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PHYSIOLOGICAL VARIABLES TO PREDICT PERFORMANCE IN CROSS-COUNTRY MOUNTAIN BIKE RACES

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ABSTRACT

Costa VP, De-Oliveira FR. Physiological variables to predict performance in cross-country mountain bike races. ***JEP****online* 2008;11(6):14-24. Mountain bike (MTB) is a recent sport derived from cycling with little information about the athletes and races. The aim of this study was to identify the morph-physiological characteristics in Elite MTB athletes and the physiological variables associated in performance during Cross-country Olympic (XCO) races. Six Elite mountain bikers (26.5 ± .6 years; 69.1 ± 2.1 kg; 174.0 ± 1.2 cm; 5.9±0.9 % body fat estimated; 9.0 ± 1.3 years of training) were included in this study. The participants were submitted to the Wingate test and an incremental progressive exercise. Then they were evaluated during the XCO World Cup and XCO Brazilian National Championship. The results indicate that riders presented similar morphologic characteristics to the international athletes. However, the sub-maximal and maximal power outputs are lower. The maximal power output (W_{max}) relative to body mass was significantly associated with performance in two races. The power at second lactate threshold (WLL_2) was only significantly correlated in XCO World Cup when normalized to exponent of mass 0.79. Therefore, the results of this study provide the support to the use of the W_{max} and WLL_2 in the physiological assessments of mountain bikers. Furthermore, the body size should be taken into account to evaluate off road cyclists.

Key Words: Cycling, Off-Road Cycling, Maximal Oxygen Uptake, Power, Lactate.

INTRODUCTION

The Cross-country Olympic (XCO) is a modality in mountain bike (MTB) racing with competitions generally performed over one day. This kind of competition is performed on off-road circuits consisting of a predetermined number of laps (frequently 5-7 laps for professional riders), where all participants start together in a mass group. Mountain bike races are held on various types of terrain and often include several hill climb sections. The physiological demands of professional off-road cycling races suggest that XCO races require the athlete to maintain a high exigency of aerobic power and capacity indicators such as maximal oxygen uptake (VO_{2max}) and the lactate or ventilatory thresholds (LT and VT, respectively) for approximately 2 – 2 h 15 min (1,2,3,4). In addition, Dal Monte and Faina (4) reported elevated values in blood lactate during simulated competition suggesting a high participation of anaerobic metabolism. Indeed, Stapelfeldt et al. (3) reported that during XCO competitions the off-road cyclists attain elevated values in power output above their maximal aerobic power output (W_{max}) during hard climbs. In addition, isometric contractions of the upper extremities are used extensively in shock absorption when riding technical trails (2). Therefore, it seems that mountain bikers need to develop both the power and capacity for aerobic systems to attain success during XCO races.

Over the years the scientific literature has primarily focused on the identification of physiological indices and the relationship with endurance performance (5,6,7,8,9,10). There is a consensus that these measures are used by researches and coaches to prescribe and/or control endurance training (4). To understand which physiological variables are associated with XCO performance, Impellizzeri et al. (5) reported strong correlations between various measured parameters of aerobic fitness and performance in a heterogeneous group of competitive off-road cyclists, particularly when normalized to body mass. In a further study (6), these authors reported that the only physiological indices of aerobic fitness correlated with off-road cycling performance were power output and oxygen uptake at the second VT, mainly when normalized to body mass. Indeed, it was clear that the indicator of aerobic capacity when normalized to body mass presented significant association with XCO performance in both homo and heterogeneous group of athletes.

More recently, some authors suggesting that the participation of anaerobic systems and neuromuscular characteristics are important components to explain endurance performance (11, 12, 13). The previous studies on endurance performance in XCO races have just examined with the physiological aerobic parameters, no one has reported the relation with anaerobic indicators (5, 6). Therefore the aim of this study was to characterize the physiological variables in the top level of Brazilian mountain bikers and to verify the relationship between aerobic and anaerobic indicators with XCO endurance performance.

METHODS

Subjects

Six Elite Brazilian mountain bikers collaborated voluntarily in our research in accordance with previous contact and signed an informed consent form prior to participation. This study was approved by the ethical committee of University of Santa Catarina State University (number: 017/05 - Florianópolis - Brazil). During the test period athletes were in the competitive phase of their season.

Table 1. Subjects` characteristics (mean ± S.D).

Group	*Age (yr)*	*Height (cm)*	*Weight (kg)*	*Body Fat Estimated (%)*	*Sum of Skinfolds*	*Years of Training*
E (n = 6)	26.5 ± 3.6	174.0 ± 1.2	69.1 ± 2.1	5.9 ± 0.9	21.1 ± 1.9	9.0 ± 1.3

Procedures
Laboratory Data Collection
The athletes completed three different evaluations on the same day. First, the off-road cyclists reported to laboratory to have their anthropometric measures recorded to estimate the percentage of body fat (BF) according to Jackson and Pollock's three site formula: pectoral, abdomen and quadriceps (14) and sum of the skinfolds (∑ SK).

The athletes then completed a Wingate Test (WT) (15) carried out on mechanically braked cycle-ergometer (CEFISE®, 1800). The cycle-ergometer was adapted with specific pedals clippers and saddle for mountain bikers. The subjects had to stay seated on the saddle throughout the test. A 5-min warm-up period at the level of 1 kp at free rpm was performed before the test. During the warm-up the cyclists performed two bouts riding as fast as possible while the resistance was increased to 3-5 kp during 3-5 s. The subjects were given a 2-min rest before beginning the WT. The subjects had to overcome the inertial wheel in static position at the beginning of the test. The athletes were oriented to pedaling as fast as possible. The workload for the WT was fixed at 0.10 kp per kg body weight. The computerized WT program was used to record power output every second for the duration of the test. Mean power was calculated as the average of the power outputs during the thirty seconds. Peak power (PP) was defined as the highest 5-s power output during the 30-s test. The fatigue index (FI), defined as the percentage drop in power output from the highest to the lowest segment (PL) was determined by the follow equation:

$$FI\ (\%): [(PP - PL)/PP] \times 100$$

After a minimum interval of 30 min, the subjects completed a graded exercise test on their own mountain bike on a cycle-simulator (CompuTrainer™ RacerMate® 8000, Seattle WA), which was calibrated in accordance with the manufacturer's recommended procedures. An 8-min warm-up period at the level of 70 W followed by 2-min of passive recovery was performed before the test. The test began at 100 W and intensity was increased 30 W every 3 min. until the end of the test. The participants were instructed to maintain a cadence between 90 – 110 rpm. The exercise test was finished voluntarily by the subject or when the minimum cadence could not be maintained (90 rpm). If the final stage of the exercise test was not completed, the W_{max} was calculated using the equation of Kuipers et al. (16).

$$W_{max} = Wf + (t/180 \times 30)$$

Where Wf was the last completed workload, and t is the time in seconds of the uncompleted workload.

Heart rate was continuously recorded during the whole test with a heart rate monitor (Polar Vantage NV, Polar Electro OY, Finland). Gas exchange data was collected continuously using a pre-calibrated metabolic analyzer *Aerosport* KB1-C (*Aerosport*®, Inc., Ann Arbor, MI). During the last 30 s of each stage, capillary blood samples were obtained from the right ear lob of each subject and immediately analyzed using an electromagnetic technique (YSI® 1500 Sport, Yellow Springs Instruments, Yellow Springs, OH). The analyzer was calibrated in accordance with the manufacture's recommended procedures. The lactate thresholds were identified in according with Berg's methodology (17). Briefly, the first lactate threshold (LT_1) was identified with workload that corresponds to the calculated minimum of the $Lac.W^{-1}$ ratio of each subject. The second lactate threshold (LT_2) was identified with workload that corresponds to 1.5 $mmol.l^{-1}$ above LT_1. The LT_1 can be used as a measure of aerobic working capacity (18) and the LT_2 has been shown to coincide with the maximal steady-state level of

[La] derived from a threshold test (19). At the end of each stage, the subjects reported their perceived effort using 10 points Borg's scale (20).

Field Data Collection

All of the elite athletes were evaluated during two XCO competitions which were separated by 14 days: the first race was the 6th round of UCI World Cup XCO races and second was the Brazilian National Championship, respectively. The XCO races took place in July in 2005 and the environmental conditions were very different for each event. During the World Cup race the weather was sunny at a temperature of ~28^{o} C and the relative air humidity of ~55%. In contrast, during the Brazilian National Championship the weather was cold and raining at a temperature of ~7^{o} C and the relative air humidity of ~70% (Table 2).

During the XCO World Cup and Brazilian Championship, only the final rank positions were used as a performance indicator. We were forced to take this decision because there is a particular rule in XCO competitions from UCI. Briefly, any rider whose time being 80% slower of that of the race leader's first lap will be pulled out of the race. Lapped riders must complete the lap during which they were lapped. If that rule applies, the lapped riders will be listed in the results in the order in which they are pulled out of the race Therefore, only one Elite Brazilian's athlete had completed the overall number laps definite by the UCI organization.

Statistical Analyses

Descriptive statistics were calculated for all variables identified in the laboratory and field testing through SPSS software 11.5 for windows. The Kolmogorov-Smirnov test was applied to ensure a Gaussian distribution of the data. Then, to correlate the physiological parameters with endurance performance, Spearman Rank product moment correlation was used. For all analyses the level of statistical significance was established at an alpha level of $p<0.05$.

RESULTS

The characteristics of the XCO races revealed that courses present different elevation and distance. The information from the organization of the events shows that the XCO circuit in the Brazilian National Championship was shorter and the unevenness of the ground was less accentuated than World Cup. In spite of the circuit in the Brazilian Championship being shorter the total race distance was larger due a larger number of laps (Table 2).

Table 2. Descritive characteristics of the XCO races.

	Brazilian National Championship	***World Cup***
Distance (km)	31.5	28.0
Time (s)	142.5 ± 4.5	143.4 (n=1)
Speed average ($km.h^{-1}$)	12.8 ± 0.8	11.7 (n=1)
Laps	7	5
Temperature (^{o}C)	7	28
Air Humidity (%)	70	55

The anaerobic and aerobic variables of the athletes are presented in Table 3, and the sub-maximal variables from the incremental exercise test are presented in Table 4. The W_{max} normalized to body mass was significantly associated to XCO performance in both the World Cup and National Championship. The WLT_2 normalized to mass exponent of 0.79 was significantly correlated with XCO performance only in the World Cup (Table 5).

DISCUSSION

Table 3. Anaerobic and aerobic laboratory tests.

Wingate Test		Incremental Exercise Test	
PP (W)	886.9 ± 66.7	***W_{max} (W)***	349.2 ± 15.6
$PP._{kg}^{-1}$ ($W.kg^{-1}$)	12.8 ± 0.8	***$W_{max.kg}^{-1}$ ($W.kg^{-1}$)***	5.1 ± 0.2
PM (W)	741.4 ± 39.6	***HR_{max} (bpm)***	187 ± 5
$PM._{kg}^{-1}$ ($W.kg^{-1}$)	10.7 ± 0.5	***VO_{2max} ($l.min^{-1}$)***	4.8 ± 0.2
IF (%)	36.3 ± 3.1	***$VO_{2max.kg}^{-1}$ ($ml.kg^{-1}.min^{-1}$)***	69.8 ± 3.5
		$[La]_{peak}$ ($mmol.l^{-1}$)	10.9 ± 2.3
		RPE	8 ± 1

PP = anaerobic peak power output; PM = power average; IF = fatigue index; W_{max} = aerobic peak power output; HR_{max} = hear rate maximum; VO_{2max} = maximum oxygen uptake; $[La]_{peak}$ = blood lactate peak; RPE = rating of perceived exertion; $.kg^{-1}$ = relative to body mass

The aim of this study was to characterize the physiological variables in Elite Brazilian off-road cyclists and verify any relationship of anaerobic and aerobic variables with XCO endurance performance. The morphological characteristics of the athletes have indicated that body mass and %BF are similar to other mountain bikers (2,5,6). In addition, the morphologic conditions found in these athletes may represent information that can aid in endurance performance because the physiologic parameters are frequently normalized by alometric scale (21). Indeed, Impellizzeri et al. (5) presented the most important factors that could affect performance in XCO races are both indicators of aerobic power and capacity normalized by body mass. According to the authors, the strong associations found can be explained by repeated climbs present in XCO circuits. Lee et al. (22) compared the morph-physiological characteristics between road cyclists and mountain bikers. They found more significant differences in mountain bikers when the parameters were expressed relative to body mass. It is noted that body weight associated with reduced %BF represents an important adaptations for off-road cyclists that looking for success XCO races.

Table 4. Sub-maximal variables incremental exercise test.

	Values	Values (%)
WLT_1 (W)	205 ± 16	59 ± 6
WLT_2 (W)	275 ± 15	79 ± 3
$HRLT_1$ (bpm)	131 ± 8	70 ± 4
$HRLT_2$ (bpm)	160 ± 8	85 ± 4
VO_2LT_1 ($ml.kg^{-1}.min^{-1}$)	34.9 ± 7.5	50 ± 10
VO_2LT_2 ($ml.kg^{-1}.min^{-1}$)	51.0 ± 5.4	73 ± 6

W = power output; HR = heart rate; VO_2 = oxygen uptake; LT_1 = first lactate threshold; LT_2 = second lactate threshold

To evaluate the anaerobic variables, Heller and Novotny (12) reported through WT that mountain bikers of the Kazakhstan National Team had similar values with the present study. In the same test, Machado et al. (23) found inferior values for PP and PM in Brazilian mountain bikers (815.6 144.1 and 697.9 102.3 W, respectively). However, in the last study the resistance used for WT execution was corresponding to 0.075 $g.kg^{-1}$, and this value does not seem ideal for athletes. In contrast with the XCO riders, the down-hillers presented elevated scores in PP (1125.0 W and 17.7 $W.kg^{-1}$) (4). It can be partly justified for the specificity of these modalities, it is speculated that the downhill proof presents different physiologic exigency rather than XCO. In general, downhill is an event that involves maximal effort and great skills for the mountain bikers in a short trail course during descents. In this regard, it is believed that there is greater utilization of anaerobic metabolism and would explain the higher values found in down-hillers.

Table 5. Physiological variables correlate to performance during XCO Brazilian National Championship and World Cup.

	Brazilian National Championship			World Cup		
	Absolute Values	$Values.kg^{-1}$	$Values.kg^{-0.79}$	Absolute Values	$Values.kg^{-1}$	$Values.kg^{-0.79}$
VO_{2max}	-0.45	-0.50	-0.70	-0.45	-0.30	-0.60
W_{max}	-0.09	-0.88*	-0.93**	-0.09	-0.88*	-0.81*
WLT_1	0.29	0.00	0.00	-0.09	-0.35	-0.35
WLT_2	-0.09	-0.32	-0.37	-0.43	-0.78	-0.83*
PP	-0.03	-0.03	0.03	-0.14	-0.03	-0.09
PM	-0.09	-0.29	-0.14	0.14	-0.12	-0.03
FI	0.23	-	-	0.23	-	-

* $P < 0.05$. ** $P < 0.01$. VO_{2max} = maximum oxygen uptake; W_{max} = aerobic peak power output; WLT_1 = power output at first lactate threshold; WLT_2 = power output at second lactate threshold; PP = anaerobic peak power output; PM = power output average; FI = fatigue index

In relation to aerobic variables, the appraised athletes present inferior values of W_{max} in comparison with international literature. Lucia, Hoyos and Chicharro (24) suggested that professional cyclists reach lower W_{max} in protocol with high load increment and duration of the stages. Lee et al. (22) used a protocol with increments of 50 W in each stage with 5 min duration to evaluate a group of professional Australian mountain bikers. They verified the W_{max} approximately 413 ± 36 W. In contrast to our study the increments were 30 W every 3 min, and the W_{max} was only 349.2 ± 19 W. When the W_{max} was normalized by alometric scaling it is observed that values are inferior to international riders. Wilber et al. (25) evaluated North American off-road cyclists and they found 5.9 ± 0.3 $W.kg^{-1}$. Impellizzeri et al. (6) investigated Italian mountain bikers and the values are close to 6.4 ± 0.6 $W.kg^{-1}$. Besides the difference in employed methodologies, it is evident the discrepancy of W_{max} in Brazilian athletes investigated here when compared with international off-road cyclists.

In spite of the inferior absolute and relative values of W_{max}, the VO_{2max} and $VO_{2max.kg-1}$ are in agreement with professional off-road cyclists 4.6 to 5.1 $l.min^{-1}$ and 66.5 to 78.3 $ml.kg^{-1}.min^{-1}$ (2, 5, 6). Besides methodological differences, the possible explanation for discrepancy in smallest load where VO_{2max} is found can be related to differences in cycle-ergometers and may cause doubts on precision results. Earnest et al. (26) compared the cycle-simulator CompuTrainer TM (used in present study) with cycle-ergometer Lode Excalibur in amateur road cyclists. Briefly, the results indicate that cycle-simulator can underestimate (between to 30 and 45 W) the W_{max}, WLT_1, WLT_2, and total time during the test. In addition, some authors believe that years of cycling training and the continuous participation in high level races could allow physiologic adaptations such as muscular efficiency and positively effect the distribution in Type I muscular fibers (27,28). However all the participants in our study were considered experienced (8.6 ± 4.6 years training). Therefore, we believe that the quality of training; the lack of participation in international competitions during the season, and methodological differences can explain the discrepancies in workload where VO_{2max} is achieved.

In relation to the $[La]_{peak}$ the off-road cyclists in our study reached higher values than the professional and elite road cyclists investigated by Lucia et al. (29) (10.9 ± 2.3 and 12.4 ± 2.8 vs 7.4 ± 1.5 and 9.4 ± 3.0 $mmol.l^{-1}$, respectively). In a general way, it is suggested by Lucia et al. (29) that athletes that present larger aerobic aptitude tend to present smaller $[La]_{peak}$. Recently, Costa et al. (30) found that mountain bikers reached significantly higher values in $[La]_{peak}$ after incremental exercise when compared to road cyclists. This result may suggest that the intermittent nature of XCO can promote larger demand and utilization of anaerobic metabolism during training and/or races. Indeed, Stapelfeldt et al. (3) used mobile dynamometers to quantify the intensity during XCO races. The results indicate that 42% of the race total time was disputed above WLT_2. In addition, in the start, overtaking and short climbs, the athletes produce power output above W_{max} reached in the laboratory (3). In this sense, it is speculated that XCO races in spite of be predominantly aerobic, requires high anaerobic power and capacity of the athletes. In agreement to our $[La]_{peak}$ result, Lucia et al. (31) found significant differences in the $[La]_{peak}$ in climbers and time trialists. The best climbers are known for their ability to rapidly switch from already demanding pace to high speeds during hill stages. Moreover some are able to perform repeated short bouts of maximum intensity exercise during ascends (31). Therefore, the possible explanations can be related partly with the increase in recruitment of fast contraction unit motors and buffer systems (31).

The sub-maximal variables investigated are represented by lactate thresholds and frequently are referenced as indicators of aerobic capacity. In a general way, the obtained values in power output are inferior to professional off-road cyclists, however, the percentage where these thresholds are found are similar to Lee et al. (22). In addition, the values can be inferior to other studies due to methodological differences besides previous speculations in relation to W_{max} and VO_{2max}. For instance, Impellizzeri et al. (2) used OBLA as reference for the LT_2, these results reveal higher values in power output and percentage of maximal. In another hand, Stapelfeldt et al. (4) as well as the present study used Berg's methodology for the LT_2 identification. In this sense, it is clear to see the discrepancy in references values of the sub-maximal variables. High percentages values in LT_2 can be interpreted as an ability of the cyclist in maintain high intensity during long periods without much blood lactate accumulation.

The second aim of this study was to verify the association of physiological variables and XCO performance. In general, all absolute physiological variables investigated have non-significant association with endurance performance. However, the major finding was a significant correlation between W_{max} normalized to body mass with XCO performance.

Previous studies in road cycling reported W_{max} as an indicator of performance (32, 33). Bentley et al. (34) found that W_{max} was correlated with average power output during a 90 min. time trial ($r = 0.91$; $p< 0.01$) and moderate association with 20 min. time trial ($r = 0.54$; $p< 0.01$). However, Balmer et al. (32) showed that W_{max} has strong association with power output average during 16 km time trial ($r = 0.99$; $p< 0.001$). Indeed, other studies have presented similar results with W_{max} and total time during 20 km ($r = - 0.91$) and 40 km time trial performance ($r = - 0.87$) respectively. (33, 35). Based on these studies it seems that W_{max} is good predictor for cycling time trial performance in spite of different measures of performance.

The significant correlations found between the absolute values of W_{max} and cycling time trial performance can decrease when normalized by alometric scaling. Hawley and Noakes (33) reported that W_{max} relative to body mass reduces the relationship with performance due to cyclist's body mass. However, Swain (21) was probably the first to estimate the mass exponent of 0.32, associated with oxygen consumption when investigating the energy cost of cycling over flat ground. Time trials are usually held on flat ground where the heaviest cyclists present smaller body surface areas consequently, they are faster (21). In contrast to time trial, XCO circuits present several climbs with steep ascents where the reduced body mass is crucial because the athletes needs to over come gravity force (22). Similarly, the results found in the present study can confirm these speculations since W_{max} relative to body mass is significantly associated with endurance performance in two XCO races.

Recently, Impellizzeri et al. (5) investigated the associations among several physiologic variables with performance during Italian XCO Championship. The VO_{2max}; W_{max}; LT_1; and LT_2 were significantly associated with performance ($r = - 0.62$ to $- 0.94$) and for all variables the relationships were heavier when normalized by alometric scalng. In a further study, Impellizzeri et al. (6) analyzed ventilatory variables with XCO performance in a homogeneous group of mountain bikers. The results have indicated that power output and oxygen uptake at respiratory compensation point, both normalized by body mass were significantly associated with XCO performance (r = - 0.61 and – 0.66; p <0.05).

The physiological variables that predict performance in our study are partly different from the investigations of Impellizzeri et al. (5, 6) because the only significant relation to performance was W_{max} relative to body mass in both events and WLL_2 relative to body mass (0.79) in XCO World Cup. The possible differences for the results are partially related with the own conditions found during the races. The XCO Brazilian National Championship was accomplished in a day with high index pluviometer that probably elevates the technical difficulty level in the circuit. In addition the strong rain can also increase the risk of mechanical problems in the bikes and the technical ability seems to be more decisive in homogeneous group than that of heterogeneous mountain bikers. In contrast, the XCO World Cup race was accomplished on dry ground without rain. Another limitation was the position of the athletes at the start line because in both competitions the better ranked mountain biker's started in front and benefited in the single-tracks after race begin.

CONCLUSIONS

The present study revealed the morphologic and physiological characteristics of a small group of Elite Brazilian mountain bikers. The W_{max} relative to body mass was significantly associated with endurance performance in Brazilian National XCO Championship and XCO World Cup. The only one physiological variable that has significantly associated with performance in XCO World Cup was WLL_2 relative to exponent of mass 0.79. Therefore, it was concluded that aerobic variables increase the discriminatory power when normalized by alometric scale. Like this, to obtain success in XCO races it is speculated that mountain bikers needs to develop physical qualities such as power and capacity of aerobic systems.

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