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Reliability of Time to Exhaustion Above the Power Output at VO_{2peak} in Trained Mountain Bikers

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ABSTRACT

International Journal of Exercise Science 16(4): 654-664, 2023. To our knowledge, no study has investigated the reliability of the time to exhaustion (TTE) test during constant-load trials in Olympic distance cross-country mountain bike (XCO-MTB) athletes. Thus, the aim was to analyze the reliability of the TTE test at intensities above peak oxygen uptake (VO_{2peak}) in trained XCO-MTB athletes. Fifteen male XCO-MTB athletes (mean ± SD: age 31.5 ± 6.6 years, stature 174.0 ± 5.4 cm, body mass 67.2 ± 5.1 kg, VO_{2peak} 64.5 ± 4.7 $mL \cdot kg^{-1} \cdot min^{-1}$) completed 2 TTE tests on the cycle ergometer with 4 different intensities above the maximal work rate in the incremental test (W_{max}) (105%, 120%, 130%, and 140% of W_{max}). There was moderate reliability between TTE tests at 105% (intraclass correlation coefficient (ICC) = 0.81, $p \leq 0.001$; coefficient of variation (CV) = 9.1%; standard error of measurement (SEM) = 18.3%), and 120% (ICC = 0.88, $p \leq 0.001$; CV = 6.6%; SEM = 9.3%) W_{max}. For intensities of 130% (ICC = 0.53, $p = 0.018$; CV = 9.2%; SEM = 15.8%) and 140% (ICC = 0.56, $p = 0.012$; CV = 12.2%; SEM = 13.5%) W_{max}, the reliability results proved to be questionable. In addition, no significant differences were found between the 2 TTE tests in all intensities ($p > 0.05$). Caution should be taken when assessing TTE above VO_{2peak} or when using it as a performance indicator, given its moderate to questionable reliability.

KEY WORDS: Exercise testing, mountain biking, off-road cycling, reproducibility

INTRODUCTION

Traditionally, time-to-exhaustion (TTE) protocols performed at constant power output or speed have been used in the scientific literature, where the intensity (expressed as the percentage of peak oxygen uptake (VO_{2peak}) or maximal work rate in the incremental test (W_{max}) is maintained until exhaustion (12). Exercise physiologists have widely used the TTE test to assess individuals' tolerance for specific exercise intensities, with applications for high-intensity interval training prescription (7, 31) and athletes' performance prediction (31). In turn, a test needs to be reliable to detect changes due to training effects rather than inter-individual differences or measurement errors (6).

Closed-loop performance time trials (TT) are paramount to the final overall standings of professional multi-stage cycling races. For instance, the performance in time trials showed a low variation in the power output (~2-3.5%) performed indoors and outdoors. On the other hand, several studies have analyzed the reliability of so-called open loop tests (e.g., TTE) during constant-load trials, where the exercise duration varied from 1 minute to 2 hours (12). In trained male cyclists, studies showed highly significant correlations between different TTE tests at VO_{2peak} ($r \geq 0.8$) (11, 30). However, the coefficient of variation (CV) of TTE during such open-loop tests varied significantly (ranging from 1.7% to 26.6%) (11, 26, 32).

In Olympic distance cross-country mountain bike (XCO-MTB) circuit races, 37% of the race is performed above the second ventilatory threshold, and 25% is spent above maximal aerobic power (16). In addition, this sport modality is also characterized by large variations in power output (15), possibly due to the characteristics of the terrain on which the XCO-MTB racing is conducted. Thus, aerobic and anaerobic power and capacity are important factors underlying performance in XCO-MTB races (21). Cross-sectional studies have confirmed the strong relationship between XCO-MTB races performance and W_{max} and the ability of repeated anaerobic efforts (5 x 30-second Wingate test) (24, 37).

Few studies have assessed the reliability of TTE tests at W_{max} only with trained cyclists (11, 30). Curiously, no study has investigated the reliability of TTE during constant-load trials at high intensities in XCO-MTB athletes. Therefore, this study is justified for two reasons: (a) Firstly, the high TTE test reproducibility at intensities above the W_{max} could be the initial step to introduce this test with XCO-MTB athletes. It is interesting for XCO-MTB athletes that use numerous efforts above W_{max} during the XCO-MTB race (21, 38), and (b) Secondly, the utilization of TTE tests could significantly impact monitoring progression and detection changes following training and experimental interventions in XCO-MTB athletes.

Thus, the present study aimed to analyze the TTE tests' reliability at intensities above VO_{2peak} of trained XCO-MTB athletes. We hypothesized that the different TTE tests at intensities above VO_{2peak} would show questionable results in XCO-MTB athletes. This hypothesis was elaborated because one study showed that in trained cyclists, the second TTE test at VO_{2peak} was significantly greater than the first TTE test (30).

METHODS

Participants

Fifteen male XCO-MTB athletes (see the descriptive data in Table 1) were recruited from several cycling clubs for this study and have previously maintained a training routine of 6 days a week and were classified as performance level 3 (PL3 - trained) according to the guidelines published by De Pauw et al. (13). Because the XCO-MTB athletes were recruited for convenience, no *a priori* power calculation was previously performed. This study was approved by the local Ethics Committee (approval number: 052.2010) in compliance with the Declaration of Helsinki, and written informed consent was obtained from all XCO-MTB athletes. The ethical procedures followed the previous recommendation (35). XCO-MTB athletes were included if: (a) having a minimum of 5 years of previous experience with XCO-MTB training and racing and were excluded if: (a) they used any caffeinated or alcoholic beverages 2 days before each experimental session; (b) they performed any strenuous exercise < 24 hours before each experimental session.

Table 1. Characteristics of the XCO-MTB athletes (n = 15).

Variables	Mean	SD
Age (years)	31.5	6.6
Stature (cm)	174.0	5.4
Body mass (kg)	67.2	5.1
Body fat (%)	7.0	2.4
VO_{2peak} (mL·kg^{-1}·min^{-1})	64.5	4.7
W_{max} (W·kg^{-1})	4.4	0.3

XCO-MTB = Olympic distance cross-country mountain bike; VO_{2peak} = peak oxygen uptake; W_{max} = maximal work rate in the incremental test; SD = standard deviation.

Protocol

This study was performed in 9 visits. On the first visit, anthropometric assessments and maximal incremental tests were performed using a cycle ergometer. The maximal incremental test was performed to measure the VO_{2peak} and W_{max}. Then, the XCO-MTB athletes were submitted to the TTE tests (105%, 120%, 130%, and 140% W_{max}) performed in a randomized order from the second to fifth visits. The second visit occurred at least 24 hours after the maximal incremental test, and all other visits took place 24 hours apart. The TTE tests (sixth to ninth visits) were repeated in a randomized order (performed 1 week apart). All tests were conducted in the same laboratory, at the same time of day (~2 hours of variation), and the ambient temperature was adjusted to 21° C. The XCO-MTB athletes were instructed to avoid solid foods up to 3 hours preceding tests and maintain water consumption *ad libitum*.

Anthropometry: Athletes' body mass and height were measured using a weighing scale and stadiometer (110 CH, Welmy, São Paulo, Brazil). Also, body composition was estimated based on body density (25) and fat percentage (39) by skinfold thickness measurement (chest, thigh, and abdominal) using a skinfold caliper (Slim Guide, Rosscraft Innovations, Inc., Vancouver, Canada). All technical procedures followed the American College of Sports Medicine guidelines (1).

Maximal incremental test: The maximal incremental test on a bicycle rear wheel coupled to an electronic cycle ergometer (Computrainer™ Lab 3D, RacerMate, Seattle, USA) determined the VO_{2peak} and W_{max}. The XCO-MTB athletes performed a 10 min warm-up set at 100 W, and the test began with a load of 100 W, with 30 W increments every 5 min. This protocol was selected based on a previous study with XCO-MTB athletes (23). The XCO-MTB athletes could choose the preferred cadence between 70 to 90 revolutions per minute ($rev \cdot min^{-1}$) (33). The exercise interruption was the maximum voluntary exhaustion or when the prescribed minimum rotation of 70 $rev \cdot min^{-1}$ was not maintained for 10 s. There was continuous heart rate monitoring (Polar® RS 800 CX (Polar Electro, Oy, Finland). The respiratory gas exchange variables were measured by a Vacumed Vista-Mini CPX (Ventura, California, USA) metabolic analyzer and a Vista Turbo Fit 5.1 (Ventura, California, USA) software in an open circuit. For the determination of VO_{2peak}, the higher average of 30 s oxygen consumption during the maximal incremental test was used. The W_{max} was defined as the last stage load completed by the XCO-MTB athletes. When the stage was not completed, the Kuipers, Verstappen, Keizer, Geurten and van Kranenburg (27) equation was used to determine W_{max}. Although the equation was adjusted from its original format for use in this study, we emphasize that the equation is a mathematical adjustment that can be applied in several possibilities considering the time and load progression. Furthermore, this equation has been used in the literature with different increment durations (22, 44). The cycle ergometer calibration was performed following the manufacturer's instructions, with the rear tire calibrated at 100 *psi* before the start of the 10 min period performed at 150 W. Subsequent calibration took place immediately after the 10 min and the ergometer was accelerated to 40 $km \cdot h^{-1}$ and allowed to decelerate a minimum of 3 times. This procedure was adopted in order to adjust the resistance of the tyre on the flywheel at an appropriate level. The metabolic analyzer was also calibrated as recommended by the manufacturer. In addition, the Computrainer was found to be a reliable measurement device (36). The CV between test-retest trials was 0.7-1.1% for time and 1.7-2.7% for mean power (28, 41).

Time to exhaustion (TTE) test: The TTE tests were determined in seconds in the same cycle ergometer used to perform the maximal incremental test, and the same evaluator applied the test and retest. The Computrainer was calibrated as recommended by the manufacturer. The XCO-MTB athletes performed 4 constant power tests at intensities of 105%, 120%, 130%, and 140% of W_{max} in random order. These intensities were chosen due to the high-intensity intermittent characteristic of the XCO-MTB race (16). The XCO-MTB athletes performed a 10 min warm-up set at 100 W before each test. Pedal cadence was freely chosen between 60 and 100 $rev \cdot min^{-1}$ throughout the tests (17). The TTE test was finished when the participant could not maintain a pedal cadence of at least 60 $revs \cdot min^{-1}$ for more than 5 s (2) despite standardized verbal encouragement (3). The XCO-MTB athletes did not receive any feedback about the work rate, elapsed time (as this would have introduced potential bias with XCO-MTB athletes targeting previous times), or encouragement during any of the TTE tests performed in the present study.

Statistical Analysis

The Shapiro-Wilk test was applied to check a Gaussian distribution of all results. In order to analyze the reliability of the TTE tests, the intraclass correlation coefficient (ICC, 2-way fixed) with a confidence interval of 95% ($CI_{95\%}$) was performed (43). The ICC above 0.90 was classified as high, between 0.80 and 0.89 as moderate, and below 0.80 as questionable (42). The standard error of measurement (SEM) was estimated as follows (10): SEM = $SDd / \sqrt{2}$, where SDd = SD of the difference scores. The CV was established for each XCO-MTB athlete based on the ratio of the standard deviation of each pair of measures to their mean values (CV% = [(SD ÷ mean) * 100]). Subsequently, these data were reported on the mean values of the group for each intensity. The mean values of the test and retest in each intensity (105%, 120%, 130%, and 140% of W_{max}) were compared using the paired samples *t*-test. Also, the Bland-Altman plots with their limits of agreement (LoA) (9) were used to identify potential systematic bias(4). All calculations were performed using IBM® SPSS® Statistics 23 software (IBM Co., USA). The significance level was set at $p \leq 0.05$.

RESULTS

Reliability between TTE trials: There was moderate reliability between TTE trials at 105% W_{max} and 120% W_{max}. For higher intensities (130% W_{max} and 140% W_{max}), the reliability results proved to be questionable. All descriptive values, ICC ($CI_{95\%}$), CV, and SEM, are shown in Table 2.

Table 2. Comparison and reliability between TTE trials at each intensity (n = 15).

%W_{max}	Trial 1 (s)	Trial 2 (s)	*p*	CV (%)	ICC (CI 95%)	*p*	SEM (%)	SEM (s)
105%	388.4 ± 193.3	363.1 ± 111.6	0.78	9.1	0.81 (0.53 to 0.93)	≤ 0.001	18.3	68.8
120%	189.9 ± 54.6	203.2 ± 53.0	0.07	6.6	0.88 (0.69 to 0.96)	≤ 0.001	9.3	18.3
130%	134.9 ± 32.3	133.8 ± 29.2	0.89	9.2	0.53 (0.04 to 0.81)	0.018	15.8	21.2
140%	93.2 ± 17.3	95.5 ± 21.0	0.63	12.2	0.56 (0.09 to 0.83)	0.012	13.5	12.7

Values are mean ± SD. CI 95% = confidence interval 95%; CV = coefficient of variation; ICC = intraclass coefficient correlation; s = seconds; SEM = standard error of measurement; TTE = time to exhaustion; %W_{max} = percentage of maximal work rate in the incremental test.

Differences between both TTE trials in each intensity: No significant differences were found between TTE trials at 105, 120, 130, and 140% W_{max} (see Table 2).

Potential systematic bias: The bias and limits of agreement (upper and lower) between the mean of both trials vs. the difference between 2 trials (i.e., the X and Y axis on the Bland-Altman plot, respectively) in each %W_{max} (105%, 120%, 130%, and 140% W_{max}) are shown in Figure 1.

DISCUSSION

The study analyzed the reliability of the TTE tests at different intensities above VO_{2peak} in trained XCO-MTB athletes. The main finding of this investigation is the moderate reliability at 105% and 120% W_{max} and questionable reliability at 130% and 140% W_{max}. Besides, no significant differences were found between TTE tests at 105, 120, 130, and 140% of W_{max}.

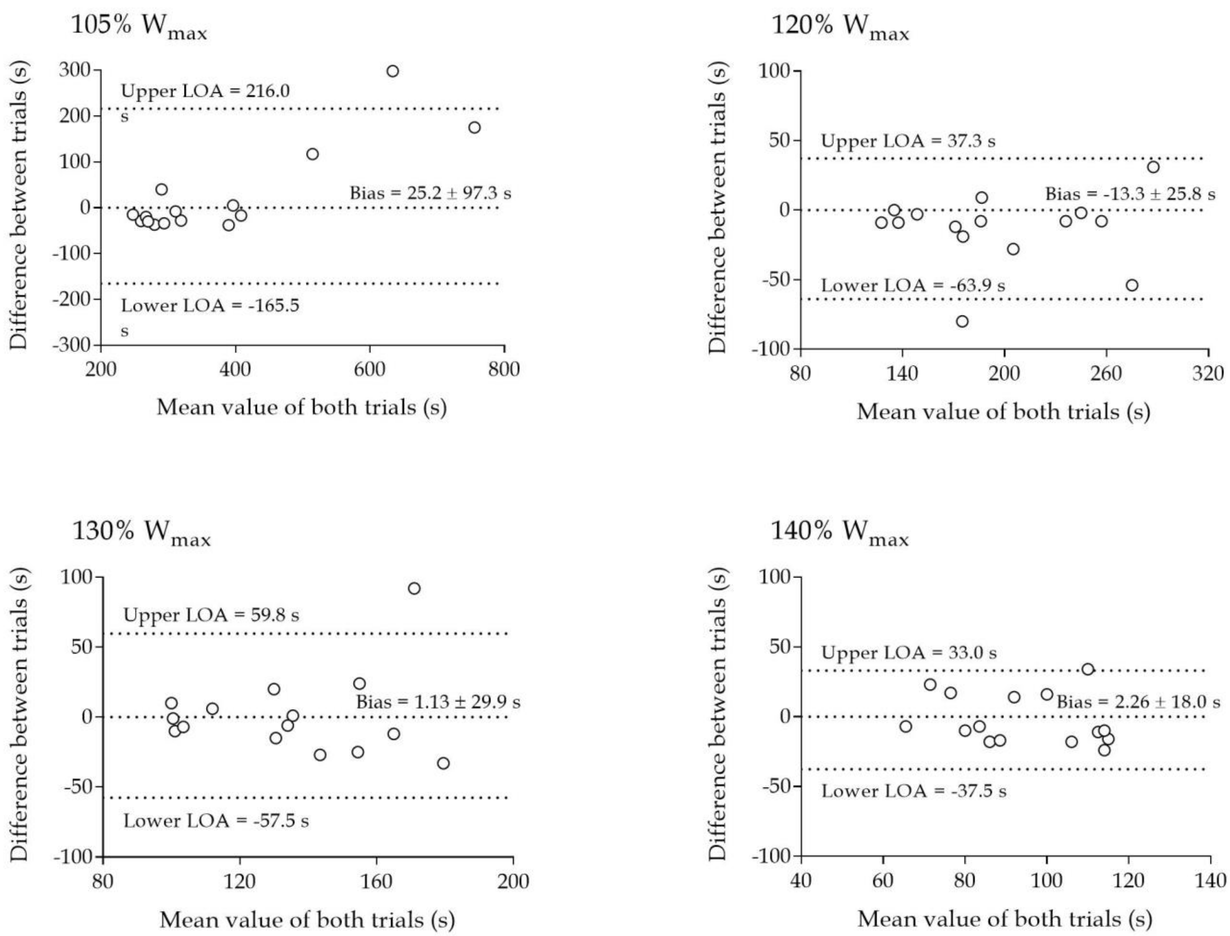

Figure 1. Bland-Altman plot with the difference between trial 1 and trial 2 values on the vertical axis and the average of trial 1 and trial 2 values on the horizontal axis. The horizontal dashed lines represent the observed bias with 1.96 standard deviations. LOA = limits of agreement.

The mean TTE value at 105% of W_{max} in the present study was ~380 s which is higher than 100% of VO_{2peak} observed in trained cyclists: 238.6 ± 33.5 s (11) and 245 ± 57 s (30). This discrepancy may have occurred due to differences between protocols. The protocol of the present study was long, which may have underestimated the W_{max} and altered the TTE values. However, the mean TTE values at 105%, 120%, 130%, and 140% W_{max} in the present study are similar to the study by Hill et al. (18), which was performed with 11 active individuals, and reported TTE values at 95% (558 ± 150 s), 100% (371 ± 65 s), 110% (245 ± 39 s) and 135% (130 ± 14 s) W_{max}.

The reliability analyses used in our research were performed using the ICC (2-way fixed). Previous studies have recommended this analysis (20, 43) as more appropriate. The Pearson product-moment correlation coefficient is typically discouraged for assessing test-retest reliability due to the inability to detect systematic errors (43). Despite the limits of agreement (LOA) described by Bland and Altman (9) not measuring reliability per se, the use of LOA as an index of reliability has been suggested by Atkinson and Nevill (4).

Atkinson and Nevill (5) suggest that external factors and boredom may reduce the reliability of longer-duration TTE tests. However, the present study showed that TTE of longer duration (~6 min) has better reliability considering the ICC. In contrast, no difference in the variability of TTE was shown in the longer (~18 min) or shorter (~6 min) trials in the study by Laursen et al. (29). Perhaps only longer TTE tests (> 60 min) are influenced by external factors and boredom, as suggested by Atkinson and Nevill (5). However, this hypothesis still needs to be further investigated.

Laursen, Shing, and Jenkins (30) and Costa et al. (11) showed in trained male cyclists significant correlations between both TTE tests at VO_{2peak} ($r = 0.80$, $p = .01$ and $r = 0.88$; $p < .001$ respectively). However, they reported a significant statistical difference between the two tests in both studies (11, 30). These results are in contrast with the findings of the present study (no significant differences between TTE tests at any intensity (see Table 2). These differences between studies can be explained by the different protocols used to determine the VO_{2peak}, competitive periods, participants' levels, cycle ergometers used, and differences between sports modalities. For example, the ability of XCO-MTB athletes to produce successive brief, high-intensity efforts separated by short recovery periods could be better compared to road cyclists or triathletes. However, this hypothesis still needs to be further investigated.

The data from the present study, despite the non-significant differences between test and retest, CV values ranged from ~7% to ~12%, and SEM values ranged from ~9% to ~18% suggest that the exercises called open-loop (time to exhaustion tests) are not sensitive enough to monitor training programs in XCO-MTB athletes. It is worth noting that the mean duration sustained until exhaustion at the intensity of 120% W_{max} was approximately 3 min, and that intensity had the lowest CV (6.6%) and SEM (9.3%). This result can be explained at least in part by the type of training performed by the XCO-MTB athletes. Based on anecdotal evidence provided by XCO-MTB athletes, the most frequently performed stimulus lasted 3 min during high-intensity interval training. In this sense, trained athletes can more easily identify the intensity levels they experience most frequently (14). On the other hand, exercises with closed-loop characteristics (time trials) have lower CV values, as suggested by Zavorsky et al. (45) in a 20 km time trial (CV = 1.4%) and Smith et al. (40) evaluating cyclists in 40 km time trials (CV = 1.0%). Therefore, according to Laursen et al. (30) and Jeukendrup et al. (26), closed-loop exercises may be more appropriate for monitoring performance in cyclists. Corroborating the previous findings, Laursen et al. (29) investigated the reliability of TTE tests vs. time trials in runners and reported lower variability and greater reliability (CV = 2.0 to 3.3%; ICC = 0.88 to 0.95) compared to the TTE tests (CV = 13.2 to 15.1%; ICC = 0.45 to 0.57). In addition, Billat et al. (8) found an intra-individual variation of 10% between two TTE tests at VO_{2peak}. In this sense, TTE could be interesting in detecting training effects in a group of subjects. On the other hand, TTE is probably not sensitive enough to monitor training programs for a single athlete due to significant individual variation. However, some authors disagree that TTE tests cannot be used for training monitoring (2, 19). Therefore, a CV of ~10% may be high for time trial tests but not for a TTE test.

This study had some limitations, which suggest caution when interpreting the results. The first limitation was the performance level of XCO-MTB athletes. In elite athletes, the results related to TTE variation could be different. The second limitation is the use of only two TTE tests. The increased number of tests may provide higher reliability of TTE tests (12). However, in practical terms, it is challenging to perform a large number of tests on athletes to verify TTE at different intensities due to training and competition routines. Also, the lack of familiarization trials is a limitation; however, XCO-MTB athletes often perform high-intensity efforts above VO_{2peak} in training and racing, which may have minimized this limitation. Fourth, the VO_{2peak} protocol used was long, which may have underestimated the W_{max} values and consequently altered the TTE values. The fifth limitation, the present study did not use women due to the lack of a female sample. In this sense, the results cannot be extrapolated to female XCO-MTB athletes. Future studies in recreational and elite populations should increase the number of female participants (34). Finally, our study did not calculate the sample size. This fact limits an extrapolation of our findings. However, it should be noted that we used a convenience sample considering the limited number of well-conditioned XCO-MTB athletes available to participate in this study.

Caution should be taken when assessing TTE above VO_{2peak} or when using it as a performance indicator, given its moderate to questionable reliability, especially during TTE tests with higher intensities (i.e., above 130% W_{max}). These findings have important practical applications for XCO-MTB training prescription and monitorization. TTE tests do not seem to be the best option, and using closed-loop tests (e.g., time trials) could be an alternative strategy. In addition, TTE tests with longer durations or intensities/durations that athletes frequently perform in training and racing are preferable.

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