cyclists on different technical and non-technical sections during an XCC MTB event. Twenty male professional cross-country cyclists (25.9 ± 5.4 years; categories: eight U23 and twelve Elite), performed 6 laps of an XCC International Mountain Bike Cup. In addition to categories, cyclists were divided into four different groups (n = 5 each) according to their overall race completion time; group 1 (G1) being the fastest and sequentially until group 4 (G4) being the slowest. Average speed (by lap and in five different track sections) was analyzed according to all athletes, categories and race time group. Both categories adopted a positive pacing profile. In relation to race time groups, G1 maintained a more uniform pacing, while G2 and G3 adopted a positive and G4 a reverse J-shaped pacing profile. No difference in speed was found between categories across laps and track sections ($p>0.05$). Furthermore, G1 was 17.9% ($p<0.01$) and 8.3% ($p<0.01$) faster than G4 on the sustained non-technical uphill and on the more technical short climbs and descents sections, respectively. Regardless of category, the majority of athletes adopted a general positive pacing profile during XCC. Nevertheless, the better performance in XCC was associated with the higher ability to adjustment in speed across the laps and higher performance mainly during sustained non-technical uphill.

Keywords: speed, race pace, off-road cycling, MTB, cycling.

3.2 INTRODUCTION

Cross-country short track (XCC) is a mass-start mountain biking (MTB) event, performed on a closed-loop with a distance ranging from 1.1 to 2.3 km (*e.g.*, as in XCC 2021 World Cup in Albstadt-Germany and 2020 MTB International Cup in Araxá-Brazil, respectively). This event lasts between 20-60 minutes and includes repeated uphill and downhill sections performed over a diverse range of terrains including forest tracks, earth or gravel paths (Union Cycliste Internationale [UCI] regulations, Part 4 mountain bike, version from 11 February 2020). Despite Cross-Country Olympic (XCO) being the most popular MTB event, XCC has gained increased attention in recent years. Indeed, in the year 2021, a world XCC championship was developed for this event, and race results are likely to influence the starting position of XCO events and UCI world rankings. However, factors important to overall performance, such as pacing and performance on the technical and non-technical sections, within XCC events are currently lacking.

Pacing is generally defined as the control of speed (or effort/energy expenditure) throughout an exercise task and, it is well recognized as a critical factor that dictates performance within competition (ABBISS; LAURSEN, 2008; ST CLAIR GIBSON et al., 2006b). It has been suggested that pacing regulation occurs through the complex relationship between brain and other physiological systems (ST CLAIR GIBSON et al., 2006b). It means that information received by the brain, via afferent sensorial feedback from physiological systems, are identified, interpreted and then, an appropriate neural command is generated to reach an ideal speed over the race. However, pacing during head-to-head competition is further complicated, maybe due to numerous external factors, such as different behavior opponents (KONINGS; HETTINGA, 2018b). Moreover, the particular pacing profile adopted by cyclists during competition differ among genders, ages and athlete performance level (ABBISS et al., 2013; MOSS et al., 2019). While significant research exists outlining optimal pacing strategies during discrete, stable, closed-loop exercise tasks (KONINGS; HETTINGA, 2018b), the ideal pacing profile to adopt during dynamic tasks, such as XCC, is more complex and less understood (SMITS; PEPPING; HETTINGA, 2014). Thus, it is essential to know the XCC pacing profile because its understanding provides insights for coaches, athletes and sport researchers.

A high degree of technical ability is required to succeed in MTB due to the variety of terrains including up- and downhill, drops, obstacles and influence of other competitors. Therefore, in addition to pacing profile, previous researchers have investigated the performance of riders, with different overall race completion times, on these technical and non-technical up- and downhill sections in XCO (ABBISS et al., 2013) and cross-country marathon events (XCM) (MOSS et al., 2019). However, to date, this has not been examined in XCC. During an XCO competition, bottom finishers cyclists spend more time in technical uphill sections, compared with top finishers athletes, which could explain, at least in part, the overall performance differences (ABBISS et al., 2013). Nevertheless, the XCC track course is comprised of few technical sessions, and these have a low degree of difficulty, when compared with XCO or XCM (UCI regulations, part 4 mountain bike, version from 11 February 2020), which ultimately may impact overall performance. In this context, the aims of this study were to investigate pacing profile adopted by professional cross-country cyclists and assess their performance on technical and non-technical up- and downhill sections during an official XCC competition, examining whether there is influence of category and performance level on these parameters.

3.3 MATERIALS AND METHODS

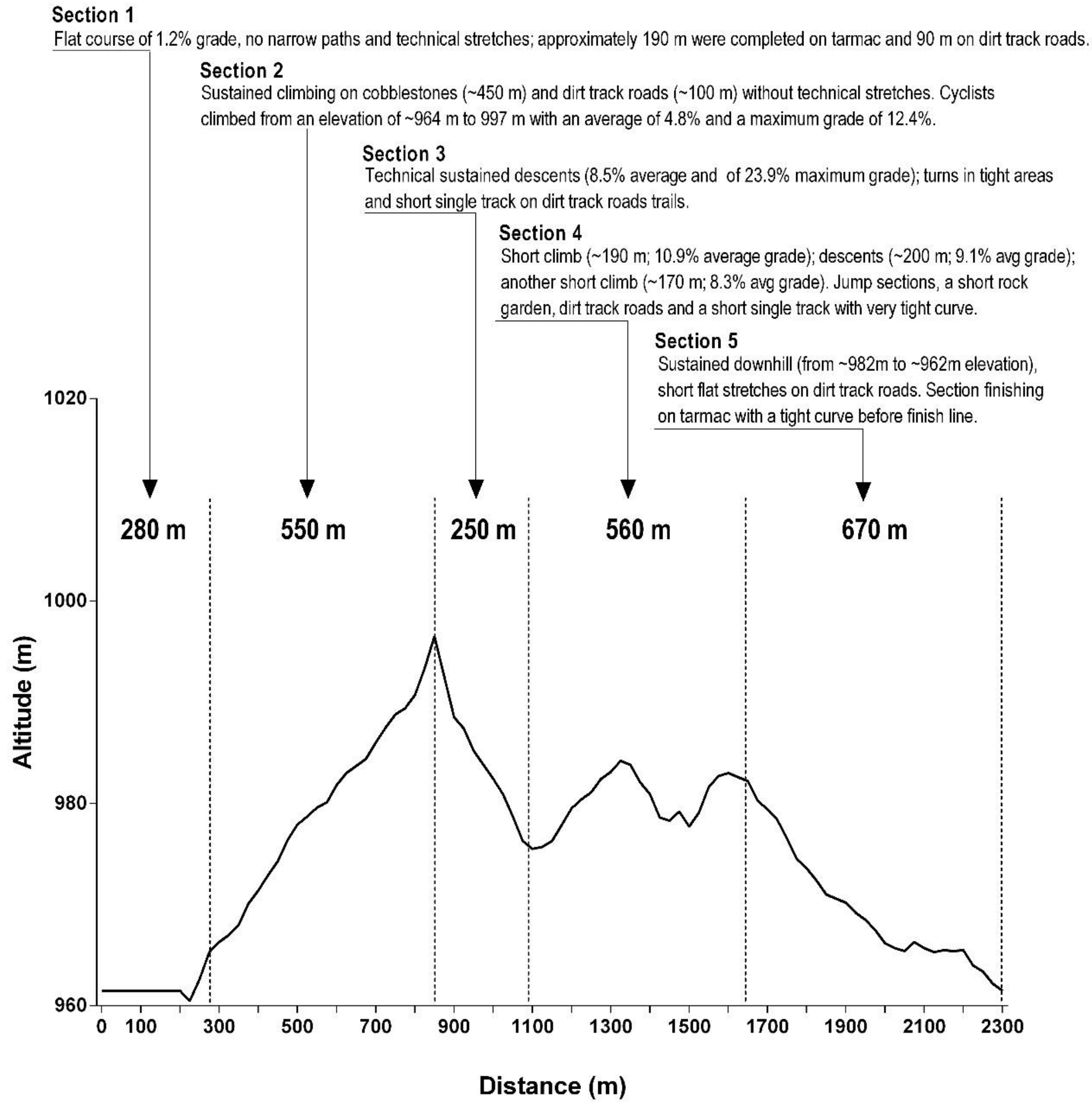
3.3.1 Participants

The performance of twenty male professional cross-country cyclists [25.9 ± 5.4 yrs; range: 19 – 39 yrs; categories: eight Under 23 (U23) and twelve Elite] was assessed within this study. Based on the study of Moss et al. (2019), cyclists were categorized into one of four groups based on their overall race completion time: first fastest cyclists (G1; n = 5; 24.6 ± 4.3 yrs; range: 19 - 30 yrs), second fastest cyclists (G2; n = 5; 26.2 ± 5.1 yrs; range: 20 - 32 yrs), third fastest cyclists (G3; n = 5; 27.0 ± 7.8 yrs; range: 21 - 39 yrs), and fourth fastest cyclists (G4; n = 5; 25.8 ± 5.2 yrs; range: 20 - 32 yrs). All cyclists were registered by the local cycling confederation and had experience in at least one national and/or international competition (*i.e.,* National championship, MTB International Cup and MTB World Cup). Previous results showed that sixteen of the athletes finished at the least once in the top 20 and four in the top 10 positions in one of above competitions. The mean time of participants of this study was about 6.3% (range: 1.7 – 12.2 %) higher than the winner's overall race time to complete this XCC competition (the top one of 2020 World rank). This study was performed in accordance with the Declaration of Helsinki, and approved by the local ethical committee for human experiments (n. 4.120.625).

3.3.2 XCC competition and track course profile

XCC competition was performed during the 2020 UCI International Mountain Bike Cup, involving six laps on a circuit. All cyclists of both U23 and elite categories performed the XCC race at the same time. Total distance cycled per lap (2.3 km), total elevation gain (280 m), altitude (998 m), temperature (24.8 ± 1.4 ºC) and average speed of the wind (24.5 km/h) were measured and provided by event organization (http://cimtb.com.br). The XCC track comprised a combination of 5% of tarmac, 10% of cobblestones and 85% of dirt-track composed of uphill, downhill and flat, but with less single tracks, obstacles (rock gardens, tree roots and mud), narrow turns and technical sections when compared with other MTB competitions (ABBISS et al., 2013; MOSS et al., 2019). We decided to separate the XCC track course into five sections according to topography (uphill, downhill and flat), technical and non-technical sections to determine the influence of increasing lap number during XCC competition on performance in each section. To be considered technical, the section should be composed by natural or artificial obstacle such as rock gardens, drops, tree roots, very tight curve or single track. Otherwise, the section was classified as non-technical. These technical sections were assessed and classified by the researcher involved in this study, following the UCI cycling regulations (Part 4 mountain bike, version from 11 February 2020). We have also assessed the performance of both elite and U23 category and of the four groups of riders on each section. Figure 12 show the XCC course profile and characteristics of each section.

Figure 12 - Cross-country short track (XCC) course profile, location and characteristics of each track section for an individual lap



Source: elaborated by the author (2022).

3.3.3 Data collection

Total time, distance and speed over entire race were recorded through of individual devices (Garmin® Edge, Kansas City, United States; and Polar®, Finland), which posteriorly were downloaded for each cyclist directly in the Strava® program. Strava is a mobile app for helping athletes in controlling training session and season, which they can record and share their own race or training data with the public. Therefore, the data were of public domain, and only publicly accessible sources were used. All data were downloaded from Strava and analyzed by two independent reviewers. Based on the Abbiss et al. (2013) study, we correlated total race time recorded by individual devices with the time recorded by the official system of the International Mountain Bike Cup, which was classified as nearly perfect ($r = 0.999$, $p < 0.01$) (MUKAKA, 2012). To analyze pacing profile, we examined average speed lap by lap, and to analyze pace across the five sections, we examined average speed of the section in each lap. The percentage speed coefficient of variation (%CV) across laps and of each section across laps was determined using standard deviation (SD) divided by average speed (AS) multiplied by 100 [i.e. %CV = (SD/AS)*100].

3.3.4 Statistical analysis

IBM SPSS (Version 23) and GraphPad (PRISM®, 6.0, San Diego, USA) statistical program were used for performing the data analyses. Shapiro-Wilk test was used for checked the normality of the data. To compare total race time, average race speed and %CV of speed between U23 and elite athletes, and among race time groups, an independent Student t-test or Mann-Whitney test and an one-way analysis of variance (ANOVA) or Kruskal-Wallis test were used, respectively. Considering all athletes, a separate one-way ANOVA for repeated measures (or Friedman test) was conducted for analyzing average speed across the laps, and average speed and %CV of speed among distinct sections. In addition, the same test was used to compare the average speed of the section in each lap. Two-way ANOVA mixed model was conducted for each independent variable (categories and race time) to analyze within and among groups the average speed across laps, and average speed and %CV of speed among distinct sections. When necessary, a Bonferroni's post-hoc test was employed. The level significance adopted was $p \leq 0.05$.

3.4 RESULTS

3.4.1 All athletes

All athletes performed the XCC race with a total distance of 13.8 km and duration of 38 ± 1 min without known injury or mechanical delays. Average race speed was of 21.6 ± 0.7 km/h with %CV of speed across laps of 2.8 ± 1.1% (Table 6). During competition, average speed was similar between Lap 1 and Lap 2, decreased from the Lap 2 to Lap 3, and it was similar from the lap 3 until Lap 6 (Figure 13A).

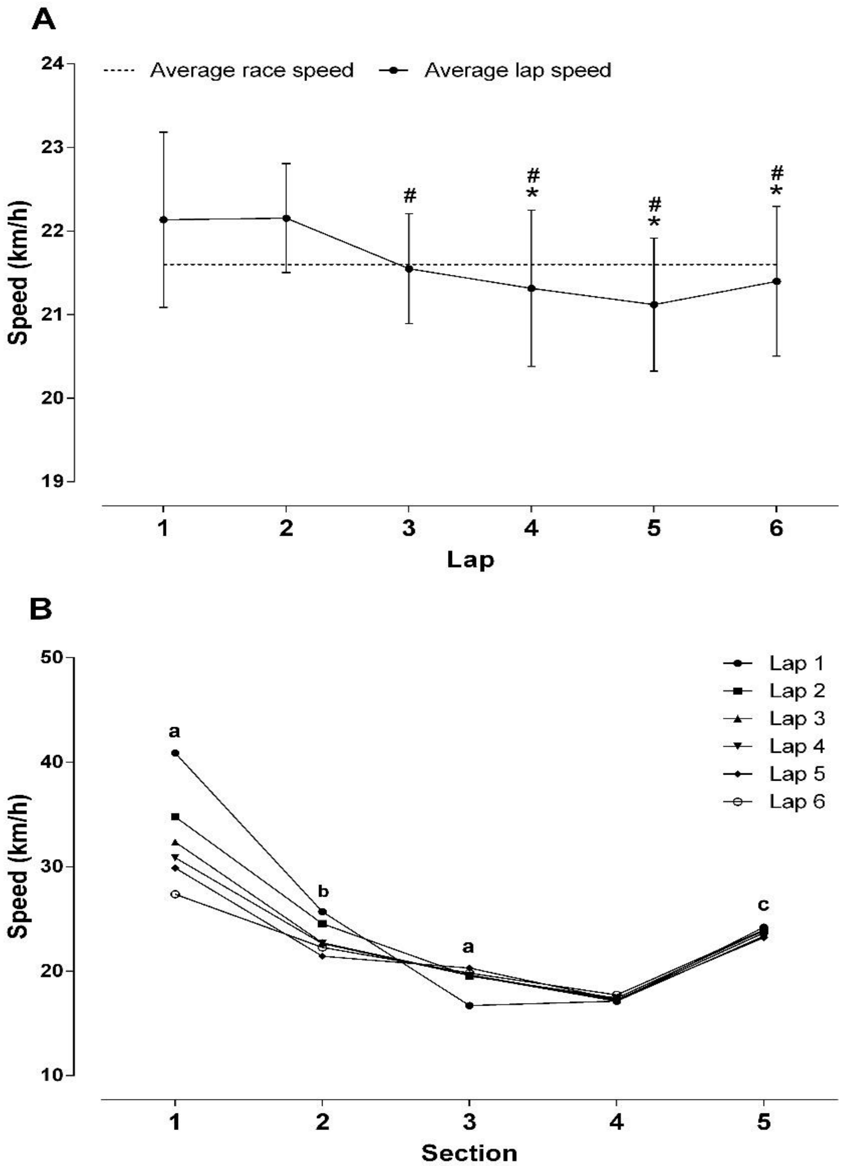
Cyclists were significantly faster in section 1 and slowest in section 4. %CV of speed across each section was greatest in section 1 and lowest in section 5 (Table 7). In section 1, speed decreased over the laps. In section 2, after lap 1 and lap 2, speed decreased in Lap 3 and was maintained from the Lap 3 until Lap 6. Speed increased from lap 1 to lap 2, in section 3, which was maintained until lap 6. In section 4, a difference in speed was not observed between laps ($p = 0.09$). In section 5, speed was maintained from lap 1 until lap 3, significantly decreased in lap 4 and lap 5 compared with lap 1, and it increased from the Lap 5 for lap 6 (Figure 13B).

Table 6 - Total time, average speed and coefficient of variation of speed (%CV) across laps of the cyclists according to general, categories and race time groups in overall race

	Total Time (min)	**Speed (km/h)**	**%CV**
General			
All athletes	38 ± 1.3	21.6 ± 0.7	2.8 ± 1.1
Categories			
U23	39 ± 1.4	21.4 ± 0.8	3.2 ± 1.1
Elite	38 ± 1.2	21.7 ± 0.7	2.5 ± 1.0
Race time			
G1	37 ± 0.1[b,c,d]	22.5 ± 0.1[b,c,d]	2.1 ± 0.6
G2	38 ± 0.5[a,c,d]	22.0 ± 0.3 [a,c,d]	2.8 ± 0.6
G3	39 ± 0.4[a,b,d]	21.3 ± 0.2 [a,b,d]	3.7 ± 0.9
G4	40 ± 0.3[a,b,c]	20.7 ± 0.2 [a,b,c]	2.5 ± 1.5

Data are mean ± SD. [a] $p < 0.05$ compared with group 1; [b] $p < 0.05$ compared with group 2; [c] $p < 0.05$ compared with group 3; [d] $p < 0.05$ compared with group 4.
Source: elaborated by the author (2022).

Figure 13 - Pacing profile (A) and average speed of each section in each lap (B) according to all cyclists over the entire XCC competition



Data are expressed as mean ± SD in A and as mean in B. * $p < 0.05$ compared with Lap 1; # $p < 0.05$ compared with lap 2; a $P < 0.05$ = lap 1 compared with all other laps within same section; b $p < 0.05$ = lap 1 compared with lap 3 to 6 within same section; c $p < 0.05$ = lap 1 compared with lap 4 and 5 within same section.
Source: elaborated by the author (2022).

Table 7 - Average speed and coefficient of variation of speed (%CV) across laps of cyclists according to general, categories and race time groups in each track section

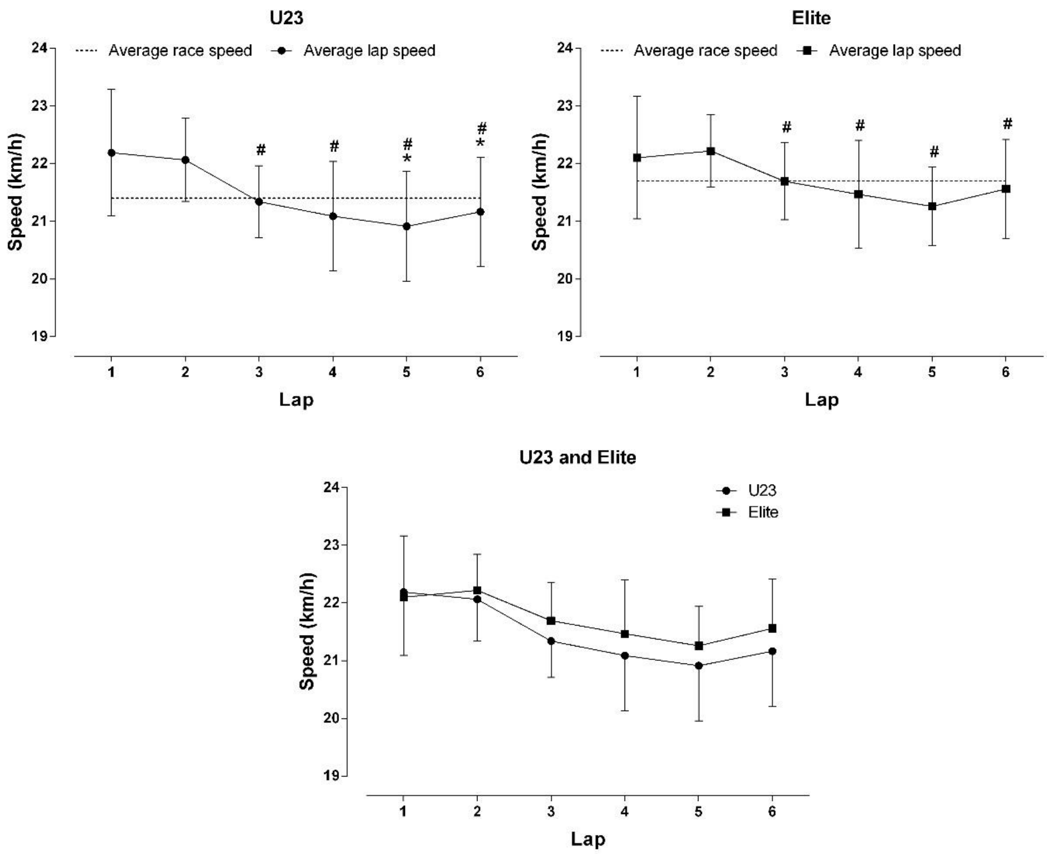
	Section 1		Section 2		Section 3		Section 4		Section 5	
General	**Km/h**	**%CV**	**Km/h**	**%CV**	**Km/h**	**%CV**	**Km/h**	**%CV**	**Km/h**	**%CV**
All athletes	32.7*	15.5*	23.2	8.7	19.3*	10.1	17.3*	3.8*	23.7	2.6*
Categories										
U23	32.4*	15.0	23.0	9.8	19.4*	9.2	17.0*	3.2	23.7	3.0
Elite	32.9*	15.8	23.4	7.9	19.2*	10.7	17.5*	4.1*	23.7	2.3*
Race time										
G1	31.8*	17.1*	25.6[b,c,d]	7.1	19.7	7.5	18.1[d]	3.1	24.2	2.3
G2	34.5*	14.0	23.7[d]	7.3	18.9	9.0	17.5	4.6	24.2	2.9
G3	32.9*	16.0	22.5	10.6	19.0	13.6	17.1*	4.0	23.4	2.9
G4	31.5*	14.9	21.0	9.5	19.4	10.3	16.6*	3.4	23.2	2.3

Data are mean. * $p < 0.05$ compared with all other sections of the same group; comparison within the same section: [b] $p = 0.03$ compared with group 2; [c] $p < 0.01$ compared with group 3; [d] $p < 0.01$ compared with group 4.
Source: elaborated by the author (2022).

3.4.2 U23 and elite

Total race time, average race speed and %CV of speed across laps were similar between U23 and elite categories (Table 6). Pacing profile adopted during the XCC competition by both categories was similar. They maintained a similar speed in Lap 1 and Lap 2, but decreased in Lap 3. After this reduction, cyclists of both categories were able to maintain a similar speed until Lap 6. This information is displayed in figure 14.

Figure 14 - Pacing profile according to U23 and elite categories over the entire XCC competition



Data are expressed as mean ± SD. * $p < 0.05$ compared with Lap 1; # $p < 0.05$ compared with lap 2.
Source: elaborated by the author (2022).

Both U23 and elite were significantly quicker in the section 1 and slower in the section 4, and they presented a higher %CV of speed in the section 1 and a lower in the section 5. No significant difference was found for speed and %CV of speed in each circuit section between categories (Table 7).

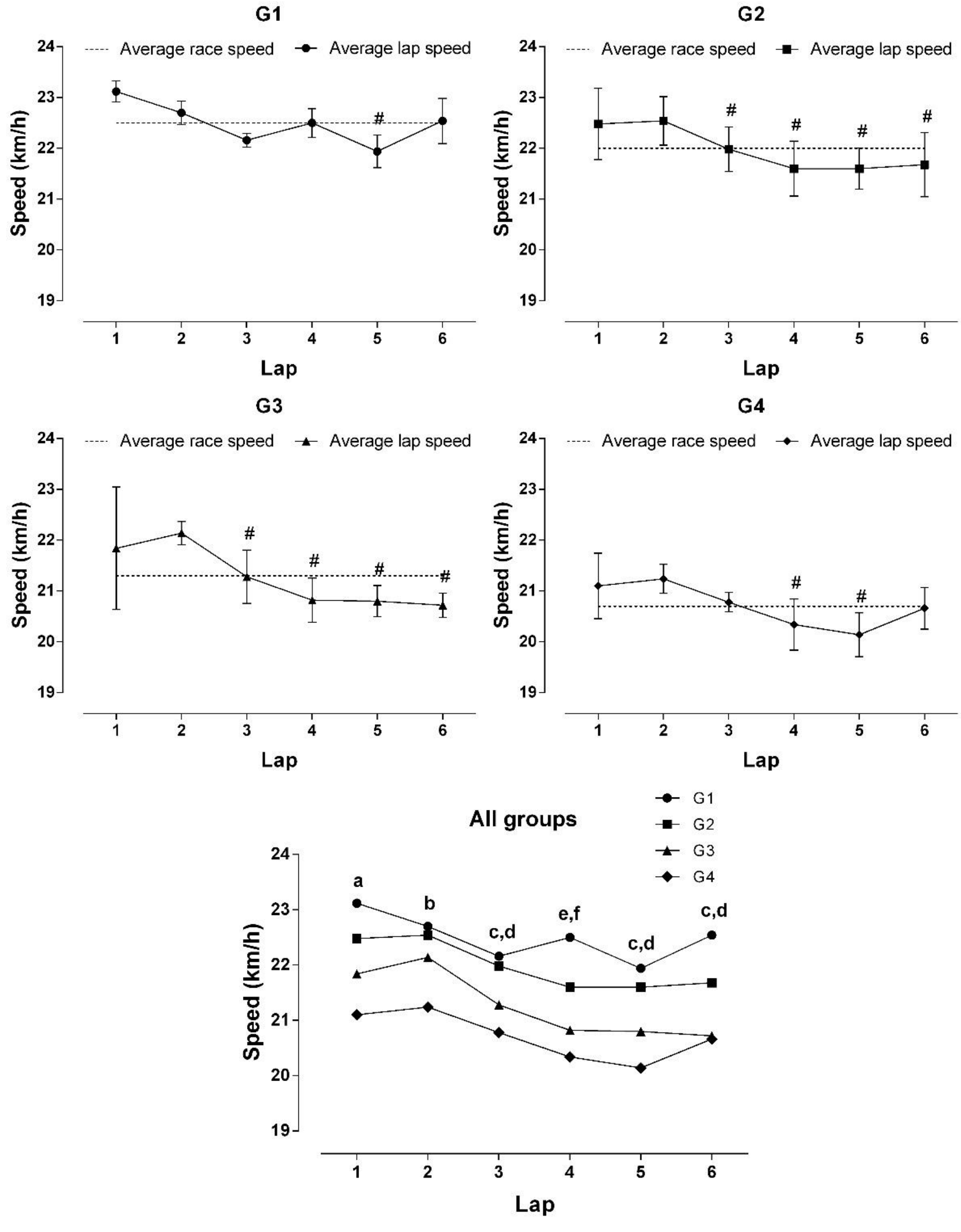
3.4.3 Race time

As expected, total race time and average race speed were significantly different among race time groups. Average race speed was significantly higher in G1, and sequentially decreased for each slower group. Total race time was lower in G1, and sequentially increased for each slower group. No significant change in %CV of speed across laps was found among groups (Table 6). However, G1 maintained a significantly more even pacing over the race, while G2 and G3 adopted a positive pacing and G4 a parabolic-shaped pacing profile (Figure 15).

In Lap 1 and Lap 2, G1 was significantly faster than G4, but similar when compared with the other groups. In lap 3, lap 5 and lap 6, both G1 and G2 were significantly faster than G3 and G4. However, in lap 4, G1 was significantly faster than all other groups (Figure 15).

During race, all race time groups were significantly quicker in the section 1 and slower in the section 4, and they presented a higher %CV of speed in the section 1 and a lower in the section 5 of the XCC track course. G1 was significantly faster G2, G3 and G4 in the section 2 (groups: 1 vs 2 = 7.4% faster; 1 vs 3 = 12.1% faster; 1 vs 4 = 17.9% faster), and was faster than G4 in the section 4 (1 vs 4 = 8.3% faster). Furthermore, G2 was significantly faster than G4 in the section 2 (11.4% faster) (Table 7).

Figure 15 - Pacing profile according to race time group over the entire XCC competition



Data are expressed as mean ± SD in G1, G2, G3, G4 and as mean in All groups. * $p < 0.05$ compared with Lap 1; # $p < 0.05$ compared with Lap 2; a $p < 0.05$ = group 1 compared with 4; b $p < 0.05$ = group 4 compared with 1, 2 and , 3; c $p < 0.05$ = group 1 compared with 3 and 4; d $p < 0.05$ = group 2 compared with 3 and 4; e $p < 0.05$ = group 1 compared with 2, 3 and 4; f $p < 0.05$ = group 2 compared with 4.
Source: elaborated by the author (2022).

3.5 DISCUSSION

The purpose of this study was to investigate the pacing profile adopted by professional cross-country cyclists and assess their performance on technical and non-technical uphill and downhill sections during a XCC competition, examining if there is influence of the categories and performance level on these parameters. Our main finding was that, regardless of category, cyclists adopted a positive pacing profile. However, faster cyclists adopted a more even pacing profile and reporting higher speed during a sustained non-technical climbing and during a technical section composed by shorter uphill/downhill of the XCC track.

Previous researchers have analyzed important factors that may influence MTB cycling performance (ARRIEL et al., 2020), including pacing profile in XCO (ABBISS et al., 2013) and XCM (MOSS et al., 2019). However, this is the first study to analyze the pacing profile during an official XCC competition. Following the actual UCI recommendations (Part 4 mountain bike, version from February 2020), XCC race duration must be of 20 to 60 minutes, which is in line with our value (38 ± 2 min). Average race speed was of 21.6 ± 0.7 km/h, which indicate that the XCC was 9.7% faster than XCO competition (GRANIER et al., 2018).

During XCC race, after faster first and second lap, cyclists significantly reduced speed followed by an even pacing until the end of the competition, which is representative of a positive pacing (Figure 13A). Both U23 and elite cyclists also adopted a positive pacing, showing that this parameter is not influenced by category level (U23 and Elite) (Figure 14), which is in line with previous study in MTB (ABBISS et al., 2013). The regulation of pacing has been attributed to the relationship between a brain algorithm, which was created through knowledge of the endpoint and memory of previous similar events, and other physiological system (ST CLAIR GIBSON et al., 2006b; ULMER, 1996). That is, through afferent sensorial feedback from other physiological systems (e.g., cardiovascular, muscular, respiratory…), together with data from the external conditions (as environmental), the brain algorithm calculates whether the athlete’s speed (or power output) is appropriate to reach the end of the exercise at the shortest time possible without inducing premature fatigue, which impairs overall performance. In this hand, we can speculate that this large acceleration of the cyclists at the commencement of the XCC race was interpreted by brain algorithm as unsustainable until the end of the race, leading the cyclists to a reduction in speed after the second lap. Nevertheless, it is relevant to highlight that during mass-start event, as in XCC and XCO competitions, athletes tend to adopt an aggressive race start (GRANIER et al., 2018) in order to place themselves in the front positions to benefit from riding solo, avoiding congestion and crashes in sections composed of single track and turns in tight areas, which could impair their overall performance. Indeed, across the laps we observed that athletes were faster in the section 1 and slower in section 3 (section composed of a single track) on the first lap (Figure 13B), showing that cyclists really adopted an aggressive race start and probably experienced a congestion and/or crashes after this. After the second lap, cyclists placed themselves in better positions, allowing them to reduce speed. Previous MTB studies evaluating pacing profile in XCO competition support this (ABBISS et al., 2013; GRANIER et al., 2018; VIANA et al., 2018). However, during XCO, the decline in speed was after the start loop (GRANIER et al., 2018), while in XCC was after the second lap, showing that cyclists needed more than one lap to achieve a best position. The competitive environment really affects pacing-related decisions, especially during the initial phase of the race (KONINGS; HETTINGA, 2018a). Therefore, we have suggested that coaches and athletes consider this interaction with the XCC race environment in their training routine.

It is interesting to note that cyclists achieving different race time display different pacing profile. Despite majority of cyclists adopted a positive pacing profile during XCC, when pacing was assessed among race time groups, we observed that G1 was able to maintain a more consistent average speed over entire race (i.e. a more even pacing profile), while G2 and G3 performed a positive pacing and G4 a reverse J-shaped pacing profile (ABBISS; LAURSEN, 2008). Although the utility of an even pacing profile has been questioned (THOMAS et al., 2013), the results of the current study and previous research (ABBISS et al., 2013; MARTIN et al., 2012) provided support that an even pacing profile is adopted by faster athletes in MTB events. Indeed, faster cyclists adopted a more even distribution of pacing during an XCO event, which was evidenced by a significantly lower standard deviation and range in average lap speed, when compared with slower riders (ABBISS et al., 2013). Although %CV of speed across laps during XCC was not significantly different among race groups, G1 presented a lower %CV value when compared with all the other groups, which may justify, at least in part, the more even pacing adopted. The parabolic pacing profile performed by the G4 group consists of a relative fast start, declining middle period followed by an increase in speed during the latter period of the race. This pacing profile has been reported as close to optimal for well-trained cyclists in a simulated 20 km time trial in a cycle ergometer (THOMAS et al., 2013). However, during head-to-head competition, such as in XCC race, the effects of external factors are more predominant (e.g. behavior of opponent), influencing the pacing decision (KONINGS; HETTINGA, 2018b).

Previous analyses have identified different pacing profile among athletes with different overall race time (RENFREE; CRIVOI DO CARMO; MARTIN, 2016), including MTB competition (ABBISS et al., 2013; MOSS et al., 2019). A possible explanation would be higher efficiency of faster cyclists in processing information and speed adjustments over the XCC. In this type of race, cyclists are confronted with a wide range of information involving internal (e.g. physiological response) and external (action of the opponent) factors, which should be identified and interpreted by the brain. After this, the brain triggers an efferent neural command to select the more appropriate speed (or power output) in order to maximize exercise performance (RENFREE et al., 2014; ST CLAIR GIBSON et al., 2006a). We suggest that a better information processing avoids an excessive or more conservative speed over the race, resulting in a most even speed attainable. Therefore, it is probably that faster cyclists (G1) had higher accuracy to assess the information and consequently selected the more appropriate speed over the race, which resulted in a more consistent speed and superior performance. Once the faster off-road cyclists also adopted a more even speed during XCO competition (ABBISS et al., 2013), we would like to highlight the relevance of improvements in training methods for information processing over the race for XCC and also similar competitions.

Of the five sections of the XCC course, G1 was faster than G2, G3 and G4 on the section 2 of the circuit composed of sustained non-technical uphill. Although the cyclists of all groups were able to maintain a more stable speed (%CV across laps) on the section 2 (Table 7), G1 was able to maintain greater speed across the laps. Such result was also reported by previous research in XCO formats (ABBISS et al., 2013) but on a sustained technical uphill. During uphill sections, cyclists tend to produce more power output, when compared with a flat section, and significant performance improvements can be obtained from specific uphill training (NIMMERICHTER et al., 2012). Moreover, cyclists with more training experience in uphill terrain report lower perceived exertion and blood lactate concentration to a similar relative intensity during an uphill trial (GANDIA SORIANO et al., 2021). Therefore, it is probable that the non-technical uphill ability of the slower cyclists may be improved through of specific training conditions, consequently improving overall performance in XCC competition.

In addition to section 2, G1 was also faster than G4 on the section 4 composed for short technical uphill and downhill. Such result was also reported in a XCM format (MOSS et al., 2019). The authors showed that, in addition to adopting a more even speed, better cross-county cyclists were faster on the section composed by short climbs and descents when compared with the less successful performers. It is interesting to note that the quicker cyclists of the present study were significantly faster than all other groups on the non-technical uphill (Section 2) and it was only faster than G4 during the technical uphill/downhill section (section 4). Moreover, the percentage change of speed between the faster and slower riders was higher on the non-technical uphill (G1 vs G4 = 17.9% faster) than on the technical uphill/downhill (G1 vs G4 = 8.3% faster). Although both non-technical and technical ability could be improved in order to reach success in MTB events (ABBISS et al., 2013; MOSS et al., 2019), XCC track course is comprised of less technical sessions, and these have a low degree of difficulty (UCI regulations, Part 4 mountain bike, version from 11 February 2020). Thus, our findings show that the ability to perform a sustained non-technical uphill may be more meaningful to performance than technical uphill/downhill ability to success in XCC competition, indicating that such fact may be an XCC characteristic. However, due to observational characteristic ex-post-facto of this study, it is unclear whether such advantage can be achieved through of a meaningful improvement in MTB technique (as pedaling technique, stabilize the bike, pedaling seated or standing and technical ability to maneuver), physical ability (as aerobic and anaerobic power) or both.

Average and %CV of speed in non-technical flat (Section 1) across laps did not differ among race time groups. Although performance in non-technical flat section can be important to cycling performance (NIMMERICHTER et al., 2010), in the present study, cyclists used this section to hydrate and/or to energy replacement. This indicates that cyclists did not use this section to gain advantage on their opponent. Therefore, it is unclear whether riding faster on the flat could be an important determinant to performance in this XCC course. Moreover, %CV of speed and average speed in technical downhill (Section 3) and sustained non-technical downhill (Section 5) across laps were also not different among race time groups. Again, although MTB events require that cyclists have high degree of technical ability in order to gain advantage on their less technical opponent and/or decrease time lost in other sections of the course, in the XCC track profile these technical sections have a relatively low degree of difficulty, which could benefit the less technical cyclists. Therefore, it appears that having a greater technical downhill ability does not seem to be a determining factor in XCC competition performance.

To data from the current study, we can suggest that athletes incorporate in their training routine methods to enhance their ability of information processing over the race in order to select the more appropriate speed. Moreover, they must include specific training for improve performance in sustained non-technical uphill section in order to achieve superior performance in XCC. However, we would like to highlight some limitations of this study. As the analyses of the present study were conducted only on a single XCC course, such response in pacing profile could be influenced by topographic profile, track settings (as difficult technical) and race dynamics of other events. Thus, future research should consider and assess a higher number of XCC events within the same analysis. Moreover, due to the observational characteristic of this study, we did not carry out performance test to define and classify the training status of the cyclists.

3.6 CONCLUSION

Although the majority of the MTB cyclists adopt a positive pacing profile during XCC, faster cyclists tend to adopt a more even pacing profile and were found to be faster on sustained non-technical uphill section and on a technical section composed by shorter uphill/downhill section. However, this advantage was greater on the non-technical uphill section. Therefore, our finding show that better performance in XCC was associated with the higher ability to adjustment in speed across the laps and higher performance mainly on sustained non-technical uphill cycling.

3.7 ACKNOWLEDGEMENTS

The State Funding Agency of Minas Gerais, Brazil (FAPEMIG) for the scholarship of Rhaí André Arriel e Oliveira.

4 STUDY 3 – PACING PROFILE, POWER OUTPUT AND CADENCE DURING MOUNTAIN BIKE WORLD CUP CROSS-COUNTRY OLYMPIC AND SHORT TRACK EVENTS: A COMPARATIVE STUDY.

4.1 ABSTRACT

Mountain bike cross-country short track (XCC) event is performed on the same terrain settings than cross-country Olympic (XCO). However, due to its modified course profile (e.g., lower elevation gain and total distance) and the low degree of difficulty on the technical sections, parameters as power output (PO) and cadence (CA), and pacing profile adopted by cyclists in XCC could be different for those adopted in XCO. Thus, the aim of this study was to assess mechanical parameters and pacing profile during XCC and XCO events. The performance of twelve male elite mountain bikers (29.2 ± 4.8 years) during XCC and XCO races was assessed. During both competition, total race time, speed, PO and CA were recorded and posteriorly analyzed. Compared to XCO, total race time was lower (21.0 ± 0.5 vs 84.0 ± 3.0 min; $p<0.01$) but 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 rpm; $p=0.01$) were higher in XCC. While a variable pacing profile was adopted during XCC, a positive pacing 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 pacing profile and mechanical parameters adopted by cyclists are different between XCC and XCO. Therefore, mountain bikers must develop specific strategy and training methods in order to obtain success in each competition.

Keywords: pace; MTB; cyclists; exercise intensity.

4.2 INTRODUCTION

Mountain biking (MTB) 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. One of its most popular events is Cross-Country Olympic (XCO), which was included in the Olympic Games programme. During XCO races, athletes complete several laps on a closed-loop (lap length of 4 to 6 km) (Union Cycliste Internationale [UCI] regulations, Part 4 mountain bike, version from February 2020) lasting approximately 90 ± 10 min (GRANIER et al., 2018). In addition to XCO, the cross-country short track (XCC) event has drawn the attention of athletes and coaches because defines the XCO starting grid in the world cup, adds points to the UCI world ranking and, in the year 2021, a world XCC championship was developed. XCC is performed on the same terrain settings than XCO, however, the circuit distance (1.2 to 2.3 km), elevation gain and race time (20 to 60 min) are shorter, and its technical sections have a low degree of difficulty (UCI regulations, Part 4 mountain bike, version from February 2020).

Both XCO and XCC competition represent a complex environment, exposing the participants to a numerous amount of information that influence the regulation of muscular work rate (pacing) during the activity (RENFREE et al., 2014; SMITS; PEPPING; HETTINGA, 2014). It has been suggested that the self-regulation of pacing is regulated by the brain through afferent feedback from the peripheral systems and efferent neural commands (ST CLAIR GIBSON et al., 2006b). This regulation is continuous and extremely important for success in self-paced endurance event, where a failure will compromise the overall performance (RENFREE et al., 2014). Therefore, athletes must learn to select an appropriate pacing in order to achieve the success in an MTB endurance competition.

The pacing regulation is 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 (RENFREE et al., 2014). During XCO competition, athletes tend to adopt a fast start followed by a more even pacing, which is representative of a positive pace (GRANIER et al., 2018). As XCO is 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. Although the XCC is also a mass-start event, the race format is different and the number of participants is smaller (40 athletes), which could influence the choice of pacing profile, including power output (PO) and cadence (CA) distributions, during this competition. However, no study has examined it. In fact, previous studies with road cyclists have shown that some of these responses are substantially influenced by race format (as time trial and mass start competition), including type of terrain (as flat, uphill) and total race time (LUCÍA; HOYOS; CHICHARRO, 2001; SANDERS; HEIJBOER, 2019).

In MTB, previous studies focused largely in evaluating the pacing profile (ABBISS et al., 2013; GRANIER et al., 2018), PO and CA on XCO competition (GRANIER et al., 2018; PRINZ et al., 2021), and no study focused on XCC or compared two or more events. Thus, it remains to be known whether pacing profile, PO and CA adopted by professional off-road cyclists during XCC differ of the more traditional MTB competition. This comparison is important because understanding the differences among MTB 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 assess pacing profile, PO and CA adopted by elite mountain bikers during a XCC and XCO world cup competition.

4.3 METHODS

4.3.1 Data collection of the participants

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 UCI world ranking. Three of these cyclists finished in the first five positions of the UCI world ranking and won at least once XCC or XCO competition in the UCI MTB world cup. The exclusion criteria were mechanical issues or any other factor that could compromise the final performance result. An informed consent form was not required because data were of public domain.

4.3.2 XCC and XCO competitions and track course profile

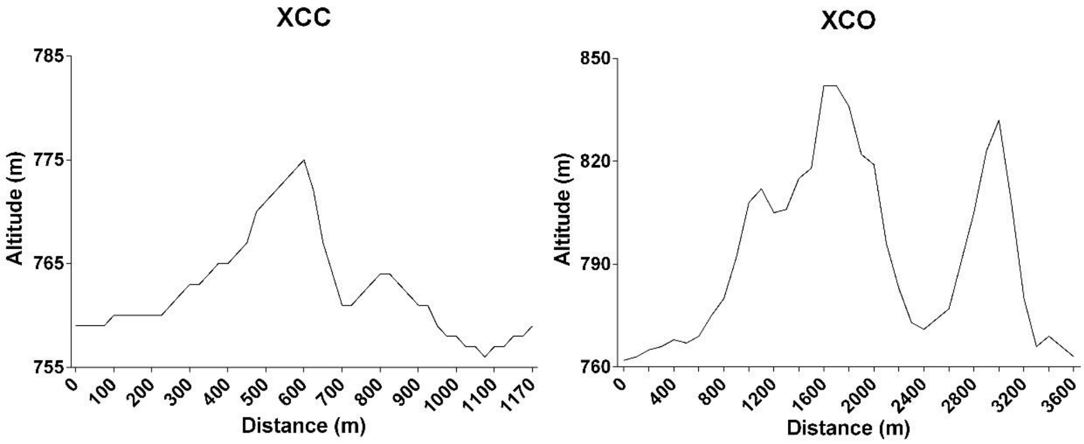
The XCC and XCO races were performed during the 2021 UCI MTB World Cup competition, which involved repeated laps on a hilly closed-loop of approximately 1.17 and 3.6 km, respectively. The XCC competition involved eight laps, and XCO was composed of a start loop (~2.8 km) and six more laps. The number of laps, total race time, total race distance, total elevation gain, altitude of both XCC and XCO are reported in table 8. 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 UCI technical delegate (UCI regulations, Part 4 mountain bike, version from February 2020). The course profile of both XCC and XCO races was measured by the researchers of this study through the GPS device (Garmin® Edge, Kansas City, United States) used by a cyclist involved in this study (Figure 16).

Table 8 - 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
Altitude (m)	775	846

SL, start loop.
Source: elaborated by the author (2022).

Figure 16 - Cross-country short track (XCC) and cross-country Olympic (XCO) course profile for an individual lap



Source: elaborated by the author (2022).

4.3.3 Data collection

All cyclists practiced both XCC and XCO tracks course according to their own personal preferences days before the competition begin. The XCC and XCO data were collected over the entire race through of individual devices that measured total race distance and time, speed, PO, CA (without excluded the time spent not pedaling) and elevation gain (Garmin® Edge, Kansas City, United States; and Wahoo® elemnt bolt, United States) that posteriorly were downloaded for each cyclists directly in the Strava® program. Strava is a mobile app, which cyclist can record and 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 (BROCHERIE et al., 2020). Athletes used their own mobile power meter and cadence sensor to measure PO and CA during the races. Due to the characteristic ex-post-facto of this study, the devices brand were not identified. Two independent reviewers of this study analyzed the data. Based on the Abbiss et al. (2013) study, we correlated the total race time recorded by individual devices with official system of UCI MTB World Cup organization (XCC = Pearson correlation coefficient = 0.994, $p < 0.01$; XCO = Pearson correlation coefficient = 1.00, $p < 0.01$). Both associations were classified as nearly perfect (MUKAKA, 2012). 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 (SD) divided by average value of variable (AV) multiplied by 100 [i.e. %CV = (SD/AV)*100]. It is important highlight that the effects of external factors (such as crashes 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 (ABBISS et al., 2013).

4.3.4 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 $p \leq 0.05$.

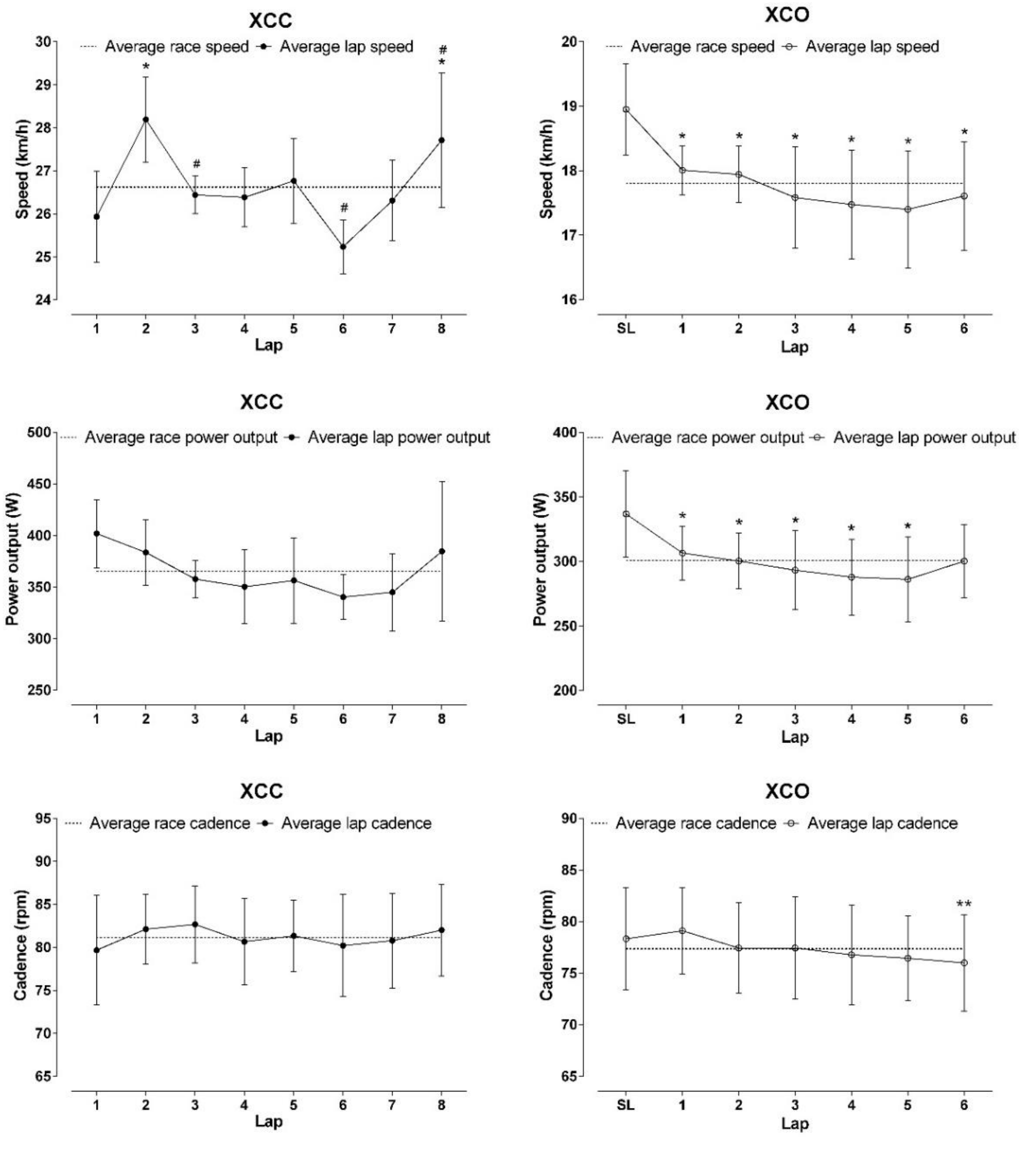
4.4 RESULTS

4.4.1 Pacing profile, power output and cadence distribution

Cyclists performed both XCC and XCO races without injure or faced mechanical problems. During XCC, cyclists oscillated speed during the race, which is representative of a variable pacing profile, with two speed peaks in 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 17).

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 17). 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 17). 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 17 - Average speed, PO and CA during XCC and XCO races



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: elaborated by the author (2022).

4.4.2 Race time, speed, power output and cadence

When compared with XCO, they completed the XCC competition in a shorter time and with a lower peak of speed, but with significant higher mean values of speed, PO and CA. The CV of speed, PO and CA across laps were similar between competitions (Table 9).

Table 9 - 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
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} (rpm)	9	81.2 ± 4.7	77.4 ± 4.3	0.011
CA_{peak} (rpm)	9	130.1 ± 18	147.6 ± 15.7	0.055
CV of CA (%)	9	2.9 ± 1.1	2.5 ± 1.2	0.489

Data are mean ± SD; CV = coefficient of variation across the laps; PO = Power output; CA = Cadence.
Source: elaborated by the author (2020).

4.5 DISCUSSION

The aim of this study was to evaluate PO, CA and pacing profile during both XCC and XCO world cup competition. Our main find was that the athletes performed XCC in a higher mean of PO, CA and speed, adopting a variable pacing profile during XCC and a positive pacing during XCO. Distribution of PO and CA across laps were similar during 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 MTB 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 8) are in line with actual UCI regulation (UCI regulations, Part 4 mountain bike, version from 11 February 2020). 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 (ABBISS; LAURSEN, 2008) and mechanical responses (SANDERS; HEIJBOER, 2019), 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 fluctuations in speed. It is probable that such fluctuations were more apparent in XCC due to constant attempts to overtake of opponent during competition, which does not occur during XCO. This interaction with 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 (KONINGS; HETTINGA, 2018b) in order to achieve the first place. As XCC is a short time competition, a decision to remain on 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 may indicate that the athletes are more required to continually make decision 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 (KONINGS; HETTINGA, 2018b; RENFREE et al., 2014; SMITS; PEPPING; HETTINGA, 2014), 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

(GRANIER et al., 2018), during XCC, they adopted a more conservative starting pace (below average race speed) (Figure 17). This decision-making can be due to number of competitors competing within a race (KONINGS; HETTINGA, 2018a), where XCC was performed with 40, and XCO was performed with 154 participants. That is, with high number of competitors, as in XCO, athletes tend to adopt an aggressive starting. During XCO, cyclists increase speed in the initial phase in order to place themselves in the front positions for avoid crashes and congestion (GRANIER et al., 2018; VIANA et al., 2018) 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; HETTINGA, 2018a). The authors demonstrated that 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 stating required in XCO is not required in XCC. However, futures studies are encouraged for better investigate this aspect.

Although pacing refers to time and/or speed, its regulation is also dictate by the ability to resist fatigue (ABBISS; LAURSEN, 2008). Thus, examine the PO produced by the cyclists during competition is of extreme importance for better understanding the physical requirements (GRANIER et al., 2018). During XCO, it was observed a decline in the average speed after SL, which was associated with 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. (2018) 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 an aggressive starting in order to place themselves in the front positions. In contrast with XCO, our results showed that the speed fluctuations observed during XCC was not significantly correlated with PO responses ($r = 0.462$; $p = 0.249$). Perhaps a higher speed generates a smaller change in PO. That is, an increase in speed does not necessarily correspond to an increase 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 sustain high intensity effort (i.e. high PO) and a high speed to be competitive in MTB has been confirmed (PRINZ et al., 2021; VIANA et al., 2018). Nevertheless, these mechanical variables can be affected by race format (SANDERS; HEIJBOER, 2019). Our findings showed that athletes completed XCC with average PO and speed higher compared to XCO (Table 9), 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 (SANDERS; HEIJBOER, 2019). Therefore, our results indicate that XCC is the most demanding event in elite MTB in terms of speed and intensity when compared with most popular MTB event (i.e., XCO). Given such difference, 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 (GRANIER et al., 2018)]. However, cyclists of the current study had a better place in the 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 (DE PAUW et al., 2013). In relation to XCC, no study assessed PO during race. Therefore, more research are necessary to confirm our findings. Although reporting average PO is a more basic methodology (LEO et al., 2021), this method is widely adopted to describing the mechanical responses of MTB events (GRANIER et al., 2018; PRINZ et al., 2021; STAPELFELDT et al., 2004).

CA is an important factor for cycling performance that has been widely investigated in recent years (BRENNAN et al., 2019; MATER; CLOS; LEPERS, 2021). Although CA of ~60 rpm 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 rpm), as has been previously reported (BRENNAN et al., 2019). Nevertheless, we observed that cyclists adopted a CA higher during XCC. Probably, this preferred higher CA selected by the cyclists can be associate to specific demands of this competition. There is a trend of increases in CA as PO and speed increased (HANSEN; SMITH, 2009). 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 (BRENNAN et al., 2019). 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 (ANSLEY; CANGLEY, 2009). That is, cyclists adopted specific CA in response for 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 (ARGENTIN et al., 2006). Perhaps such decrease may be due to decrease force production and fatigue development (HANSEN; SMITH, 2009).

Among the limitations of this study, 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 (GRANIER et al., 2018). Therefore, we suggest that future research take this into account.

4.6 CONCLUSION

Compared to XCO, XCC was performed with higher PO, CA and speed, showing that mechanical parameters required for success in XCC are different for those required in XCO. Moreover, pacing profile adopt by professional cyclists was different between competitions. Mountain bikers therefore must incorporate in their training routine, strategies and methods specifics in order to improve their performance in each competition.

4.7 ACKNOWLEDGEMENTS

The State Funding Agency of Minas Gerais, Brazil (FAPEMIG) for the scholarship of Rhaí André Arriel e Oliveira.

5 STUDY 4 - THE RELATIVE PEAK POWER OUTPUT OF AMATEUR MOUNTAIN BIKERS IS INVERSELY CORRELATED WITH BODY FAT BUT NOT WITH FAT-FREE MASS

This study was published following peer-review.

ARRIEL, R. A. et al. The relative peak power output of amateur mountain bikers is inversely correlated with body fat but not with fat-free mass. **Motriz: Revista de Educação Física**, v. 26, 19 out. 2020.

5.1 ABSTRACT

To evaluate whether body mass (BM) and body composition may influence mountain bike cycling performance. Forty male amateur mountain bikers attended the laboratory on two non-consecutive days. At the first visit, anthropometric measures (height, BM, body fat [BF], fat-free mass [FFM] and body mass index [BMI]) and familiarization to incremental cycling test were performed. On the second visit, cyclists performed again the incremental cycling test to measure peak power output (PPO), peak power output relative to BM (PPO-BM), and time to exhaustion (TE), which were posteriorly correlated with BM and anthropometric measures. A moderate and strong significant correlation were observed between TE and BM ($p<0.01$; $r=0.40$) and FFM ($p<0.01$; $r=0.56$), respectively. Moderate significant correlation was found between PPO and BM ($p<0.01$; $r=0.45$), BMI ($p=0.03$; $r=0.35$) and strong with FFM ($p<0.01$; $r=0.59$). Also, PPO-BM significantly correlated with BM ($p=0.04$; $r=-0.31$), BMI ($p=0.02$; $r=-0.35$) and BF ($p<0.01$; $r=-0.55$). No other significant correlations were observed. Considering PPO-BM as mainly performance variable, BM and BF can be a determining factor in mountain biking performance but FFM did not.

Keywords: cyclists, performance, body composition, off-road cyclists, body mass, body mass index**.**

5.2 INTRODUCTION

Mountain biking (MTB) is an off-road cycling modality including various types of terrain and repeated up- and downhills (IMPELLIZZERI; MARCORA, 2007b). Since it was included in the Olympic Games programme, it became a more traditional and widespread sport around the world, comprising a large number of recreational, amateur and elite cyclists (IMPELLIZZERI; MARCORA, 2007b).

In this sense, the determinants of MTB performance are drawing the attention of sports scientists (ENGELBRECHT; TERBLANCHE, 2017; IMPELLIZZERI; MARCORA, 2007b; SÁNCHEZ-MUÑOZ; MUROS; ZABALA, 2018). They included technical ability, nutritional strategies, physiological aspects, and body composition (BC) (IMPELLIZZERI; MARCORA, 2007b), being the last one also a determinant of performance in various other sports modalities (BARBIERI et al., 2017; BARLOW et al., 2014; SIEGEL-TIKE et al., 2015). In sprint runners, a greater fat-free mass (FFM) and lower body fat (BF) are directly correlated with better speed performance (BARBIERI et al., 2017), and in ultra-marathon runners, body mass index (BMI) was positively correlated with the race time (KNECHTLE et al., 2011a). Lastly, in recreational male Ironman triathletes and ultra-cyclists, the percent BF was associated with total race time (RÜST et al., 2012).

Although the BC, which includes BF, FFM and both alter body mass (BM), depends on the genetic compound, this parameter can be modified accordingly physical training (MUJIKA; RØNNESTAD; MARTIN, 2016) and/or nutritional behavior (ROSSI et al., 2017). Considering that MTB performance indicators, such as power output and oxygen consumption, are more determinants when normalized by BM (IMPELLIZZERI et al., 2005b), it can be hypothesized that the BC components are relevant to success in this modality. Elite MTB athletes have a BC quite homogeneous (BEJDER et al., 2019), however, it does not occur for amateurs (SIEGEL-TIKE et al., 2015). Therefore, a BC variation of amateur cyclists can lead to a direct influence on performance.

Although their effect on road (DEL VECCHIO et al., 2019) and elite MTB (BEJDER et al., 2019) cyclists performance were presented, there is still limited evidence on amateur mountain bikers (KNECHTLE et al., 2011b; SIEGEL-TIKE et al., 2015). Therefore, considering these parameters, this study aimed to evaluate whether BC and BM influence the performance of amateur mountain bikers.

5.3 METHODS

5.3.1 Subjects

Forty male amateur mountain bikers were recruited to participate in the study. The power statistic was calculated by G*power software (FAUL et al., 2007) based on the current sample size in this study (test power = 0.63). To inclusion, they needed to have a cycling training with a minimum of 2 hours per week and achieve at least 250 W or more in the incremental test (JEUKENDRUP; CRAIG; HAWLEY, 2000). The exclusion criteria were: i) any cardiovascular, metabolic, or respiratory disease; ii) any potential substance that could improve the exercise performance; iii) musculoskeletal, bone, or joint injury that could unsettle the exercise performance; iv) caffeine supplement intake; v) smoking history. This information, as well as the information about training and cycling experience, were identified via a questionnaire. Table 10 shows the volunteers' characteristics. This study was approved by the local Ethics Committee (number 2.250.458) for human experiments and was carried out in conformity with the Declaration of Helsinki. All the volunteers were informed about the testing procedures. Furthermore, all of them provided written informed consent about the research.

Table 10 - Demographic and anthropometric characteristics of volunteers

Characteristics	**N = 40**
Age (years)	27.9 ± 4.19
Height (m)	1.75 ± 0.4
Body mass (kg)	77.8 ± 9.65
Body fat (%)	15.6 ± 4.21
Body mass index (kg/m^2)	25.3 ± 2.7
Fat-free mass (kg)	65.6 ± 7.3
Skinfolds	
Pectoral (mm)	10.6 ± 2.7
Abdominal (mm)	22.5 ± 7.4
Thigh (mm)	20.5 ± 7.4

Indices of Performance	
Time to exhaustion (s)	796.6 ± 141.8
Power output (W)	326.4 ± 53.9
Power output ($W.kg^{-1}$)	4.2 ± 0.7
Training History	
Experience (years)	5.1 ± 4.26
Hours per week	2.5 ± 0.96

Data are mean ± SD
Source: elaborated by the author (2020).

5.3.2 Experimental design

The cyclists attended the laboratory on two non-consecutive days (48 h of the interval), at the same time of day to prevent circadian influences (FERNANDES et al., 2014). All tests were performed in a controlled environment (temperature: 22.3 ± 1.5˚C; relative humidity: 72.7 ± 7.2%). At the first visit, anthropometric measures and familiarization with the incremental test were performed. At the second visit, which happened 48 hours later, they performed an incremental test for analysis. The cyclists were also asked to maintain their dietary intake throughout the experiment. They were instructed to did not perform any moderate or intense physical exercise, and not taking products with caffeine, tea and alcohol 48 h before the tests.

5.3.3 Body composition

The anthropometric dimensions were taken by an experienced and trained professional. Height (m) and BM (kg) were measured to the nearest 0.1 kg using calibrated scales and 0.5 cm using calibrated stadiometer (Health-O-Meter, model 402EXP; Badger Scale, Inc., Milwaukee, WI, USA), respectively, with participant's unshod and wearing cycling apparel. Three skinfold thicknesses (Sanny®, Brazil, precision 0.5 mm) at three sites (pectoral, abdominal, and thigh) were taken on the right side of the body. All measurements of skinfold thicknesses were taken three times in a non-consecutive way, and then the mean value was used for calculation.

BF percentage (%BF) was estimated according to Jackson and Pollock (1978). Absolute BF was determined multiplying BM by %BF divided by 100; FFM was estimated through the difference between BM (kg) and BF (kg) (BM – BF); and finally, BMI using BM divided by squared height.

5.3.4 Incremental test

The cycle ergometer (Monark 839 E, Sweden) was used in all incremental tests. The bike setup was done by the cyclists before the familiarization test and maintained during the test for analysis. Participants completed a 4-minute warm-up at 40 W. The test then started at 40 W that was increased by 20 W per min until voluntary exhaustion and the participants were required to maintain a cadence of 80-90 rpm (measured electronically). The test was terminated on voluntary exhaustion or failure to maintain the required cadence for 10 seconds, where the time to exhaustion (TE) was recorded (total exercise time performed). The peak power output (PPO) was defined by multiplying the cadence by the total load (this load indicates the force applied on the pedals to spin the flywheel that was tensioned by a broken belt connected by a pendulum weight) of the final stage. The peak power output relative to BM (PPO-BM) was measured by PPO divided by the BM of the cyclists. The incremental test procedures were based on the Arriel et al. (2018) and De Groot et al. (2010) studies.

5.3.5 Statistical analysis

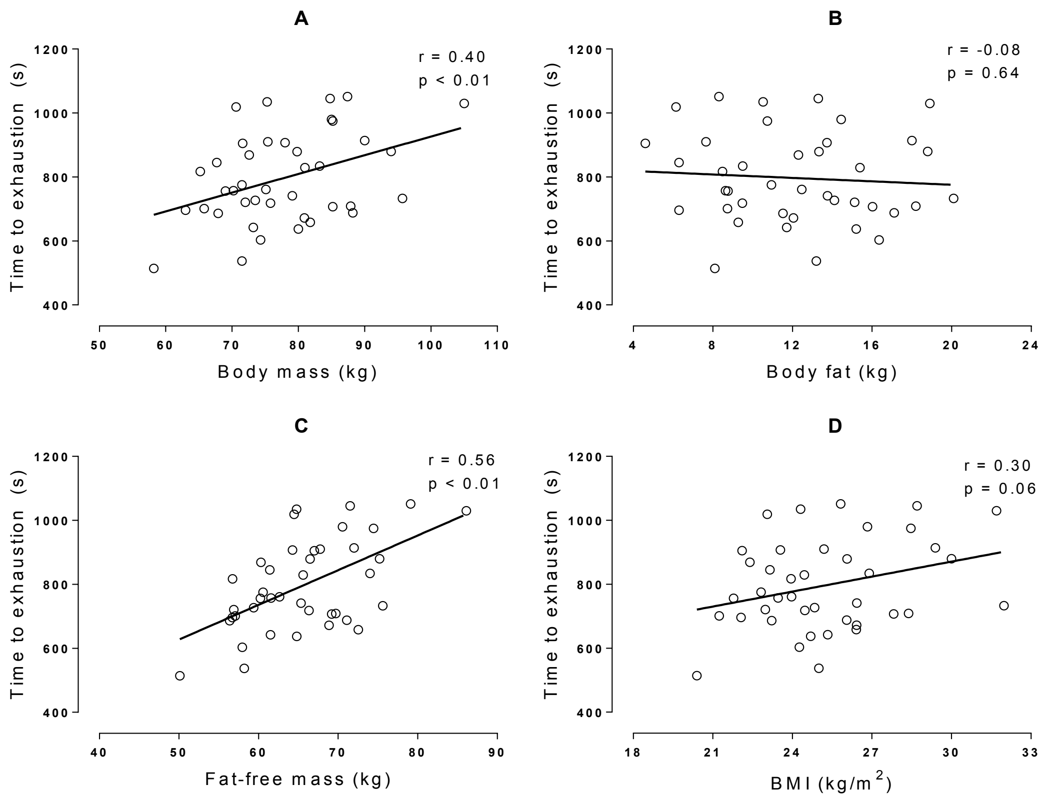
The statistical analysis was performed through software GraphPad® (Prism 6.0, San Diego, CA, USA). The Shapiro-Wilk test was used to verify the normality of the data. For measurement of the correlations between anthropometric and performance variables, Pearson´s or Kendall´s bivariate correlations test were performed, using a scale to analyze the correlation coefficient (proposed by Hopkins - www.sportsci.org), where: < 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. The level of significance adopted was ≤ 0.05.

5.4 RESULTS

The TE was significantly correlated with BM (Figure 18A) and FFM (Figure 18C) ($p < 0.05$). Although the TE did not correlate significantly with BMI (Figure 18D) (p >

0.05), there was a low correlation coefficient (r = 0.30). No significant association between TE and BF (Figure 18B) was found (p > 0.05).

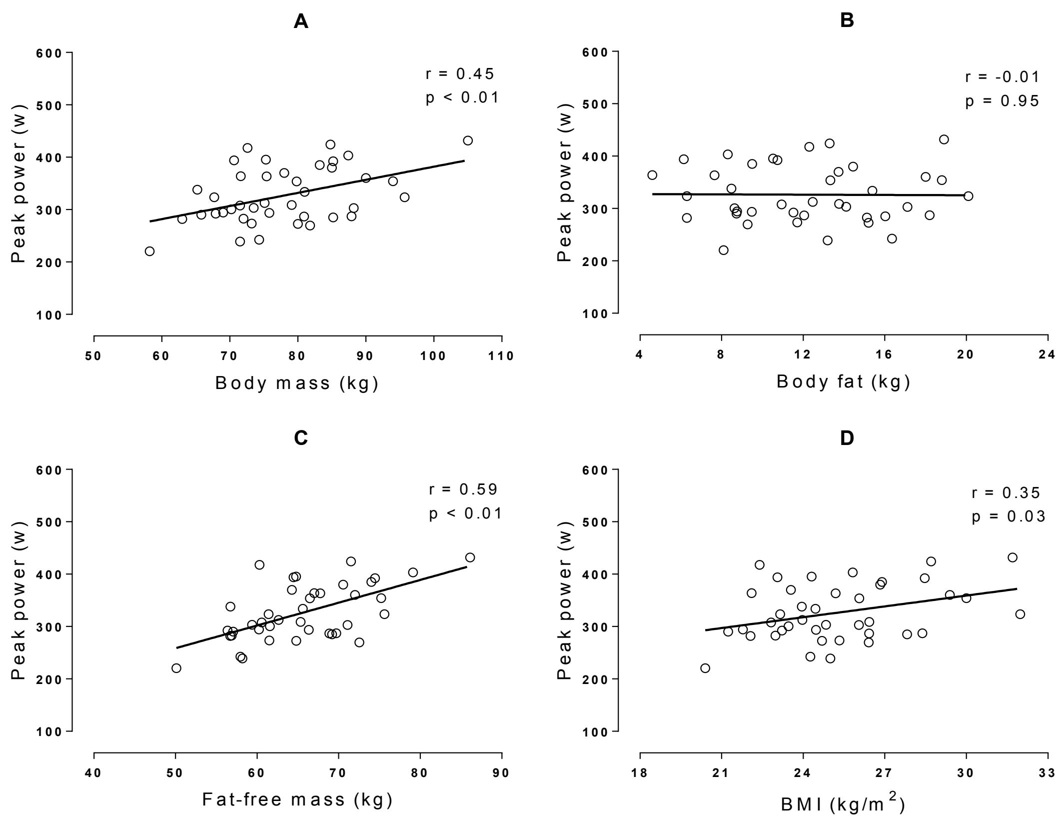
Figure 18 - Correlation between time to exhaustion and body mass (A), body fat (B), fat-free mass (C) and body mass index (BMI) (D)



The values of r and p are shown in each figure.
Source: elaborated by the author (2020).

Regarding PPO, moderate correlations were found with BM (Figure 19A) and BMI (Figure 19D), but strong to FFM (Figure 19C) (p < 0.05). No significant correlation between PPO and BF (Figure 19B) was found (p > 0.05).

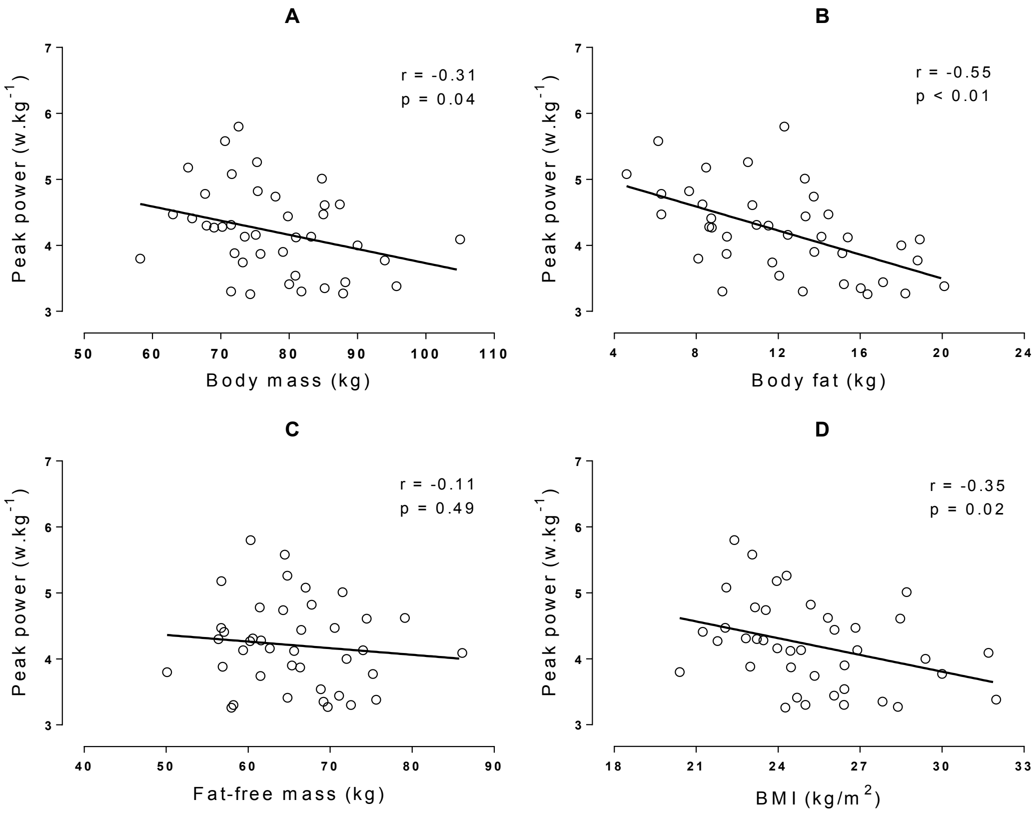
Figure 19 - Correlation between peak power output and body mass (A), body fat (B), fat-free mass (C) and body mass index (BMI) (D)



The values of r and p are shown in each figure.
Source: elaborated by the author (2020).

When peak power output was normalized to BM (PPO-BM), there was a moderate significant correlation with BM (Figure 20A) and BMI (Figure 20D), and a strong significant correlation to BF (Figure 20B) ($p < 0.05$). However, no significant correlation between PPO-BM and FFM (Figure 20C) was found.

Figure 20 - Correlation between peak power output relative to BM and body mass (A), body fat (B), fat-free mass (C) and body mass index (BMI) (D)



The values of r and p are shown in each figure.
Source: elaborated by the author (2020).

5.5 DISCUSSION

This study aimed to investigate whether BC and BM influenced the performance of amateur mountain bikers. Our findings were that some components of BC have a significant correlation with TE, PPO, and PPO-BM. In absolute values, the most significant findings were the possible influence of FFM and BM on TE and PPO. In relative values, a possible negative influence of the BM, BMI, and, mainly, BF on PPO-BM, but in FFM did not. However, it is important to highlight that indices of aerobic fitness, such as power output or oxygen uptake, when normalized to BM are more determinants of performance (IMPELLIZZERI et al., 2005b). Moreover, the incremental test performed in this study was in cycle ergometer, which considers only absolute performance values. Thus, the PPO-BM value is closest to the actual values of a field test, which considers BM. Therefore, our finds identify possible effects of BF on cycling performance of amateurs MTB athletes.

The BF is an important energetic substrate for long time exercise. However, the excess of BF leads to an increase of BM which is associated with a negative effect on anaerobic (MACIEJCZYK et al., 2015) and aerobic (MACIEJCZYK et al., 2014) exercise performance of non-professional athletes, possibly caused by a decrease of the maximal power output and maximal oxygen uptake normalized to BM, respectively. However, in elite MTB athletes, no significant correlation was found between BF and race time performance in Olympic cross-country (BEJDER et al., 2019). As observed in figure 20, the subjects with higher BF had a lower PPO-BM and the subjects with smaller BF had a higher PPO-BM. However, in figures 18 and 19, we did not find the influences of BF on TE and PPO. As the BF is a passive tissue during exercise, its excess may lead the subject to great effort on the same workload during weight-bearing activities, but without influence on stationary exercises. Thus, these results suggest that an increase in BF could negatively influence the aerobic performance of amateur MTB cyclists in field test or race time.

On the other hand, a greater in BM, resulting from an increase in muscle mass, as a consequence of anaerobic (MACIEJCZYK et al., 2015) but not aerobic (MACIEJCZYK et al., 2014) exercise performance. According to the study of Maciejczyk et al. (2014), a higher BM may be a limiting factor, regardless of BC, because substantially reduced aerobic endurance performance of recreationally active subjects, where an excess of BF or high muscle mass levels exhibited similar responses. Unlike our findings, the BF adversely affects PPO-BM, but the FFM level, which contains a high muscle mass value, did not. However, the PPO and TE were significantly correlated with FFM. Therefore, in endurance performance, the change in FFM does not seem to be a determinant factor to modify the performance of amateur MTB athletes in exercises with weight-bearing, such as field tests and MTB races. The same has been related to elite MTB athletes (BEJDER et al., 2019).

The BMI and skinfold thicknesses are the most used anthropometric indicators of BC. According to Malina (2007), BMI is reasonably well correlated with BF. However, BMI has limitations with professional and amateur athletes since this parameter did not consider the BC of the subjects, once physically active persons present a higher FFM (MACIEJCZYK et al., 2014). In this study, we found significate adverse effects on PPO-BM when correlated with BMI, BM, and BF but no significate result to FFM. The BMI

(BM/Body height^2) is influenced by BM and body height. However, as the height of the participants was well homogeneous (1.75 ± 0.4 m), the BM of the cyclists (77.8 ± 9.65 kg) had a greater influence on BMI. Therefore, during weight-bearing activities, we can suggest that a high BMI can adversely affect the performance of amateur MTB cyclists due to a high BM, probably resulting from a high BF and not FFM.

The incremental cycling test is often used in research to evaluate psychophysiological responses (ARRIEL et al., 2019; IMPELLIZZERI et al., 2005b), which are highly correlated with cycling performance (IMPELLIZZERI et al., 2005b). However, for greater accuracy in correlation analysis, especially in laboratory studies, the indices of aerobic fitness should be normalized to BM. In our study, the BM influenced TE and PPO positively, but PPO-BM negatively. Probably this fact happened because the tests performed on cycle ergometers do not consider BM. In this way when the indices of aerobic fitness are normalized to BM, the results are different compared to non-normalized. To confirm this, Siegel-Tike et al. (2015), investigating the relationship of the BC parameters on recreational trained cyclists performance, found a strong significant correlation between relative maximal oxygen uptake (i.e. ml/kg/min) and BF ($r = -0.81$; $p < 0.05$). However, no correlation was found between PPO and BF ($r = 0.19$; $p > 0.05$). The same happened for muscle mass. Although our study did not evaluate maximal oxygen uptake, considering the BF, the result is in line with our finding when considered the PPO but not when considered PPO-BM. Moreover, Lee et al. (2002) found no differences between elite mountain bikers and professional road cyclists in maximal oxygen uptake, PPO, and the lactate threshold expressed in absolute values. However, the same variables, when normalized to BM, presented higher values to mountain bikers. These results confirm the importance of relative parameters to BM in elite (IMPELLIZZERI; MARCORA, 2007b) and amateur mountain bikers.

5.5.1 Limitations

The variability of the methods used for BC estimation could be highlighted as a limitation of this study since there are more precise methods. Skinfolds method presents a low cost and it is more feasible (JACKSON; POLLOCK, 1978). However, for not measuring the FFM components (such as water, mineral, protein, and additional minor constituents), this model may present some limitations when compared with a more current model of four-compartment (SILVA et al., 2009). In this way, the within-subject differences, particularly in the proportion of water and mineral, can interfere in FFM measurement. Thus, the correlation between indices of performance (such as TE, PPO, and PPO-BM) and FFM should be analyzed with caution.

Other tests, as Wingate (INOUE et al., 2012) and time trial (BURT; TWIST, 2011), can also measure performance. However, the characteristics of each test (i.e. time, intensity, and environment) may influence the relationship between BC and exercise performance. For example, anaerobic power performance is not affected by an increase in BM resulting only from an increased FFM (MACIEJCZYK et al., 2015), but maybe a limiting factor to aerobic performance (MACIEJCZYK et al., 2014). In this study, we correlate BC with TE and PPO values that are above of lactate threshold and below the maximal power anaerobic achieved in short-time exercise, which is crucial for MTB performance (IMPELLIZZERI; MARCORA, 2007b; INOUE et al., 2012). Therefore, the results of this study should not be generalized.

Lastly, it is important to highlight that, as related by Impellizzeri et al. (2005b), significant positive or negative correlation does not imply causality. Therefore, futures experimental studies should investigate whether the changes in BM or BC components lead to changes in the performance of mountain bikers.

5.5.2 Practical applications

Considering our results, changes in BM and BC (in order to reduce the fat mass that is a passive tissue during pedaling exercise) may be effective at improving MTB performance due to an increase in PPO-BM. However, the FFM should be maintained because, although this variable may increase BM, it is an important tissue to optimize power output in a short time duration such as sprints and technical climbs. In this hand, the nutrition strategy and the resistance training, as the main strategy to increase or maintain FFM and maximal force, should be included in the training routine of MTB amateur athletes.

5.6 CONCLUSION

The body mass and body composition could be determinant for mountain biking performance, where body fat influenced negatively the performance of amateur mountain bikers but the fat-free mass did not.

5.7 ACKNOWLEDGEMENTS

The authors would like to thank the Federal University of Juiz de Fora for the support given to the study.

6 INSIGHTS FOR FUTURES RESEARCH AND FINAL CONSIDERATIONS

6.1 INSIGHTS FOR FUTURES RESEARCH

In general, despite increasing investigations related to MTB, most of them have explored the characteristics and demands of the XCO competition. Therefore, future studies should investigate these important factors to performance in other XC events. Moreover, number of studies conducted with women XC cyclists is limited, assuming unsatisfactory conclusions for this population.

Regarding bicycles, we should have caution with the results. The most of studies explored benefits of the bike components, such as suspension, wheel diameter, crank systems and dropper seatpost on the circuits with similar XC-MTB characteristics. However, number of laps, total time and total distance of the XC events can be significantly lower or higher than those explored by the studies. Therefore, further investigations are need to explore benefits of this components taking into account the characteristic of each XC-MTB.

Acute and overuse injuries associated with MTB were reported. However, there is still a lack of data about these injuries in XC events, considering all cyclists' level performance. Perhaps the evolution of the bicycle components as well as the improvement of protective equipment and the training program quality have influenced the risk, severity and number of accidents.

Among investigations presented here, XCC studies are the first to investigate important factors to overall performance within topic. In this context, new studies are necessary to provide information more precise on this event. For example, there is a lack of evidences on physiological responses and mechanical demands in the XCC race format, such as relative and absolute intensity over the races, time spent within different intensity zones, number of efforts performed above MOP, among other factors. This information provide important insights for cyclists determine training and competition strategies to improve their performance in XCC.

Lastly, despite the existence of an association between XC-MTB performance measures and body composition of XC cyclists, the development of experimental studies could better clarify the probable relationship of cause and effect between these parameters.

6.2 FINAL CONSIDERATIONS

The purpose of this thesis was to provide a current perspective of MTB-XC and increase the knowledge on XC events as well as on relationship between BC and measures related to XC-MTB performance. For this, four studies were development. The review study showed that the number of events within XC-MTB have been increased and its rules and race format have been modified along the years. Nonetheless, the most relevant studies on XC-MTB have focused on XCO, but few or no study was conducted to analyzed relevant factors to performance in XCS, XCM and XCC. In XCO, evidences show that the total race time was reduced over the years, but average intensity of the competition and the time spent at the high intensity (above the second threshold) were significantly increased. In general, ~43% and ~46% of the total time of the XCO is spend at high (above second threshold) and low intensity (below first threshold), respectively, with a high PO and CA variation. In addition, the cyclists tend to adopt a higher speed / PO (above the average race speed / PO) at the beginning of the competition and they perform a high number of efforts of short duration at intensity above the MOP (> 300 efforts), showing the importance of the ability to produce high PO in a shorter time, where the non-oxidative metabolism is essential. In XCS, the most of the time is spent at low and moderate intensity, resulting in a lower average intensity when compared with XCO. Furthermore, the time spend in high intensity is reduced throughout the competition, probably due to the fatigue accumulation. Therefore, the capacity to sustain submaximal PO during several hours may be more meaningful to performance than high capacity to sustain multiple efforts in high intensity (above second threshold) to obtain success in XCS competition. In relation to XCM and XCC, no study was conducted to analyze these responses during these competitions. Lastly, when compared to slower cyclist, it was noted that the faster cyclists have a higher ability to perform technical and / or non-technical climbs on the circuits of XCO and XCM competitions.

The review study also analyzed the general characteristics of the XC cyclists, such as physiological and anthropometric measures, bike components and the main injuries in XC-MTB. It was observed that the general characteristics of the XC cyclists differ according to their level performance. Compared with trained, the professional cyclists have a higher VO_{2max} and MOP, but a lower BM and BF. Moreover, professional cyclists have a higher ability to produce high PO within a short time, which is associated with race time in some XC-MTB events. Thus, we suggest that cyclists and coaches should pay attention to these parameters during the cyclist's physical preparation process to compete at a high level in XC-MTB. The effects of the bike components on the performance of XC-MTB cyclists were also analyzed. Limited evidence indicate that bicycle equipped with 29" wheel promotes more performance and FS frame more comfort throughout pedaling on the circuits with characteristics of the XC-MTB. Additionally, FS bike seems to reduce muscle stress, mitigating exercise-induced muscle damage. In this context, we can suggest that the FS bicycle can be the better choice to compete events of long duration, such as XCM and XCS. However, more studies should be conducted taken into account the characteristics of each XC event. Other bike components, such as gear systems and drop seatpost, can be effectives, but its effects on the physiological, perceptual and performance responses should be examined in the future. Lastly, in relation to acute and overuse injuries in XC-MTB, it was observed that the loss of bike control is the main cause of fall that lead to acute injuries, such as skin contusion, bone, soft tissue, head/neck and spinal cord fractures, while the accumulated stress in a certain body region induces overuse injury, which normally affect the neck, hand/wrist, low back and knees. In this sense, the use of accident prevention measures, protective equipment and alternatives as bike fit and resistance training can be effective in reducing the risk of these injuries.

The pacing profile adopted by professional XC-MTB cyclists and their performance in different sections across the laps during an XCC event were also examined in this thesis. It was noted that the faster cyclists adopted a more even pacing profile and were faster than their opponent who finished in the lower positions during a non-technical sustained climbing section of the circuit, which appear to be a characteristic this event. Therefore, it is recommended that cyclists improvement their speed adjustments and non-technical sustained climbing ability across the laps to obtain success in XCC. Additionally, it is important to highlight that pacing profile and mechanical parameters, such as speed, PO and CA adopted by cyclists are different between XCC and XCO. In this sense, mountain bikers must develop specific strategy and training methods in order to obtain success in each competition.

Finally, both BM and BC are determinants factors to XC-MTB performance. In addition to BM, BF was negatively correlated with measures related to XC-MTB performance, but BFF did not. In this respect, it is recommended that cyclists decrease BM through reduction in BF. Although a reduction in BM can be achieved by decreasing FFM, this alteration should be evaluated with caution, because FFM is an important factor to optimize PO that is a measure related to XC-MTB performance.

REFERENCES

ABBISS, C. R. et al. The distribution of pace adopted by cyclists during a cross-country mountain bike World Championships. **Journal of Sports Sciences**, v. 31, n. 7, p. 787–794, 2013.

ABBISS, C. R. et al. Role of Ratings of Perceived Exertion during Self-Paced Exercise: What are We Actually Measuring? **Sports Medicine (Auckland, N.Z.)**, v. 45, n. 9, p. 1235–1243, set. 2015.

ABBISS, C. R.; LAURSEN, P. B. Describing and understanding pacing strategies during athletic competition. **Sports Medicine (Auckland, N.Z.)**, v. 38, n. 3, p. 239–252, 2008.

ADAMO, D. E.; MARTIN, B. J.; JOHNSON, P. W. Vibration-induced muscle fatigue, a possible contribution to musculoskeletal injury. **European Journal of Applied Physiology**, v. 88, n. 1–2, p. 134–140, nov. 2002.

ANSARI, M.; NOURIAN, R.; KHODAEE, M. Mountain Biking Injuries. **Current Sports Medicine Reports**, v. 16, n. 6, p. 404–412, dez. 2017.

ANSLEY, L.; CANGLEY, P. Determinants of “optimal” cadence during cycling. **European Journal of Sport Science**, v. 9, n. 2, p. 61–85, 1 mar. 2009.

ARGENTIN, S. et al. Relation between preferred and optimal cadences during two hours of cycling in triathletes. **British Journal of Sports Medicine**, v. 40, n. 4, p. 293–298; discussion 298, abr. 2006.

ARRIEL, R. A. et al. Declines in exercise performance are prevented 24 hours after post-exercise ischemic conditioning in amateur cyclists. **PloS One**, v. 13, n. 11, p. e0207053, 2018.

ARRIEL, R. A. et al. Ischemic preconditioning delays the time of exhaustion in cycling performance during the early but not in the late phase. **Motriz: Revista de Educação Física**, v. 25, n. 1, 2019.

ARRIEL, R. A. et al. The relative peak power output of amateur mountain bikers is inversely correlated with body fat but not with fat-free mass. **Motriz: Revista de Educação Física**, v. 26, 19 out. 2020.

BARBIERI, D. et al. Body composition and size in sprint athletes. **The Journal of Sports Medicine and Physical Fitness**, v. 57, n. 9, p. 1142–1146, set. 2017.
BARLOW, M. J. et al. Anthropometric variables and their relationship to performance and ability in male surfers. **European Journal of Sport Science**, v. 14 Suppl 1, p. S171-177, 2014.

BARON, R. Aerobic and anaerobic power characteristics of off-road cyclists. **Medicine and Science in Sports and Exercise**, v. 33, n. 8, p. 1387–1393, ago. 2001.

BAZAŃSKA-JANAS, M.; JANAS, M. Changes in Physical Performance of Amateur Mountain Bikers in the Preparatory Period. **Polish Journal of Sport & Tourism**, v. 27, n. 1, p. 3–8, mar. 2020.

BEJDER, J. et al. Physiological determinants of elite mountain bike cross-country Olympic performance. **Journal of Sports Sciences**, v. 37, n. 10, p. 1154–1161, maio 2019.

BOPP, M.; SIMS, D.; PIATKOWSKI, D. **Bicycling for Transportation: An Evidence-Base for Communities**. [s.l.] Elsevier, 2018.

BRENNAN, S. F. et al. The Effect of Cadence on the Mechanics and Energetics of Constant Power Cycling. **Medicine and Science in Sports and Exercise**, v. 51, n. 5, p. 941–950, maio 2019.

BROCHERIE, F. et al. Influence of environmental factors on Olympic cross-country mountain bike performance. **Temperature (Austin, Tex.)**, v. 7, n. 2, p. 149–156, 2020.

BUCHHOLTZ, K. et al. Incidence of Injuries, Illness and Related Risk Factors in Cross-Country Marathon Mountain Biking Events: A Systematic Search and Review. **Sports Medicine - Open**, v. 7, n. 1, p. 68, 25 set. 2021.

BURT, D. G.; TWIST, C. The effects of exercise-induced muscle damage on cycling time-trial performance. **Journal of Strength and Conditioning Research**, v. 25, n. 8, p. 2185–2192, ago. 2011.

CHOW, T. K.; KRONISCH, R. L. Mechanisms of injury in competitive off-road bicycling. **Wilderness & Environmental Medicine**, v. 13, n. 1, p. 27–30, 2002.

COSTA, V. P. et al. Test-retest reliability and validity of the Stages mountain bike power meter. **Isokinetics & Exercise Science**, v. 27, n. 1, p. 55–61, mar. 2019.

CRAMP, T. et al. Effects of preexercise carbohydrate ingestion on mountain bike performance. **Medicine and Science in Sports and Exercise**, v. 36, n. 9, p. 1602–1609, set. 2004.

D JACOBS, R. et al. The effect of cadence on cycling efficiency and local tissue oxygenation. **Journal of Strength and Conditioning Research**, v. 27, n. 3, p. 637–642, mar. 2013.

DE GROOT, P. C. E. et al. Ischemic preconditioning improves maximal performance in humans. **European Journal of Applied Physiology**, v. 108, n. 1, p. 141–146, jan. 2010.

DE PAUW, K. et al. Guidelines to classify subject groups in sport-science research. **International Journal of Sports Physiology and Performance**, v. 8, n. 2, p. 111–122, mar. 2013.

DEL VECCHIO, L. et al. Effects of Combined Strength and Sprint Training on Lean Mass, Strength, Power, and Sprint Performance in Masters Road Cyclists. **Journal of Strength and Conditioning Research**, v. 33, n. 1, p. 66–79, jan. 2019.

DODWELL, E. R. et al. Spinal column and spinal cord injuries in mountain bikers: a 13-year review. **The American Journal of Sports Medicine**, v. 38, n. 8, p. 1647–1652, ago. 2010.

EDWARDS, A. M.; POLMAN, R. C. J. Pacing and awareness: brain regulation of physical activity. **Sports Medicine (Auckland, N.Z.)**, v. 43, n. 11, p. 1057–1064, nov. 2013.

ENGELBRECHT, L.; TERBLANCHE, E. Physiological performance predictors in mountain bike multi-stage races. **The Journal of Sports Medicine and Physical Fitness**, 28 abr. 2017.

FAISS, R. et al. The effect of mountain bike suspensions on vibrations and off-road uphill performance. **The Journal of Sports Medicine and Physical Fitness**, v. 47, n. 2, p. 151–158, jun. 2007.

FAUL, F. et al. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. **Behavior Research Methods**, v. 39, n. 2, p. 175–191, maio 2007.

FERNANDES, A. L. et al. Effect of time of day on performance, hormonal and metabolic response during a 1000-M cycling time trial. **PloS One**, v. 9, n. 10, p. e109954, 2014.

FRANK, E.; HERMANUTZ, F.; BUCHMEISER, M. R. Carbon Fibers: Precursors, Manufacturing, and Properties. **Macromolecular Materials and Engineering**, v. 297, n. 6, p. 493–501, 2012.

GANDIA SORIANO, A. et al. Effect of cycling specialization on effort and physiological responses to uphill and flat cycling at similar intensity. **European Journal of Sport Science**, v. 21, n. 6, p. 854–860, jun. 2021.

GRANIER, C. et al. Power Output and Pacing During International Cross-Country Mountain Bike Cycling. **International Journal of Sports Physiology and Performance**, v. 13, n. 9, p. 1243–1249, 1 out. 2018.

GREGORY, J.; JOHNS, D. P.; WALLS, J. T. Relative vs. absolute physiological measures as predictors of mountain bike cross-country race performance. **Journal of Strength and Conditioning Research**, v. 21, n. 1, p. 17–22, fev. 2007.

HANSEN, E. A.; SMITH, G. Factors affecting cadence choice during submaximal cycling and cadence influence on performance. **International Journal of Sports Physiology and Performance**, v. 4, n. 1, p. 3–17, mar. 2009.

HEBISZ, R. et al. Peak oxygen uptake in a sprint interval testing protocol vs. maximal oxygen uptake in an incremental testing protocol and their relationship with cross-country mountain biking performance. **Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition Et Metabolisme**, v. 42, n. 4, p. 371–376, abr. 2017.

HEBISZ, R. et al. Predicting Changes in Maximal Oxygen Uptake in Response to Polarized Training (Sprint Interval Training, High-Intensity Interval Training, and Endurance Training) in Mountain Bike Cyclists. **Journal of Strength and Conditioning Research**, 24 abr. 2020.

HERRICK, J. E. et al. Comparison of physiological responses and performance between mountain bicycles with differing suspension systems. **International Journal of Sports Physiology and Performance**, v. 6, n. 4, p. 546–558, dez. 2011.

HURST, H. T. et al. The effect of mountain bike wheel size on cross-country performance. **Journal of Sports Sciences**, v. 35, n. 14, p. 1349–1354, jul. 2017a.

HURST, H. T. et al. Influence of wheel size on muscle activity and tri-axial accelerations during cross-country mountain biking. **Journal of Sports Sciences**, v. 35, n. 14, p. 1342–1348, 15 jul. 2017b.

IMPELLIZZERI, F. et al. Exercise intensity during off-road cycling competitions. **Medicine and Science in Sports and Exercise**, v. 34, n. 11, p. 1808–1813, nov. 2002.

IMPELLIZZERI, F. M. et al. Physiological correlates to off-road cycling performance. **Journal of Sports Sciences**, v. 23, n. 1, p. 41–47, jan. 2005a.

IMPELLIZZERI, F. M. et al. Correlations between physiological variables and performance in high level cross country off road cyclists. **British Journal of Sports Medicine**, v. 39, n. 10, p. 747–751, out. 2005b.

IMPELLIZZERI, F. M.; MARCORA, S. M. The physiology of mountain biking. **Sports Medicine (Auckland, N.Z.)**, v. 37, n. 1, p. 59–71, 2007a.

IMPELLIZZERI, F. M.; MARCORA, S. M. The physiology of mountain biking. **Sports Medicine (Auckland, N.Z.)**, v. 37, n. 1, p. 59–71, 2007b.

INOUE, A. et al. Relationship between anaerobic cycling tests and mountain bike cross-country performance. **Journal of Strength and Conditioning Research**, v. 26, n. 6, p. 1589–1593, jun. 2012.

INOUE, A. et al. Effects of Sprint versus High-Intensity Aerobic Interval Training on Cross-Country Mountain Biking Performance: A Randomized Controlled Trial. **PLoS ONE**, v. 11, n. 1, 20 jan. 2016.

INOUE, A. et al. Correlation between economy/efficiency and mountain biking cross-country race performance. **European Journal of Sport Science**, p. 1–8, 1 set. 2021.

JACKSON, A. S.; POLLOCK, M. L. Generalized equations for predicting body density of men. **The British Journal of Nutrition**, v. 40, n. 3, p. 497–504, nov. 1978.

JEUKENDRUP, A. E.; CRAIG, N. P.; HAWLEY, J. A. The bioenergetics of World Class Cycling. **Journal of Science and Medicine in Sport**, v. 3, n. 4, p. 414–433, dez. 2000.

KNECHTLE, B. et al. What is associated with race performance in male 100-km ultra-marathoners--anthropometry, training or marathon best time? **Journal of Sports Sciences**, v. 29, n. 6, p. 571–577, mar. 2011a.

KNECHTLE, B. et al. Personal best time and training volume, not anthropometry, is related to race performance in the “Swiss Bike Masters” mountain bike ultramarathon. **Journal of Strength and Conditioning Research**, v. 25, n. 5, p. 1312–1317, maio 2011b.

KONINGS, M. J. et al. The behavior of an opponent alters pacing decisions in 4-km cycling time trials. **Physiology & Behavior**, v. 158, p. 1–5, 1 maio 2016.

KONINGS, M. J.; HETTINGA, F. J. The Impact of Different Competitive Environments on Pacing and Performance. **International Journal of Sports Physiology and Performance**, v. 13, n. 6, p. 701–708, 1 jul. 2018a.

KONINGS, M. J.; HETTINGA, F. J. Pacing Decision Making in Sport and the Effects of Interpersonal Competition: A Critical Review. **Sports Medicine (Auckland, N.Z.)**, v. 48, n. 8, p. 1829–1843, ago. 2018b.

KRONISCH, R. L. et al. Acute injuries in off-road bicycle racing. **The American Journal of Sports Medicine**, v. 24, n. 1, p. 88–93, fev. 1996.

KRONISCH, R. L.; PFEIFFER, R. P. Mountain biking injuries: an update. **Sports Medicine (Auckland, N.Z.)**, v. 32, n. 8, p. 523–537, 2002.

LEBEC, M. T.; COOK, K.; BAUMGARTEL, D. Overuse Injuries Associated with Mountain Biking: Is Single-Speed Riding a Predisposing Factor? **Sports**, v. 2, n. 1, p. 1–13, mar. 2014.

LEE, H. et al. Physiological characteristics of successful mountain bikers and professional road cyclists. **Journal of Sports Sciences**, v. 20, n. 12, p. 1001–1008, dez. 2002.

LEO, P. et al. Power profiling and the power-duration relationship in cycling: a narrative review. **European Journal of Applied Physiology**, 27 out. 2021.

LUCÍA, A.; HOYOS, J.; CHICHARRO, J. L. Preferred pedalling cadence in professional cycling. **Medicine and Science in Sports and Exercise**, v. 33, n. 8, p. 1361–1366, ago. 2001.

MACDERMID, P. W. et al. The impact of uphill cycling and bicycle suspension on downhill performance during cross-country mountain biking. **Journal of Sports Sciences**, v. 35, n. 14, p. 1355–1363, jul. 2017.

MACDERMID, P. W.; FINK, P. W.; STANNARD, S. R. Transference of 3D accelerations during cross country mountain biking. **Journal of Biomechanics**, v. 47, n. 8, p. 1829–1837, 3 jun. 2014.

MACDERMID, P. W.; MORTON, R. H. A longitudinal analysis of start position and the outcome of World Cup cross-country mountain bike racing. **Journal of Sports Sciences**, v. 30, n. 2, p. 175–182, 2012.

MACDERMID, P. W.; STANNARD, S. Mechanical work and physiological responses to simulated cross country mountain bike racing. **Journal of Sports Sciences**, v. 30, n. 14, p. 1491–1501, 2012.

MACIEJCZYK, M. et al. Effect of body composition on respiratory compensation point during an incremental test. **Journal of Strength and Conditioning Research**, v. 28, n. 7, p. 2071–2077, jul. 2014.

MACIEJCZYK, M. et al. Influence of increased body mass and body composition on cycling anaerobic power. **Journal of Strength and Conditioning Research**, v. 29, n. 1, p. 58–65, jan. 2015.

MACRAE HS-H, NULL; HISE, K. J.; ALLEN, P. J. Effects of front and dual suspension mountain bike systems on uphill cycling performance. **Medicine and Science in Sports and Exercise**, v. 32, n. 7, p. 1276–1280, jul. 2000.

MALINA, R. M. Body composition in athletes: assessment and estimated fatness. **Clinics in Sports Medicine**, v. 26, n. 1, p. 37–68, jan. 2007.

MARTIN, L. et al. Even between-lap pacing despite high within-lap variation during mountain biking. **International Journal of Sports Physiology and Performance**, v. 7, n. 3, p. 261–270, set. 2012.

MATER, A.; CLOS, P.; LEPERS, R. Effect of Cycling Cadence on Neuromuscular Function: A Systematic Review of Acute and Chronic Alterations. **International Journal of Environmental Research and Public Health**, v. 18, n. 15, p. 7912, 26 jul. 2021.

MIGNOT, J.-F. The History of Professional Road Cycling. Em: VAN REETH, D.; LARSON, D. J. (Eds.). **The Economics of Professional Road Cycling**. Sports Economics, Management and Policy. Cham: Springer International Publishing, 2016. p. 7–31.

MORENO MAÑAS, E. et al. The effect of 26 versus 29-inch wheel diameter in the transmission of vibrations in cross-country mountain biking. **Sports Biomechanics**, p. 1–12, 25 ago. 2021.

MOSS, S. L. et al. Pacing during a cross-country mountain bike mass-participation event according to race performance, experience, age and sex. **European Journal of Sport Science**, v. 19, n. 6, p. 793–801, jul. 2019.

MUJIKA, I.; RØNNESTAD, B. R.; MARTIN, D. T. Effects of Increased Muscle Strength and Muscle Mass on Endurance-Cycling Performance. **International Journal of Sports Physiology and Performance**, v. 11, n. 3, p. 283–289, abr. 2016.

MUKAKA, M. A. **Statistics corner: A guide to appropriate use of correlation coefficient in medical research**. Disponível em: <https://pubmed.ncbi.nlm.nih.gov/23638278/>. Acesso em: 2 dez. 2020.

NIELENS, H.; LEJEUNE, T. Bicycle shock absorption systems and energy expended by the cyclist. **Sports Medicine (Auckland, N.Z.)**, v. 34, n. 2, p. 71–80, 2004.

NIELENS, H.; LEJEUNE, T. M. Energy cost of riding bicycles with shock absorption systems on a flat surface. **International Journal of Sports Medicine**, v. 22, n. 6, p. 400–404, ago. 2001.

NIMMERICHTER, A. et al. Evaluation of a field test to assess performance in elite cyclists. **International Journal of Sports Medicine**, v. 31, n. 3, p. 160–166, mar. 2010.

NIMMERICHTER, A. et al. Effects of low and high cadence interval training on power output in flat and uphill cycling time-trials. **European Journal of Applied Physiology**, v. 112, n. 1, p. 69–78, 1 jan. 2012.

NISHII, T.; UMEMURA, Y.; KITAGAWA, K. Full suspension mountain bike improves off-road cycling performance. **The Journal of Sports Medicine and Physical Fitness**, v. 44, n. 4, p. 356–360, dez. 2004.

NOAKES, T. D.; PELTONEN, J. E.; RUSKO, H. K. Evidence that a central governor regulates exercise performance during acute hypoxia and hyperoxia. **The Journal of Experimental Biology**, v. 204, n. Pt 18, p. 3225–3234, set. 2001.

NOVAK, A. R. et al. A multidimensional approach to performance prediction in Olympic distance cross-country mountain bikers. **Journal of Sports Sciences**, v. 36, n. 1, p. 71–78, jan. 2018.

PAGEAUX, B. The psychobiological model of endurance performance: an effort-based decision-making theory to explain self-paced endurance performance. **Sports Medicine (Auckland, N.Z.)**, v. 44, n. 9, p. 1319–1320, set. 2014.

PASSFIELD, L. et al. Knowledge is power: Issues of measuring training and performance in cycling. **Journal of Sports Sciences**, v. 35, n. 14, p. 1426–1434, jul. 2017.

PRINS, L.; TERBLANCHE, E.; MYBURGH, K. H. Field and laboratory correlates of performance in competitive cross-country mountain bikers. **Journal of Sports Sciences**, v. 25, n. 8, p. 927–935, jun. 2007.

PRINZ, B. et al. Aerobic and Anaerobic Power Distribution During Cross-Country Mountain Bike Racing. **International Journal of Sports Physiology and Performance**, p. 1–6, 12 abr. 2021.

REINPÕLD, K.; BOSSI, A. H.; HOPKER, J. G. What Does It Take to Complete the Cape Epic? **Journal of Strength and Conditioning Research**, 19 ago. 2021.

RENFREE, A. et al. Application of decision-making theory to the regulation of muscular work rate during self-paced competitive endurance activity. **Sports Medicine (Auckland, N.Z.)**, v. 44, n. 2, p. 147–158, fev. 2014.

RENFREE, A.; CRIVOI DO CARMO, E.; MARTIN, L. The influence of performance level, age and gender on pacing strategy during a 100-km ultramarathon. **European Journal of Sport Science**, v. 16, n. 4, p. 409–415, 2016.

ROSSI, F. E. et al. The Effects of a Sports Nutrition Education Intervention on Nutritional Status, Sport Nutrition Knowledge, Body Composition, and Performance during Off Season Training in NCAA Division I Baseball Players. **Journal of Sports Science & Medicine**, v. 16, n. 1, p. 60–68, mar. 2017.

RÜST, C. A. et al. A comparison of anthropometric and training characteristics among recreational male Ironman triathletes and ultra-endurance cyclists. **The Chinese Journal of Physiology**, v. 55, n. 2, p. 114–124, 30 abr. 2012.

SÁNCHEZ-MUÑOZ, C.; MUROS, J. J.; ZABALA, M. World and Olympic mountain bike champions' anthropometry, body composition and somatotype. **The Journal of Sports Medicine and Physical Fitness**, v. 58, n. 6, p. 843–851, jun. 2018.

SANDERS, D.; HEIJBOER, M. Physical demands and power profile of different stage types within a cycling grand tour. **European Journal of Sport Science**, v. 19, n. 6, p. 736–744, jul. 2019.

SEIFERT, J. G. et al. The effects of mountain bike suspension systems on energy expenditure, physical exertion, and time trial performance during mountain bicycling. **International Journal of Sports Medicine**, v. 18, n. 3, p. 197–200, abr. 1997.

SEWALL, K. A.; FERNHALL, B. Physiological characteristics and their relationship to performance in off-road cycling. **Sports Medicine, Training & Rehabilitation**, v. 6, n. 2, p. 89–95, ago. 1995.

SIEGEL-TIKE, P. et al. [BODY COMPOSITION PARAMETERS AND RELATIONSHIP WITH THE MAXIMAL AEROBIC POWER IN RECREATIONAL CYCLISTS]. **Nutricion Hospitalaria**, v. 32, n. 5, p. 2223–2227, 1 nov. 2015.

SILVA, A. M. et al. Are skinfold-based models accurate and suitable for assessing changes in body composition in highly trained athletes? **Journal of Strength and Conditioning Research**, v. 23, n. 6, p. 1688–1696, set. 2009.

SMEKAL, G. et al. Physiological Demands of Simulated Off-Road Cycling Competition. **Journal of Sports Science & Medicine**, v. 14, n. 4, p. 799–810, dez. 2015.

SMITS, B. L. M.; PEPPING, G.-J.; HETTINGA, F. J. Pacing and decision making in sport and exercise: the roles of perception and action in the regulation of exercise intensity. **Sports Medicine (Auckland, N.Z.)**, v. 44, n. 6, p. 763–775, jun. 2014.

ST CLAIR GIBSON, A. et al. The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. **Sports Medicine (Auckland, N.Z.)**, v. 36, n. 8, p. 705–722, 2006a.

ST CLAIR GIBSON, A. et al. The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. **Sports Medicine (Auckland, N.Z.)**, v. 36, n. 8, p. 705–722, 2006b.

STAPELFELDT, B. et al. Workload demands in mountain bike racing. **International Journal of Sports Medicine**, v. 25, n. 4, p. 294–300, maio 2004.

STEINER, T. et al. Performance differences when using 26- and 29-inch-wheel bikes in Swiss National Team cross-country mountain bikers. **Journal of Sports Sciences**, v. 34, n. 15, p. 1438–1444, ago. 2016.

STOOP, R. et al. Acute Injuries in Male Elite and Amateur Mountain Bikers: Results of a Survey. **Journal of Sports Science & Medicine**, v. 18, n. 2, p. 207–212, 1 jun. 2019.

THOMAS, K. et al. The effect of an even-pacing strategy on exercise tolerance in well-trained cyclists. **European Journal of Applied Physiology**, v. 113, n. 12, p. 3001–3010, dez. 2013.

TITLESTAD, J. et al. Effect of suspension systems on the physiological and psychological responses to sub-maximal biking on simulated smoothand bumpy tracks. **Journal of Sports Sciences**, v. 24, n. 2, p. 125–135, fev. 2006.

ULMER, H. V. Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback. **Experientia**, v. 52, n. 5, p. 416–420, 15 maio 1996.

VIANA, B. F. et al. Pacing Strategy During Simulated Mountain Bike Racing. **International Journal of Sports Physiology and Performance**, v. 13, n. 2, p. 208–213, 1 fev. 2018.

VIANA, B. F.; INOUE, A.; SANTOS, T. M. The influence of start position on even-pacing strategy in mountain bike racing. **International Journal of Sports Physiology and Performance**, v. 8, n. 4, p. 351, jul. 2013.

VIELLEHNER, J.; POTTHAST, W. The Effect of Cycling-specific Vibration on Neuromuscular Performance. **Medicine and Science in Sports and Exercise**, v. 53, n. 5, p. 936–944, 1 maio 2021.

WILBER, R. L. et al. Physiological profiles of elite off-road and road cyclists. **Medicine and Science in Sports and Exercise**, v. 29, n. 8, p. 1090–1094, ago. 1997.

WIRNITZER, K. C.; KORNEXL, E. Exercise intensity during an 8-day mountain bike marathon race. **European Journal of Applied Physiology**, v. 104, n. 6, p. 999–1005, dez. 2008.

ZARZECZNY, R.; PODLEŚNY, M.; POLAK, A. Anaerobic capacity of amateur mountain bikers during the first half of the competition season. **Biology of Sport**, v. 30, n. 3, p. 189–194, set. 2013.

APPENDIX A - EVIDENCE OF PUBLICATION: STUDY 1

International Journal of
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Review

Current Perspectives of Cross-Country Mountain Biking: Physiological and Mechanical Aspects, Evolution of Bikes, Accidents and Injuries

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Abstract: Mountain biking (MTB) is a cycling modality performed on a variety of unpaved terrain. Although the cross-country Olympic race is the most popular cross-country (XC) format, other XC events have gained increased attention. XC-MTB has repeatedly modified its rules and race format. Moreover, bikes have been modified throughout the years in order to improve riding performance. Therefore, the aim of this review was to present the most relevant studies and discuss the main results on the XC-MTB. Limited evidence on the topic suggests that the XC-MTB events present a variation in exercise intensity, demanding cardiovascular fitness and high power output. Nonetheless, these responses and demands seem to change according to each event. The characteristics of the cyclists differ according to the performance level, suggesting that these parameters may be important to achieve superior performance in XC-MTB. Moreover, factors such as pacing and ability to perform technical sections of the circuit might influence general performance. Bicycles equipped with front and rear suspension (i.e., full suspension) and 29" wheels have been shown to be effective on the XC circuit. Lastly, strategies such as protective equipment, bike fit, resistance training and accident prevention measures can reduce the severity and the number of injuries.

Keywords: power output; intensity; anthropometry; pacing; suspension; off-road cycling

Citation: Arriel, R.A.; Souza, H.L.R.; Sasaki, J.E.; Marocolo, M. Current Perspectives of Cross-Country Mountain Biking: Physiological and Mechanical Aspects, Evolution of Bikes, Accidents and Injuries. *Int. J. Environ. Res. Public Health* **2022**, *19*, 12552. https://doi.org/10.3390/ijerph191912552

Academic Editor: Paul B. Tchounwou

Received: 21 August 2022
Accepted: 29 September 2022
Published: 1 October 2022

1. Introduction

The bicycle was invented in the 19th century, with the purpose of improving movement and being more efficient than walking [1]. Many types of mechanical systems were tested, until a chain and ratchet system was implemented and optimized to the current standards. There are several social and cultural aspects related to the creation, development and use of the bicycle, such as the fact that it was a means of transport that preceded the automobile, generated an impact on public transport and made access to low-cost mobility possible for all and contributed to women's freedom in dress, mobility and engagement in the public sphere [1]. However, the use of bicycles as a sport modality was revolutionized the bike and cycling world.

Although the first cycling competitions were carried out in the 19th century, the popularization of this modality was consolidated with the Tour de France in 1903, becoming the most popular event in road cycling [2]. In this context, almost 70 years later and after thousands of competitions using the bicycle on the road, there was another turning point event with the first competition on hostile terrain.

Mountain biking (MTB) emerged in the 1970s in California, USA and the first official competition was reported in the 1980s and the first world championship in the 1990s, organized by Union Cycliste Internationale (UCI), the main association that promotes cycling across the world. Although there are a variety of MTB sub modalities (e.g., downhill, dual slalom, trials, enduro, trip trail), the cross-country (XC) MTB (XC-MTB) modality

APPENDIX B - EVIDENCE OF PUBLICATION: STUDY 4

Motriz, Rio Claro, v.26, Issue 3, 2020, e10200034 *DOI: http://dx.doi.org/10.1590/S1980-6574202000030034*

Original Article (short paper)

The relative peak power output of amateur mountain bikers is inversely correlated with body fat but not with fat-free mass

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Abstract - Aims: To evaluate whether body mass (BM) and body composition may influence mountain bike cycling performance. **Methods:** Forty male amateur mountain bikers attended the laboratory on two non-consecutive days. At the first visit, anthropometric measures (height, BM, body fat [BF], fat-free mass [FFM] and body mass index [BMI]) and familiarization to incremental cycling test were performed. On the second visit, cyclists performed again the incremental cycling test to measure peak power output (PPO), peak power output relative to BM (PPO-BM), and time to exhaustion (TE), which were posteriorly correlated with BM and anthropometric measures. **Results:** A moderate and strong significant correlation were observed between TE and BM ($p<0.01$; $r=0.40$) and FFM ($p<0.01$; $r=0.56$), respectively. Moderate significant correlation was found between PPO and BM ($p<0.01$; $r=0.45$), BMI ($p=0.03$; $r=0.35$) and strong with FFM ($p<0.01$; $r=0.59$). Also, PPO-BM significantly correlated with BM ($p=0.04$; $r=-0.31$), BMI ($p=0.02$; $r=-0.35$) and BF ($p<0.01$; $r=-0.55$). No other significant correlations were observed. **Conclusion:** Considering PPO-BM as mainly performance variable, BM and BF can be a determining factor in mountain biking performance but FFM did not.

Keywords: cyclists, performance, body composition, off-road cyclists, body mass, body mass index

Introduction

Mountain biking (MTB) is an off-road cycling modality including various types of terrain and repeated up- and downhills[1]. Since it was included in the Olympic Games programme, it became a more traditional and widespread sport around the world, comprising a large number of recreational, amateur and elite cyclists[1].

In this sense, the determinants of MTB performance are drawing the attention of sports scientists[1–3]. They included technical ability, nutritional strategies, physiological aspects, and body composition (BC)[1], being the last one also a determinant of performance in various other sports modalities[4–6]. In sprint runners, a greater fat-free mass (FFM) and lower body fat (BF) are directly correlated with better speed performance[4], and in ultra-marathon runners, body mass index (BMI) was positively correlated with the race time[7]. Lastly, in recreational male Ironman triathletes and ultra-cyclists, the percent BF was associated with total race time[8].

Although the BC, which includes BF, FFM and both alter body mass (BM), depends on the genetic compound, this parameter can be modified accordingly physical training[9] and/or nutritional behavior[10]. Considering that MTB performance indicators, such as power output and oxygen consumption, are more determinants when normalized by BM[11], it can be hypothesized that the BC components are relevant to success in this modality. Elite MTB athletes have a BC quite homogeneous[12], however, it does not occur for amateurs[6]. Therefore, a BC variation of amateur cyclists can lead to a direct influence on performance.

Although their effect on road[13] and elite MTB[12] cyclists performance were presented, there is still limited evidence on amateur mountain bikers[6,14]. Therefore, considering these parameters, this study aimed to evaluate whether BC and BM influence the performance of amateur mountain bikers.

Methods

Subjects

Forty male amateur mountain bikers were recruited to participate in the study. The power statistic was calculated by G*power software[15] based on the current sample size in this study (test power = 0.63). To inclusion, they needed to have a cycling training with a minimum of 2 hours per week and achieve at least 250 W or more in the incremental test[16]. The exclusion criteria were: i) any cardiovascular, metabolic, or respiratory disease; ii) any potential substance that could improve the exercise performance; iii) musculoskeletal, bone, or joint injury that could unsettle the exercise performance; iv) caffeine supplement intake; v) smoking history. This information, as well as the information about training and cycling experience, were identified via a questionnaire. Table 1 shows the volunteers' characteristics. This study was approved by the local Ethics Committee (number 2.250.458) for human experiments and was carried out in conformity with the Declaration of Helsinki. All the volunteers were informed about the testing procedures. Furthermore, all of them provided written informed consent about the research.

APPENDIX C - ADDITIONAL WORK COMPLETED DURING THE CANDIDATURE

International Journal of
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Review

Ischemia–Reperfusion Intervention: From Enhancements in Exercise Performance to Accelerated Performance Recovery—A Systematic Review and Meta-Analysis

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Received: 10 October 2020; Accepted: 2 November 2020; Published: 4 November 2020

check for updates

Abstract: It has been demonstrated that brief cycles of ischemia followed by reperfusion (IR) applied before exercise can improve performance and, IR intervention, applied immediately after exercise (post-exercise ischemic conditioning—PEIC) exerts a potential ergogenic effect to accelerate recovery. Thus, the purpose of this systematic review with meta-analysis was to identify the effects of PEIC on exercise performance, recovery and the responses of associated physiological parameters, such as creatine kinase, perceived recovery and muscle soreness, over 24 h after its application. From 3281 studies, six involving 106 subjects fulfilled the inclusion criteria. Compared to sham (cuff administration with low pressure) and control interventions (no cuff administration), PEIC led to faster performance recovery ($p = 0.004$; ES $= -0.49$) and lower increase in creatine kinase ($p < 0.001$; effect size (ES) $= -0.74$) and muscle soreness ($p < 0.001$; ES $= -0.88$) over 24 h. The effectiveness of this intervention is more pronounced in subjects with low/moderate fitness level and at least a total time of 10 min of ischemia (e.g., two cycles of 5 min) is necessary to promote positive effects.

Keywords: intermittent occlusion; blood flow occlusion; sports; ergogenic; ischemic postconditioning

1. Introduction

High-level sports performance is dependent on several factors that require high mechanical [1], psychological [2] and physiological [3] demands. Elite competitors are usually submitted to successive high volume and intensity training sessions and/or to multi-days competitions, with short intervals of recovery. These events can lead to physiological [3] and psychological [4] alterations, impairing sports performance. Thus, to increase the resistance to fatigue and to improve performance, many athletes and coaches search post-exercise recovery strategies [5].

APPENDIX D – PARTICIPANT CONSENT FORM: STUDY 4

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO - TCLE

UNIVERSIDADE FEDERAL DE JUIZ DE FORA

NOME DO VOLUNTÁRIO:

I - TÍTULO DO TRABALHO EXPERIMENTAL:

“RELAÇÃO ENTRE COMPOSIÇÃO CORPORAL E DESEMPENHO FÍSICO DE MOUNTAIN BIKERS”

Pesquisador Responsável: Rhaí André Arriel e Oliveira, portador do RG nº: 12.880.987.

II - OBJETIVOS
Avaliar a correlação entre a composição corporal e medidas de desempenho físico de ciclistas treinados em mountain biking (MTB).

III - PROCEDIMENTOS DO EXPERIMENTO

AMOSTRA

Serão recrutados 45 adultos do sexo masculino, entre 18 a 35 anos, sendo todos treinados em ciclismo na modalidade de MTB. Os mesmos não deverão apresentar nenhum problema de saúde que impeça a prática do exercício proposto. Os participantes deverão ter uma experiência mínima de 6 meses, com tempo mínimo de treinamento de duas horas por semana planejados por um profissional capacitado, e alcançar pelo menos 250 watts de potência no teste incremental que será realizado em um cicloergômetro (bicicleta estacionária).

Previamente aos testes, todos os adultos participantes da pesquisa deverão responder um questionário de prontidão para atividade física (PAR-Q), apresentar a aprovação e liberação médica para a realização da atividade proposta pelo projeto e assinarão o termo de consentimento livre e esclarecido (TCLE). É de reponsabilidade do voluntário obter a aprovação e liberação médica para a realização da atividade proposta pelo projeto.

EXAMES

O experimento, aprovado pelo comitê de ética local (número do parecer: 2.250.458), será realizado na Academia Performance – Perdões – MG. Cada indivíduo deverá comparecer dois dias não consecutivos ao local de testes, com visitas de aproximadamente 1:30 h cada dia, conforme o cronograma de atividade reportado anteriormente aos ciclistas. Abaixo estão descritos os procedimentos a serem realizados no estudo.

A primeira visita será realizada para familiarizar o voluntário com o centro de testes, avaliadores da pesquisa, equipamentos utilizados para a coleta de dados, teste incremental e para sanar todas as dúvidas dos participantes sobre os testes. Neste primeiro momento, será aplicado um questionário para verificar o histórico de treinamento do voluntário. Em seguida, será realizada a coleta do TCLE, PAR-Q e dimensões antropométricas de cada participante (Medidas de estatura, massa corporal total, massa livre de gordura e massa de gordura). Para aferir a estatura e a massa corporal total, será utilizado um estadiômetro e uma balança, respectivamente, e o voluntário deverá ficar descalço, mas vestindo a roupa de ciclismo. Para aferir/estimar a massa livre de gordura e a massa de gordura, será utilizado um adipômetro (Compasso de dobras cutâneas) para aferir as dobras cutâneas em três locais diferentes (peito, abdominal e coxa), e do lado direito do corpo. Para aferição das dobras, o voluntário deverá vestir apenas o short (ou Bretelle). Logo após a realização dessas medidas, o participante será encaminhado para uma sala reservada para a realização do teste incremental até a exaustão voluntária.

Antes da realização do teste incremental, o voluntário realizará um aquecimento composto por 4 minutos com uma carga constante (40 watts) no próprio cicloergômetro. Em seguida, o voluntário realizará o teste incremental. O teste será iniciado com uma carga de 40 watts com incrementos de 20 watts por minuto até a exaustão voluntária, mantendo uma cadencia entre 80-90 rpm. O teste poderá ser encerrado se o voluntário não conseguir manter a cadencia requerida por 10 segundos. Após o encerramento do teste, o voluntário será colocado em uma maca em posição de decúbito dorsal (Deitado de barriga para cima) para a realização de volta a calma.

Na segunda visita, todos os procedimentos realizados no teste incremental serão repetidos. Os testes serão realizados em clima considerados ideais do ambiente para se praticar exercício físico. Caso aconteça alguma intercorrência devido a sua participação ao estudo, o atleta será levado se necessário à Santa Casa de Misericórdia de Perdões - MG custeado pelo pesquisador.

Todos os procedimentos serão realizados com todo o cuidado e previamente estudado e testado pelos avaliadores.

IV - RISCOS ESPERADOS

Os testes podem causar certo desconforto físico e psicológico durante e após o teste incremental. Estes desconfortos físicos podem ser cansaço durante e após o teste, um pouco de dor muscular tardia (inicia por volta de 24 a 48 horas depois do exercício e a dor sessa por volta de 72 horas após o exercício). Além disso, qualquer problema, além dos citados, deve ser comunicado imediatamente aos avaliadores. No entanto, vale ressaltar que apenas adultos treinados na modalidade MTB do sexo masculino, com o preenchimento do PAR-Q e portando a liberação médica para a realização da atividade, participarão da pesquisa.

É importante destacar que, por se tratar de um teste de alta intensidade, durante e logo após o teste o voluntário poderá sofrer desconfortos como náusea (vontade de vomitar) e vertigem (tontura).

V – BENEFÍCIOS

Fornecer informações em relação à composição corporal e desempenho no MTB.

VI - RETIRADA DO CONSENTIMENTO

O próprio participante tem a liberdade de retirar seu consentimento a qualquer momento e deixar de participar do estudo, sem qualquer prejuízo ao atendimento a que está sendo ou será submetido.

VII – CRITÉRIOS PARA SUSPENDER OU ENCERRAR A PESQUISA

Caso ocorra algum risco ou imprevisto, a pesquisa será encerrada imediatamente. Caso contrário, a pesquisa possivelmente será encerrada ao final dos experimentos.

VIII - CONSENTIMENTO PÓS-INFORMAÇÃO

PARTICIPANTE MAIOR DE IDADE

Eu____, certifico que, tendo lido as informações acima e suficientemente esclarecido (a) de todos os itens, estou plenamente de acordo com a realização do experimento. Assim, eu autorizo a execução do trabalho de pesquisa exposto acima.

Juiz de Fora, _____ de __________________ de 20____.

NOME (legível): ____

RG: ____________________________

ASSINATURA: ____

ATENÇÃO: A sua participação em qualquer tipo de pesquisa é voluntária. Em caso de dúvida quanto aos seus direitos, escreva para o Comitê de Ética em Pesquisa em seres humanos da Universidade Federal de Juiz de Fora. Endereço: Universidade Federal de Juiz de Fora, Campus Universitário, Rua José Lourenço Kelmer, s/n - São Pedro, Juiz de Fora - MG, 36036-900 Telefone: (32) 2102-3911.

No caso de qualquer emergência entrar em contato com o pesquisador responsável. Telefones de contato: (35) 99869-2351 (Rhaí).