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**Title:** Power profiles of competitive and non-competitive mountain bikers.

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**ABSTRACT**

The performance of Olympic distance cross-country mountain bikers (XCO-MTB) is affected by constraints such as erosion of track surfaces and mass start congestion which can affect race results. Standardised laboratory assessments quantify inter-seasonal and intra-seasonal cycling potential through the assessment of multiple physiological capacities. Therefore, this study examined whether the power profile assessment could discriminate between competitive XCO-MTB and non-competitive mountain bikers (NC-MTB). Secondly, it aimed to report normative power profile data for competitive XCO-MTB cyclists. Twenty-nine male participants were recruited across groups of XCO-MTB (n=14) and NC-MTB (n=15) mountain bikers. Each cyclist completed a power profile assessment that consisted of increasing duration maximal efforts (6, 15, 30, 60, 240 and 600 s) that were interspersed by longer rest periods (174, 225, 330, 480 and 600 s) between efforts. Normative power outputs were established for XCO-MTB cyclists ranging between 13.8 ± 1.5 W·kg$^{-1}$ (5 s effort) to 4.1 ± 0.6 W·kg$^{-1}$ (600 s effort). No differences in absolute peak power or cadence were identified between groups across any effort length ($p>0.05$). However, the XCO-MTB cyclists produced greater mean power outputs relative to body mass than the NC-MTB during the 60 s (6.9 ± 0.8 vs 6.4 ± 0.6 W·kg$^{-1}$; $p=0.002$), 240 s (4.7 ± 0.7 vs 3.8 ± 0.4 W·kg$^{-1}$; $p<0.001$) and 600 s (4.1 ± 0.6 vs 3.4 ± 0.3 W·kg$^{-1}$; $p<0.001$) efforts. The power profile assessment is a useful discriminative assessment tool for XCO-MTB and highlights the importance of aerobic power for XCO-MTB performance.

**Keywords:** cycling, power output, coaching, testing, performance

## INTRODUCTION

Olympic distance cross-country mountain bike racing (XCO-MTB) requires cyclists to complete multiple laps of an off-road circuit that consists of a wide variety of terrain and obstacles. These tracks are exposed to rain, wind and erosion which affects the exposure of rocks, branches, ruts and tree roots. Additionally, other obstacles such as fallen trees or loose rocks may appear on the track and significantly impact on the route. These changes in trail conditions produce inconsistent environmental and physical influences on performance, which may affect the reliability of field-based XCO-MTB tests. Therefore, the assessment of XCO-MTB performance has been largely limited to controlled laboratory environments to avoid such confounding influences (8, 9, 11).

XCO-MTB competition can be best described as an endurance cycling discipline that typically lasts ~90 min (UCI Race Regulations: Part 4 Mountain Bike Races, 2016) and as such, initial laboratory investigations have focused on the aerobic characteristics of XCO-MTB athletes. These investigations have reported that XCO-MTB athletes possess high relative $\dot{V}O_2max$ values (e.g. national level riders: 65–75 ml·kg$^{-1}$·min$^{-1}$; international riders: 75–86 ml·kg$^{-1}$·min$^{-1}$) (2, 5, 6, 8, 9, 11, 17, 19). Further, elite XCO-MTB cyclists have demonstrated high maximal aerobic cycling power outputs relative to body mass (6-6.5W·kg$^{-1}$) (8, 11). However, while aerobic characteristics are important for XCO-MTB performance, it has been suggested that high anaerobic power outputs may also benefit performance due to the intermittent nature of XCO-MTB competition (7, 10, 12, 13). Recent studies (10, 13) have shown that anaerobic characteristics strongly correlate with XCO-MTB performance. Specifically, Inoue, Sa Filho, Mello and Santos (10) utilised both a single Wingate test as well as an intermittent protocol that consisted of five Wingate tests at 50% of single Wingate load with 30 s rest between each effort to compare against XCO-MTB performance. These data showed that peak power output during the repeat Wingate test correlated strongly with race performance (r = -0.79; p<0.01). Miller, Moir and Stannard (13) further showed that a cycling test which lasted 20 min and consisted of intermittent high-intensity efforts (20 intervals of 45 seconds work and 15 seconds recovery) correlated slightly more strongly (r = 0.886, p<0.01) with XCO-MTB performance than a standard functional threshold power test (maximal mean power output across 20 min) (1) (r = 0.858, p<0.01). Additionally, Macdermid and Stannard (12) demonstrated that XCO-MTB cycling power output was produced intermittently, reporting one surge was performed every 32 s and one supramaximal effort every 106 s. Collectively, the data suggest a high contribution from anaerobic energy metabolism during XCO-MTB, which may identify that anaerobic characteristics are worthy of further investigation.

Within the last decade, the development of the power profile assessment (PPA) has allowed both the aerobic and anaerobic power outputs of cyclists to be quantified using a single protocol lasting ~50 min (16, 18). The PPA was primarily developed for road cyclists and triathletes and has been employed as a recommended protocol to assess cycling potential (18). However, the protocol has only recently been adopted for XCO-MTB populations where various efforts were shown to contribute significantly to predictive models of performance (14). Additionally, the highly intermittent nature of XCO-MTB power output means it is unlikely that any constant effort would last for longer than 600 s (12). Therefore, the PPA may be useful for the quantification of aerobic and anaerobic characteristics of XCO-MTB athletes and may be useful as a discriminative assessment tool. This study aimed to determine whether the PPA could distinguish between competitive and non-competitive

XCO-MTB cyclists. Secondly, the study aimed to establish normative power profile data to assist coaches and athletes in the development of training and testing practices. It was hypothesised that competitive XCO-MTB athletes would demonstrate both higher aerobic and anaerobic power outputs across all efforts of the PPA than non-competitive mountain bikers.

## METHODS

### Experimental Approach to the Problem

This study adopted an observational approach, utilising the PPA (16, 18) to quantify the power output and cadence of XCO-MTB and non-competitive mountain bikers (NC-MTB) across a range of durations typical of competition. The PPA requires participants to cycle at self-paced maximal effort (6 s stationary start, 6 s rolling start, 15 s, 30 s, 60 s, 240 s and 600 s), with increasing rest periods provided between each effort (54 s, 174 s, 225 s, 330 s, 480 s and 600 s). Cyclists were then categorised as either a competitive or non-competitive XCO-MTB athlete, depending upon their competition history. Data from the PPA were then averaged and fitted to a power function that provided both an intercept and exponent which allows such data to be used in the prescription of training. Data were then compared between two cohorts.

## Subjects

Twenty-nine male participants were recruited for this study and were classified as either competitive Olympic-distance mountain bikers (XCO-MTB; n=14) or non-competitive mountain bikers (NC-MTB; n=15). The XCO-MTB cyclists (age 31.4 ± 8.4 yr; height 177.2 ± 5.4 cm; body mass 71.2 ± 7.1 kg) were currently competitive in the top grade at local competitions (≥10 XCO-MTB races per year), while the NC-MTB cyclists (age 34.8 ± 6.1 y; height 179.6 ± 6.6 cm; body mass 80.6 ± 12.2 kg) were casual mountain bikers who cycled 2-4 times per week and may have participated in occasional social mountain biking events or team-based races (≤5 events per year). All participants provided written informed consent and were screened for medical contraindications for exercise. Participants were included who were male, aged between 18-50 y and were free from medical contraindications. Participants were excluded if they did not complete the testing session in full or did not meet any of the criteria listed above. Human ethical approval was received from the University of REMOVED FOR BLIND REVIEW ethical review committee (approval number REMOVED FOR BLIND REVIEW).

## Procedures

Each participant attended the exercise testing laboratory for an individual testing session in which they completed a cycling power profile assessment as described above (18). All cyclists had completed a PPA on at least one prior occasion and were therefore familiar with the protocol. A self-paced warm-up was completed for 10 min at intensities between 100-200 W. This was followed by three, high-intensity efforts lasting six seconds each at 70%, 80% and 90% of maximal power output that were separated by 30 s of passive rest. The PPA consisted of seven maximal efforts that lasted between 6-600 s with rest periods provided between each effort. The first effort was 6 s from a stationary standing start, while the second effort was 6 s from a rolling standing start. The five remaining efforts were completed from a rolling start and lasted 15 s, 30 s, 60 s, 240 s, and 600 s. Rest intervals between the efforts were progressively increased throughout the protocol (54 s, 174 s, 225 s, 330 s, 480 s and 600 s) and participants were encouraged to undertake low-intensity active recovery (<100 W). Cyclists were encouraged to adjust gears in order to produce the highest mean power output throughout each interval. Participants were allowed to ingest water *ad libitum*. Across the 48 h prior to the PPA, participants were asked to refrain from high intensity exercise, alcohol, caffeine and any other potentially performance improving substances.

The test was completed on a UCI-legal road bicycle (Specialized Allez Comp, Specialized Bicycle Components, Morgan Hill, CA, USA) that was attached to a LeMond Revolution cycle ergometer that replaced the bicycle's rear wheel (LeMond Fitness Inc., Woodinville, Washington, USA). The bicycle seat (height and for-aft position) and the bicycle stem (height, angle and length) were adjusted to replicate each individual cyclist's normal bicycle geometry. The bicycle was fitted with an adjustable-length crankset to further ensure consistency with normal training geometry and normal muscular activation. The bicycle was fitted with Garmin Vector pedal-based power meters (Garmin Ltd, Schaffhausen, Switzerland) that have been previously validated against a scientific model SRM crankset (15). A Garmin cadence sensor was also fitted to the bicycle's crank on the non-drive side. Measures of power output and cadence were transmitted to a Garmin Edge 520 head unit at a frequency of 1 Hz. Data were then downloaded to a Microsoft Excel spreadsheet for arrangement and initial exploratory analyses (Microsoft Office 2016, Microsoft Corporation™, Redmond, WA, USA).

## Statistical Analyses

Data were assessed for assumptions of normality using the Shapiro-Wilke test and were visually inspected via box plots. Following the identification of normality within both XCO-MTB and NC-MTB groups, a 2x7 repeated measures MANOVA was completed to examine interaction effects between groups for cadence, as well as absolute values (W) and relative values ($W \cdot kg^{-1}$) of mean and peak power outputs. Where significant interaction effects were identified, independent samples t-tests were used to further examine the specific efforts in which these differences occurred. Statistical significance was identified where $p < 0.05$ and effect size was determined using partial Eta squared, with magnitudes <0.06 classified as small, values 0.06-0.13 considered medium and ≥0.14 classed as large (3). Normative data was calculated for XCO-MTB and NC-MTB groups as mean values for each effort. Individual values were also identified for the "best" XCO-MTB athlete who participated in the study, with this athlete identified as the best athlete within the laboratory test as well as in XCO-MTB competition. This cyclist was also the only rider to recently finish within the top 10 competitors in recent Australian national series XCO-MTB competitions. All statistical analyses were completed in SPSS statistical software (v23; SPSS Inc., Chicago, IL, USA). PPA plots and equations were determined for each group using Microsoft Excel's power curve function (Microsoft Office 2016, Microsoft Corporation™, Redmond, WA, USA).

# RESULTS

The mean power outputs and cadences representative of each effort of the PPA by the XCO-MTB and NC-MTB cyclists are shown in Table 1. Power outputs are reported as both absolute (W) and relative to body mass ($W \cdot kg^{-1}$). Peak power values for the first three efforts of the PPA are also reported in Table 1.

*** INSERT TABLE 1 HERE ***

For absolute values of mean power output, repeated measures MANOVA identified significant time-group interaction effects ($F = 5.117$, $p = 0.009$, $\eta^2 = 0.159$) and time effects ($F = 481.179$, $p < 0.001$, $\eta^2 = 0.947$). No significant between-subject effect was identified for group ($F = 1.116$, $p = 0.300$, $\eta^2 = 0.040$). *Post-hoc* independent samples t-tests identified significant differences between all efforts except between those completed for the 5 s stationary and rolling starts. Significant differences were also identified between groups for the 5 s stationary effort, with XCO-MTB cyclists producing significantly less absolute mean power output than NC-MTB (967 ± 140 vs. 1109 ± 187 W, $p = 0.029$).

For relative values of mean power output, repeated measures MANOVA identified no significant time-group interaction effect ($F = 1.603$, $p = 0.201$, $\eta^2 = 0.056$). However, significant within-subjects time ($F = 767.422$, $p < 0.001$, $\eta^2 = 0.966$) and between-subjects group effects ($F = 4.629$, $p = 0.041$, $\eta^2 = 0.146$) were observed. Furthermore, visual inspections of power functions produced within Microsoft Excel (Figure 1), suggested that *post-hoc* examination of differences between the two groups was warranted. Independent samples t-tests identified that relative power output was significantly different for each effort except between the 5 s efforts from stationary and rolling starts ($p = 0.108$). Independent t-tests also identified that XCO-MTB athletes produced significantly greater relative mean power outputs than the NC-MTB cohort for efforts of 60 s (6.9 ± 0.8 vs. 6.4 ± 0.6 $W \cdot kg^{-1}$; $p = 0.002$), 240 s (4.7 ± 0.7 vs. 3.8 ± 0.4 $W \cdot kg^{-1}$; $p < 0.001$), and 600 s (4.1 ± 0.6 vs. 3.4 ± 0.3 $W \cdot kg^{-1}$; $p < 0.001$).

*** INSERT FIGURE 1 HERE ***

No time-group interaction effects or between-groups effects were identified for peak power outputs or cadences for any effort. However, significant within-subjects time effects were present for absolute peak power output ($F = 28.012$, $p < 0.001$, $\eta^2 = 0.509$), relative peak power output ($F = 31.087$, $p < 0.001$, $\eta^2 = 0.535$) and cadence ($F = 18.801$, $p < 0.001$, $\eta^2 = 0.410$).

Lastly, the resultant power functions are provided in Figure 1 for XCO-MTB and NC-MTB groups as well as the individual data of the best XCO-MTB cyclist. Each of these power functions displayed good fit ($R^2 = 0.98$). The best XCO-MTB cyclist (the only cyclist to recently finish within the top 10 riders at a recent Australian national series XCO-MTB competition) produced the highest individual power output relative to body mass for four efforts (30 s, 60, 240 and 600 s) and was also within the top three individual cyclists for the shorter sprint efforts (5 s and 15 s).

**DISCUSSION**

This study aimed to determine whether the PPA could discriminate XCO-MTB performance as well as provide normative XCO-MTB data for the PPA. The key findings demonstrate that the PPA could discriminate between the laboratory performance potential of XCO-MTB and NC-MTB cyclists, with competitive amateur XCO-MTB cyclists demonstrating significantly higher relative power output across the 60 s, 240 s, and 600 s efforts than the non-competitive cyclists. Despite these differences, the XCO-MTB cyclists displayed lower absolute power output during the 5 s effort from stationary start. Furthermore, the greater relative power outputs of the XCO-MTB cyclists were not attributed to any differences in cycling cadence. These data support previous suggestions that XCO-MTB is highly reliant on aerobic capacities relative to body mass (6, 11). Separately, while the 60 s, 240 s and 600 s efforts were able to discriminate between the two groups, the shorter duration efforts (5 s, 15 s and 30 s) did not. These data indicate that anaerobic power characteristics might not be the most important to sub-elite XCO-MTB athletes or that their pacing strategies were superior to NC-MTB.

The results of this study have established normative power profiles for competitive sub-elite XCO-MTB cyclists as well as one potential elite XCO-MTB cyclist. The XCO-MTB cohort within this study produced absolute power outputs that are consistent with those reported for experienced national road cyclists (16) for efforts of 5-30 s (968-658 W vs. 986-642 W, respectively), however, power outputs of the XCO-MTB cyclists were lower for efforts of 60-600 s (489-293 W vs. 529-346 W, respectively). Given that the cyclists within the current study also possessed slightly greater body mass than the road cyclists (71.2 ± 7.1 kg vs. 67.3 ± 5.5 kg, respectively), this finding likely reflects lower competitive level and training volumes overall within the current cohort. Comparatively, the best individual cyclist within the current study produced greater absolute power output across all efforts (370-1029 W) than the mean values for either the XCO-MTB or road cohort and possessed similar low body mass to the road cyclists (66.8 kg). Separately, in comparison to six Olympic and world cup XCO-MTB competitors (4), the XCO-MTB cohort within the current study produced lower absolute and relative mean power output across 30 s (659 vs. 741 W and 9.3 vs. 10.7 $W \cdot kg^{-1}$), although the best cyclist of the current study produced comparable values to the elite Olympic level cohort (747 W and 11.2 $W \cdot kg^{-1}$). It should also be noted however, that the elite cohort (4) completed the 30 s test as an individual Wingate test from a rested state, while the current cyclists may have experienced residual fatigue from the prior 5 s and 15 s efforts. Collectively, comparisons with these studies highlight that the current cohort was representative of a competitive but non-elite population while the best athlete produced higher values across all efforts, similar to those of internationally competitive XCO-MTB populations.

In addition to providing normative data for XCO-MTB cyclists, this study has also identified that the PPA assessment is a valid method of distinguishing between XCO-MTB and NC-MTB cyclists. In particular, there were significant differences in power output relative to body mass between these groups for efforts of 60 s, 240 s and 600 s, suggesting that low body mass and a high aerobic capacity are important predictors for XCO-MTB competition, and are likely to reflect the greater training volumes undertaken by the XCO-MTB cohort. Also, the XCO-MTB cohort were likely to be more familiar with high-intensity cycling, which in turn, may have helped them employ superior pacing strategies in order to sustain greater power outputs across the longer duration efforts. These findings support previous research that has shown aerobic power and capacity to correlate strongly with performance within sub-elite XCO-MTB populations (9). However, compared to previous research, the use of the PPA and associated power curves provide novel insight separate to that of traditional incremental power tests. For example, while the PPA required only seven individual efforts, the resultant power curve provides coaches with equations (Figure 1) that can estimate the maximal power output for a variety of other effort durations. For example, cycling critical power output (CP) could be estimated using the equations provided in Figure 1. However, CP estimations that are calculated from all seven PPA efforts are likely to underestimate CP due to the over-representation of anaerobic contribution (unpublished observations). This discrepancy may be further exacerbated with changes in pacing strategies across the various length efforts. It's suggested that the 5-30 s data should be removed when estimating CP i.e. only data from the 60 s, 240 s, and 600 s efforts should be included. Participants should also be blinded from CP estimations to limit the likelihood of influencing pacing strategies between PPA tests. Estimations may also be useful to compare mobile power data from field-based training or races with the normative power functions established in Figure 1.

In addition to the practical use of the power functions, it should be noted that the power functions may additionally be used to describe the athletes' collective power characteristics. For example, the best athlete's power function produced a high y-intercept (24.142) as well as the highest exponent (-0.238). Firstly, the high y-intercept suggests that the athlete produces high power outputs during efforts that are predominantly fueled by anaerobic energy metabolism (the short efforts of the PPA). Moreover, the high exponent relates to a reduced rate of decay within the function when compared to that of the mean values of the two cohorts. It is important that these values are observed together rather than in isolation. This is due to the observation that an increase in the value of the y-intercept within subsequent testing sessions could be a result of either a higher 5 s effort or a lower 600 s effort than a previous test. In isolation, the high y-intercept would appear to be a positive result. However, when observed together with the exponent, an increase in the value of the y-intercept as a result of a lower 600 s effort will coincide with the value of the exponent decreasing and could thus be identified more appropriately and is not necessarily a positive result (depending on the current training goals). When taken together, an increase in both the y-intercept and exponent identifies that an athlete is able to produce stronger anaerobic efforts of short duration, while concurrently exhibiting greater endurance potential.

The findings of this study should be used with knowledge of several limitations. Firstly, the participants in this study were sub-elite cyclists and therefore the findings may not be generalizable to cyclists of all levels. The normative data reported in this study is applicable to those athletes competing at the top level in local competitions, while the data of the best athlete is that of a competitive national level athlete. Additionally, it should be noted that the first efforts of the PPA are completed from a rested state rather than fatigued. Therefore, caution is advised when comparing these efforts with field-based efforts in which an athlete will likely be cycling in a fatigued state and with influence of environmental factors. It should also be acknowledged that the sampling rate of the cycling cadence was limited to 1 Hz, which results in difficulties detecting changes across the shorter efforts of the PPA. This limitation is inherent with most current cycling power meters.

Overall, this study supports that the PPA is a useful discriminative tool within mountain biking populations. Additionally, the normative data and power functions provide coaches with data that can be used in the preparation of athletes at various levels of competition. Further research should determine whether the 60 s, 240 s and 600 s efforts remain important discriminatory efforts between elite and sub-elite XCO-MTB cyclists, as well as the influence of pacing strategies. Further research should also aim to determine if anaerobic power (5 s, 15 s and 30 s efforts) become discriminatory characteristics at elite levels of competition.



 

## Practical Applications

The data reported in this study can be used by coaches and athletes as a set of normative values to guide training and performance testing practices. Furthermore, coaches and athletes mays use the equations provided in Figure 1 to guide training strategies. At the sub-elite level of XCO-MTB competition, athletes should develop power outputs relative to their body mass throughout the 60 s, 240 s and 600 s efforts. Subsequently, XCO-MTB athletes aiming to progress to national and international level competitions should strive to develop power profiles beyond those of the top athlete reported in this study, which is likely due to an increase in training volume and effect pacing strategies. With the advent of cheaper and more accessible power meters for cyclists and the proliferation of online training analyses, coaches and athletes could use race and training derived PPA data to compare with laboratory PPA data. This is an important consideration for athlete monitoring, as personal best performances are often exhibited during competition.

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**Conflict of Interest:** There is no conflict of interest pertaining to the published data.

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## Table Captions

**Table 1:** Normative power profile data for competitive mountain bikers, non-competitive mountain bikers and the best mountain biker (mean ± SD).

## Figure Captions

**Figure 1:** Power profiles and equations of competitive mountain bikers (XCO-MTB), non-competitive mountain bikers (NC-MTB) and the best mountain biker.

**Table 1:** Normative power profile data for competitive mountain bikers, non-competitive mountain bikers and the best mountain biker (mean ± SD).

| | Effort | XCO-MTB | NC-MTB | Best XCO-MTB |
|---|---|---|---|---|
| Mean Power (W) | 5 s Stationary | 967 ± 140* | 1109 ± 187 | 1030 |
| | 5 s Rolling | 1023 ± 146 | 1146 ± 219 | 1078 |
| | 15 s | 848 ± 119 | 892 ± 178 | 896 |
| | 30 s | 659 ± 98 | 676 ± 140 | 747 |
| | 60 s | 489 ± 55 | 487 ± 83 | 560 |
| | 240 s | 331 ± 55 | 302 ± 39 | 420 |
| | 600 s | 292 ± 46 | 273 ± 39 | 370 |
| Mean Power ($W \cdot kg^{-1}$) | 5 s Stationary | 13.7 ± 1.7 | 13.8 ± 1.2 | 15.4 |
| | 5 s Rolling | 13.8 ± 1.5 | 14.2 ± 1.6 | 16.1 |
| | 15 s | 11.9 ± 0.8 | 11.1 ± 1.6 | 13.4 |
| | 30 s | 9.3 ± 0.8 | 8.4 ± 1.4 | 11.2 |
| | 60 s | 6.9 ± 0.8 * | 6.4 ± 0.6 | 8.4 |
| | 240 s | 4.7 ± 0.7 * | 3.8 ± 0.4 | 6.3 |
| | 600 s | 4.1 ± 0.6 * | 3.4 ± 0.3 | 5.5 |
| Peak Power (W) | 5 s Stationary | 1142 | 1253 | 1109 |
| | 5 s Rolling | 1114 | 1240 | 1124 |
| | 15 s | 1048 | 1095 | 1072 |
| Peak Power ($W \cdot kg^{-1}$) | 5 s Stationary | 16.0 | 15.6 | 16.6 |
| | 5 s Rolling | 15.7 | 15.4 | 16.8 |
| | 15 s | 14.7 | 13.6 | 16.0 |
| Mean Cadence | 5 s Stationary | 103 | 104 | 91 |
| | 5 s Rolling | 112 | 104 | 91 |
| | 15 s | 113 | 115 | 106 |
| | 30 s | 110 | 112 | 111 |
| | 60 s | 107 | 108 | 106 |
| | 240 s | 99 | 100 | 102 |
| | 600 s | 96 | 96 | 97 |

**Key:** ***** = significantly different from NC-MTB ($p < 0.05$); **NC-MTB** = non-competitive mountain bikers; **XCO-MTB** = competitive Olympic distance mountain bikers.

Figure

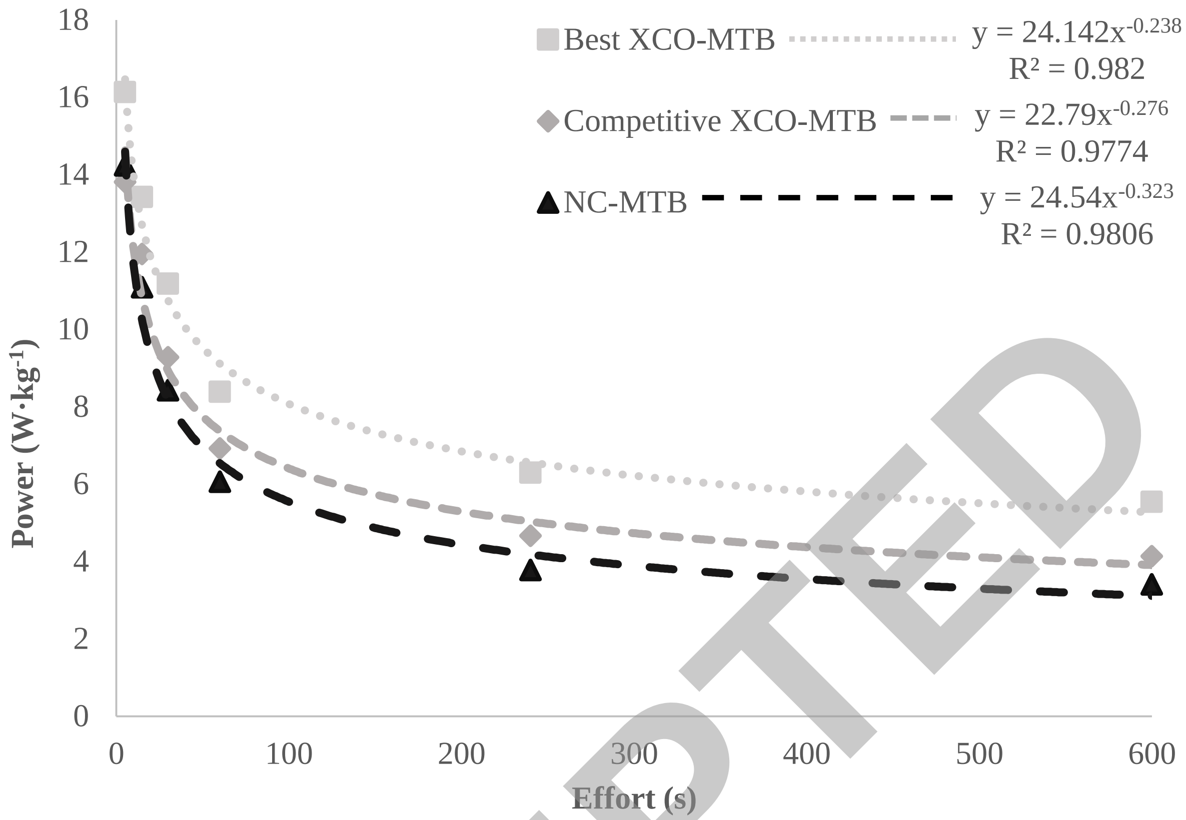


**Figure 1:** Power profiles and equations of competitive mountain bikers (XCO-MTB), non-competitive mountain bikers (NC-MTB) and the best mountain biker.