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Review

Time to exhaustion at estimated functional threshold power in road cyclists of different performance levels

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ABSTRACT

Objectives: This study assessed the functional threshold power and the time to exhaustion estimated from the Allen & Coggan test and verify whether performance level has an influence on this parameter.
Design: Cross-sectional study.
Methods: Twenty-minute test proposed by Allen & Coggan and cycling test to exhaustion were used to obtain the functional threshold power and a time to exhaustion. Cyclists were divided into performance groups based into 4 categories according to their VO_{2max}.
Results: The median (interquartile range) time to exhaustion at the functional threshold power was 35 (31–38) minutes for recreationally trained cyclists, 42 (38–51) for trained ones, 47 (41–56) for well-trained ones and 51 (44–59) for professional level cyclists. Time to exhaustion increased with cyclists' experience and performance level ($p < 0.001$).
Conclusions: The high time to exhaustion variability observed in this study suggests that functional threshold power and time to exhaustion should be assessed and reported independently for each subject. Also, cyclists' performance level and experience should be factored in when attempting to study the time to exhaustion, as better performing and more experienced cyclists consistently show longer times to exhaustion at the functional threshold power.

Practical Implications

- FTP estimated from the Allen & Coggan test should not be used interchangeably with the 60-min maximal power output as the TTE at FTP is consistently below the hour mark.
- Cyclists' level should be considered when reporting and assessing TTE at FTP as higher-performing cyclists show longer TTE.
- TTE at FTP should be assessed independently for each cyclist given the differences between individuals and also performance groups.
- Training time at FTP should be individualized as the same TTE percentage results in different absolute work times for each cyclist.

1. Introduction

Road cycling is characterized by high energetic demands, large training volumes and very selective physiological requirements in order to perform at a high level.[1] To date, several physiological markers have been linked to cycling performance.[2] Among them, power output at the maximal metabolic steady state can be highlighted as one of the best tools to categorize cyclists according to their performance level.[3,4] Until recently, the maximal metabolic steady state was normally assessed in a laboratory by using lactate and gas exchange methods, the gold standard.[5] However, technological progress in recent years has greatly broadened the horizons in this field.

During the last years, the increasing use of mobile power meters in both the professional and amateur cycling fields has provided coaches and scientists with information that would have previously only been accessible through laboratory means.[6] Among the many new advancements brought by mobile power meters, the possibility to assess the maximal metabolic steady state through power data must be highlighted.[7] This parameter can be studied either through direct observation of the power curve or through an indirect estimation with the help of a standardized field test.[8] Regarding this second possibility, one of the most popular tests was proposed by Allen & Coggan.[9] These authors suggested that subtracting 5 % to the power output obtained during a 20-minute interval could be a valid estimate of the functional threshold power (FTP), which is the name given to the metabolic steady

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state obtained through power data.[10] Several authors have attempted to verify whether this protocol can produce a valid assessment of the FTP, with varying degrees of success. Although most studies, especially those with the largest sample sizes, reported large correlations between FTP obtained through Allen & Coggan's protocol and steady state measures such as the maximal lactate steady state, lactate landmarks, or the respiratory compensation point,[3,11–16] some authors suggested that this relationship is weak at best.[17,18]

One of the best options to verify whether FTP estimated from Allen & Coggan's protocol represents a true metabolic steady state would be to attempt a time to exhaustion (TTE) test at this intensity. If this landmark truly represented a quasi- steady state, then cyclists would be able to perform at this power output for durations that are close to the hour mark. This experiment was once attempted by Borszcz et al., who reported a TTE of 50.9 ± 15.7 min in a sample of 23 trained male cyclists.[18] Although this result may seem promising, there were large differences in the TTE reported by participants, cyclists were not divided into performance groups, and the study sample given the complexity of the study was not large enough to allow an extrapolation for the broad cycling field. In this case, an increase in the number of participants could pose several benefits: a larger study sample would provide a better idea of the TTE variability and would also allow assessing the differences between performance groups.

The influence of pacing strategies in endurance sports outcomes is well known. Therefore, better cyclists, who are also commonly more experienced, should theoretically perform better in self-paced tests.[19,20] Accordingly, it could be hypothesized that cyclists with different performance levels might show different TTE at FTP. Given all the above, the objectives of the current study were a) to assess the TTE at FTP and b) to establish the relationship between performance level and TTE at FTP.

2. Methods

A total of 87 cyclists (age 37.7 ± 7.5 years, range = 21–56 years) were recruited for the study. Following the guidelines proposed by De Pauw et al., participants were classified into 4 categories according to their VO_{2max}: recreationally trained ($n = 18$), trained ($n = 31$), well trained ($n = 20$) and professional (n = 18).[21] The VO_{2max} of each participant was estimated using a predictive equation recently described for road cyclists.[22] Descriptive data of each group is provided in Table 1. The inclusion criteria were: (a) current owner of a cycling license (World Tour, Elite/U23, Masters, or recreational); (b) absence of surgical procedures and injuries in the 6 months prior to the study; and (c) absence of drug use in the 6 months prior to the study. After being informed of the benefits and potential risks of the investigation, each subject completed a health-screening questionnaire and provided written informed consent before participation in the study. The study followed the ethical guidelines of the 2013 Declaration of Helsinki and received approval from the Research Ethics Committee of the autonomous region of Aragon, Spain (PI19/447).

Participants completed the study in 2 separate days with a 72 h rest in between. Day 1: anthropometric evaluation and Allen & Coggan's protocol. Day 2: cycling test to exhaustion. All evaluations were performed during the same morning hours (between 10:00 AM and 12:00 AM) to control for diurnal hormonal variations. Data were collected under similar environmental conditions (17–18 °C, 45–55 % relative humidity). All participants performed both tests on their own bikes set up on a Tacx Neo 2T Smart bike trainer (Tacx International, Rijksstraatweg, the Netherlands). Power output was measured with the Favero Assioma pedals.[23] The bike trainer was set in automatic mode, which increases resistance when cadence is increased abnormally and vice versa.

The body mass of all cyclists was assessed through the electrical impedance method (BC-602; Tanita Co., Tokyo, Japan) in the morning hours. Height was measured with a SECA 214 stadiometer (Seca; Hamburg, Germany).

During the first day of the assessment, participants performed the twenty-minutes test protocol suggested by Allen & Coggan, which has been used in previous studies.[11,12] They could view their progress on a computer monitor and were provided with information regarding time to completion and gear choice. All other information was blinded, no verbal encouragement was provided, and water was allowed ad libitum. The warm-up duration was 50 min, as follows: (a) 20 min at a self-selected easy intensity, (b) three 1-minute fast pedaling accelerations (100–105 rpm) with a 1-min recovery between efforts, (c) 5 min at a self-selected easy intensity, (d) 5-minute time trial, and (e) 10 min at a self-selected easy intensity and 5 min of resting. The main part of the test consisted of a 20- min maximal effort, where participants were asked to produce the highest mean power output possible for this duration and adopt their personal pacing strategies. FTP was determined as 95 % of the mean power output of the 20-minute effort.

After a 72 h rest, participants returned to the laboratory to perform a cycling test to exhaustion at the intensity of the FTP estimated in the previous assessment. First, participants performed the same 50-minute warm-up that was used on the first day of the assessment. Afterwards, the bike trainer ERG mode was enabled to allow participants to exercise at the estimated FTP intensity until exhaustion. The moment at which participants stopped pedaling because they could not hold a cadence of 70 rpm was considered as the TTE at FTP.

Data cleaning, manipulation, and analyses were performed in R (version 4.0.2; R Foundation for Statistical Computing, Vienna, Austria). Data were visually inspected, and Shapiro-Wilk test was used to assess normality. Data were presented as mean ± standard deviation, or median (interquartile range), as appropriate. TTE was right skewed containing outliers. Accordingly, it was tested using one-way robust ANOVA based on 20 % trimmed means and confidence intervals were bootstrapped with 2000 random replicates. Post-hoc pairwise comparisons were performed when appropriate using linear contrasts. Effect sizes (ξ) were expressed following Wilcox (2016) recommendations, where $\xi = 0.10$, 0.30, and 0.50 correspond to small, medium, and large effect sizes. Associations were estimated using percentage-bend correlation coefficients (ρ_{pb}).[24] Mean estimates and 95 % confidence intervals (95 % CI) were reported and statistical significance was assumed when $p < 0.05$.

Table 1
Characteristics of the sample.

	Recreationally trained ($n = 18$)	Trained ($n = 31$)	Well trained ($n = 20$)	Professional ($n = 18$)
Age (years)[a]	41.1 ± 4.33	39.6 ± 8.16	37.5 ± 6.89	31.2 ± 5.8
Height (m)[a]	1.79 ± 0.07	1.77 ± 0.08	1.76 ± 0.08	1.76 ± 0.05
Weight (kg)[b]	79.4 (72.1–92.5)	69 (62.3–75.2)	66.2 (61.3–1.4)	65 (60.4–69.9)
BMI (kg/m^2)[b]	26.0 (22.5–28.3)	22.1 (20.9–23.3)	21.3 (19.6–22.4)	21 (20.2–21.8)
VO_{2max} (ml/min/kg)[a]	46.9 ± 5.04	59.5 ± 3.06	66.4 ± 1.27	74.3 ± 3.86
Experience (years)[a]	3.2 ± 0.9	3.7 ± 1.2	6.8 ± 2.1	15.3 ± 4.8

Abbreviations: BMI, body mass index; VO_{2max}, maximal oxygen consumption.
[a] Mean ± standard deviation.
[b] Median (interquartile range), as appropriate.

3. Results

Allen & Coggan's test estimated an overall power output of 271 ± 90 W, and an overall TTE of 44 (35–53) min. Group data can be found in Table 2. Coggan's power output was uncorrelated with the TTE ($\rho_{pb} = 0.18$; $p = 0.092$). Coggan's relative power output, on the other hand, had a stronger correlation with TTE ($\rho_{pb} = 0.39$; $p < 0.001$).

TTE was different among groups ($t = 11.5$; $p < 0.001$; $\xi = 0.58$). Post-hoc pairwise comparisons revealed that recreationally trained cyclists tired similarly to well-trained ones (95 % CI for the difference from −6.25 to 16 min; $p = 0.23$; $\xi = 0.81$) but earlier than trained (95 % CI for the difference from −1.88 to 18.42 min; $p = 0.031$; $\xi = 0.62$) and professional cyclists (95 % CI for the difference from 8.75 to 28.67 min; $p < 0.001$; $\xi = 0.87$). The trained and well-trained groups tired similarly (95 % CI for the difference from −6.79 to 13.55 min; $p = 0.33$; $\xi = 0.20$) but earlier than professional cyclists (95 % CI for the difference from 4.5 to 22.17 min; $p < 0.001$; $\xi = 0.28$). Lastly, the trained group tired earlier than the professional group (95 % CI for the difference from 1 to 17.32 min; $p = 0.002$; $\xi = 0.45$). Individual points and a summary of significant pairwise comparisons are plotted in Fig. 1.

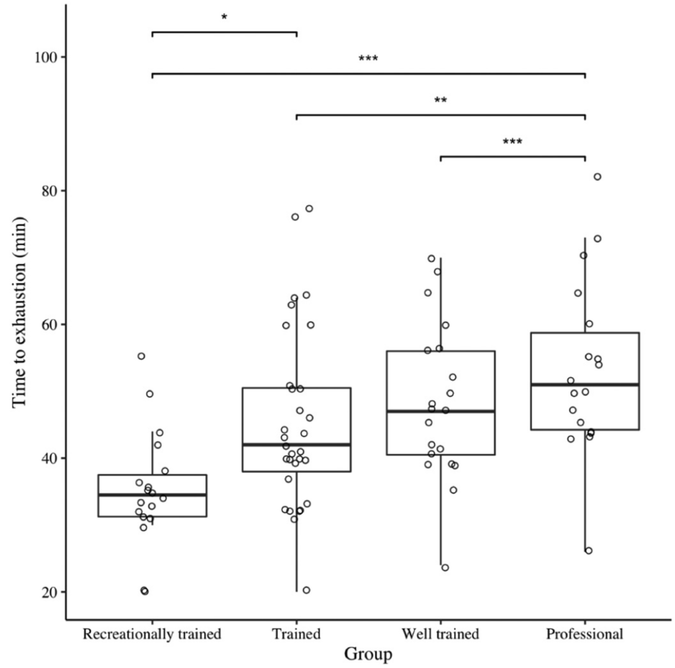

Fig. 1. Time to exhaustion at Allen & Coggan's power output by group. Pairwise differences are noted as * $p < 0.5$, ** $p < 0.01$, *** $p < 0.001$.

4. Discussion

To the best of the authors' knowledge, this is the first study assessing the TTE at FTP in road cyclists of different performance levels. The main findings were: a) the TTEs obtained in the current study were below the one-hour mark; b) there was a high variability in the TTE among cyclists and c) there were significant differences in the TTE between performance groups, with higher level cyclists presenting longer TTE.

The median TTE in the current study was 44 min. This is shorter than the number reported by the only previous study that has explored this topic, which was presented by Borszcz, et al., who described a TTE of 50.9 ± 15.7 min in a sample of 23 trained male cyclists.[18] This difference, however, could be explained by several factors: the sample size in this study was smaller and participants weren't divided by performance levels. By contrast, the current study included a large sample of participants characterized by a wide range of fitness levels. The fitness status of the sample presented by Borszcz, et al. was above the physiological values represented by the "recreationally trained" group included in the current study. Given that this group showed the shortest TTE of the entire sample, omitting this group would reduce the gap observed between overall measures from both studies. Further, the warm-up protocol used in the TTE test presented by Borszcz, et al. was much shorter and easier than the protocol used in the current study. This could have an impact on the subsequent test duration, given that less fatigued participants could, theoretically, exercise longer until exhaustion. When attempting to compare this result to those reported for other metabolic steady state markers, the scarce literature around this topic is unconclusive. TTE at the maximal lactate steady state has been reported as 37 min for moderately trained cyclists.[25] By contrast, TTE at the respiratory compensation point in recreational cyclists has been reported as only 20 minutes.[26] However, the latter result should be considered with caution given the severe limitations that exist regarding the assessment of power values at which several ventilatory landmarks occur through a graded exercise test.[27] Considering the above, it can be stated that the FTP estimated from the Allen & Coggan test results in TTEs that are consistently below the hour mark but above the durations reported for other metabolic steady state markers.

One of the main interests of the current study was to explore the hypothetical homogeneity in the TTE reported by the participants, given that this would provide scientists, coaches and cyclists with a tool that would allow to simultaneously report FTP and TTE for each cyclist. However, this was not the case given the variability in the TTE obtained in the current study. This result is in line with the information reported by other authors for both the respiratory compensation point and the FTP obtained from the Allen & Coggan's formula, with significant between-subject variability reported in both cases.[26] In light of these results, it can be stated that the TTE is highly variable and should be tested at an individual level.

To the best of the authors' knowledge, no previous studies have attempted to verify the differences in the time to exhaustion among cyclists of different performance levels. The results of the current study provide evidence that suggests that TTE at FTP increases with the cyclist's performance level. Specifically, TTE increased from 35 min in the recreationally trained to 51 min in professional cyclists. Although the high variability observed in this study could be expected given that the behavior of the power curve differs among participants, the proposed relationship between cyclist level and TTE at FTP is a novelty in the field. The most logical explanation behind this finding may be related to the influence of previous cycling experience. In this study, those with the longest TTE were the highest performing cyclists, who additionally were the most experienced. The importance of this factor

Table 2
Overall and grouped performance results.

	Recreationally trained (n = 18)	Trained (n = 31)	Well trained (n = 20)	Professional (n = 18)	All (n = 87)
PO (W)[a]	235 ± 31	266 ± 52	279 ± 44	308 ± 34	271 ± 90
Relative PO (W/kg) [a]	2.94 ± 0.55	3.78 ± 0.32	4.26 ± 0.29	4.78 ± 0.43	3.92 ± 0.73
TTE (min)[b]	35 (31–38)	42 (38–51)	47 (41–56)	51 (44–59)	44 (35–53)

Abbreviations: PO, power output; TTE: time to exhaustion.
[a] Mean ± standard deviation.
[b] Median (interquartile range), as appropriate.

should not be underestimated, given its influence on pacing strategies and on the ability to suffer at high intensities.[28–30] With this in mind, more experienced cyclists may have paced their test better, which would result in a more accurate estimation of the FTP.[28,29] Further, the suffering ability provided by experience may have helped the participants to achieve longer TTE at the same relative intensities.[30] As a summary of the above, higher-performing cyclists show longer TTE, a relationship that may be physiological but also linked to the cyclist's experience.

Fixed tests, such as the protocol proposed by Allen & Coggan, are easy to implement, simple to follow and convenient for the self-coached athlete. Although the relationship between FTP obtained from the Allen & Coggan protocol and several metabolic steady state markers has already been established, the TTE at this intensity remained unknown. According to the results reported in the current study, TTE at FTP is consistently below the hour mark but longer than the TTE reported for other metabolic steady state landmarks obtained in the laboratory such as the maximal lactate steady state and the respiratory compensation point. Further, given the high TTE variability observed in this study, it is recommended that FTP and TTE are assessed and reported independently for each subject. Lastly, cyclist's performance level and experience should be factored in when attempting to study TTE, as higher performing and more experienced cyclists consistently show longer TTE at FTP.

5. Conclusions

The high time to exhaustion variability observed in this study suggests that functional threshold power and time to exhaustion should be assessed and reported independently for each subject. Also, cyclists' performance level and experience should be factored in when attempting to study the time to exhaustion, as better performing and more experienced cyclists consistently show longer times to exhaustion at the functional threshold power.

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Declaration of Interest Statement

None.

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