Functional threshold power in cyclists: validity of the concept and physiological responses

Abstract

Functional threshold power is defined as the highest power output a cyclist can maintain in a quasi-steady state for approximately 60-min (FTP_{60}). In order to improve practicality for regular evaluations, FTP_{60} could theoretically be determined as 95% of the mean power output in a 20-min time-trial (FTP_{20}). This study tested this assumption and the validity of FTP_{20} and FTP_{60} against the individual anaerobic threshold (IAT). Twenty-three trained male cyclists performed an incremental test to exhaustion, 20- and 60-min time-trials, and a time-to-exhaustion at FTP_{20}. Power output, heart rate and oxygen uptake representing FTP_{20}, FTP_{60} and IAT were not different ($p > 0.05$), and large to very large correlations were found ($r = 0.61$ to 0.88). Bland Altman plots between FTP_{20}, FTP_{60} and IAT showed small bias (-1 to -5 W), but large limits of agreement ([-40 to 32 W] to [-62 to 60 W]). Time to exhaustion at FTP_{20} was 50.9 ± 15.7 min. In conclusion, FTP_{20} and FTP_{60} should not be used interchangeably on an individual basis and their validity against IAT should be interpreted with caution.

Keywords: cycling, time-trial, performance, pacing strategy, non-invasive test, anaerobic threshold

Introduction

The lactate threshold (LT) model distinguishes three exercise-intensity domains in which the boundaries are the aerobic threshold (LT_1) and the anaerobic threshold (LT_2) [13,18]. In sports science, training intensity prescription is often based upon target intensity zones defined according to this model [13,18]. However, most endurance athletes cannot rely on formal laboratory testing to determine LTs and therefore adopt five-zone systems with anchor points defined somewhat arbitrarily, for example, based upon percentages of maximal heart rate (HR_{max}) [26]. Because the three- and five-zone systems do not directly compare [26], the identification of LT_1 and LT_2 with practical approaches could help coaches and athletes to employ scientific knowledge to refine exercise-intensity prescription.

In cycling, power output (PO) can be measured outdoors by mobile devices, providing an instant depiction of exercise intensity. Thus, Allen and Coggan [2] have proposed a performance index, called functional threshold power (FTP), defined as the highest PO a cyclist can maintain in a quasi-steady state for approximately 60 min (FTP_{60}) without the onset of fatigue [2]. Its conceptualization resembles that of LT_2 or the maximal lactate steady state (MLSS), as exercise sustained at intensities higher than FTP does not reach steady state and leads to exhaustion [2]. Typically, a 60-min time-trial (TT) is required for FTP assessments [2]. However, in order to decrease the effort time and to improve practicality for regular evaluations, Allen and Coggan [2] have suggested FTP_{60} could be determined as 95% of the mean PO in a 20-min TT (FTP_{20}). A couple of studies have also estimated FTP_{60} as 90% of the mean PO in an 8-min TT (FTP_8) [14,25]. Despite widely used in cycling to define target intensity zones and to monitor changes in performance over a season [2], FTP research is still incipient.

Both Gavin et al. [14] and Sanders et al. [25] have assessed the agreement between FTP_8 and LTs determined by different methods in the laboratory. While FTP_8 was equivalent to LT_2 determined as blood lactate concentration [La] of 4 $mmol.L^{-1}$ in one study [14], FTP_8 overestimated by ~6% the same LT_2 index in the other [25]. These contrasting results might be explained by the use of fixed [La], as they poorly reflect interindividual differences in lactate kinetics [13]. Surprisingly, no study has thoroughly investigated the validity of the FTP_{20} concept, despite its use as a predictor of cycling performance [21], or as a predictable variable [11]. Specifically, no study has compared FTP against the individual anaerobic threshold (IAT). We have previously shown that IAT agrees more with MLSS than other LT methods [10] and presents high intraindividual reliability [17], suggesting this method could be a more robust measure to test the validity of FTP. Alternatively, a time-to-exhaustion (TTE) at FTP_{20} could provide further evidence for the validity of the concept, but, to our knowledge, this evidence has not been published yet. Therefore, this study aimed to verify the agreement between FTP_{20}, FTP_{60} and IAT and to assess the physiological and perceptual responses during the TTs used for FTP_{20} and FTP_{60} determination and during a TTE at FTP_{20}. According to Faude et al. [13], an athlete sustains LT_2 intensity for 45–60 min. Consequently, we hypothesised a good agreement between FTP_{20}, FTP_{60} and IAT, and a TTE at FTP_{20} that falls within this range.

Materials & Methods

Participants

Twenty-three trained male cyclists [9] participated in this study (age: 32.7 ± 6.5 years, height: 179 ± 5 cm, body mass: 76.4 ± 8.3 kg, peak power output (PPO): 327 ± 34 W, maximal oxygen uptake (VO_{2max}): 59.4 ± 5.9 $ml.min^{-1}.kg^{-1}$). They had at least 2 years of experience in regional- and national-level competitions and were training 10 ± 3 h and 198 ± 56 km per week during the study period. After verbal and written explanations of the procedures, participants signed an informed consent, approved by the institutional ethics committee. This study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [16].

Experimental design

Over 3 weeks, cyclists completed 4 laboratory-testing sessions separated by at least 48 h. In the first session, participants performed a graded exercise test. In the second and third sessions, cyclists performed 20- and 60-min TTs, randomly, for FTP_{20} and FTP_{60} determination. In the fourth session, a TTE at FTP_{20} was performed. Cyclists were asked to maintain their diet and lifestyle for the duration of the study and to refrain from strenuous exercise, alcohol and caffeine during the 48 h preceding each test. All tests were conducted under standardised laboratory conditions of 20–22°C and 40–50% relative humidity, using an electrically-braked bicycle ergometer (Velotron Dynafit Pro, RacerMate, Seattle, USA) modified with racing saddle, adjustable stem, and participants' pedal system (the accuracy of Velotron has been described elsewhere [1]). No verbal encouragement was provided during the TTs and the TTE, as per standard recommendations [7]. Water was ingested *ad libitum*.

Graded exercise test

The graded exercise test started at 100 W and increased by 40 W every 4 min until voluntary exhaustion. Oxygen uptake (VO_2) and heart rate (HR) were continuously measured using a gas analyser (Quark PFTergo, Cosmed, Rome, Italy) calibrated in accordance with the manufacturer's instructions. During the final 30 s of each stage, 20 µL of blood was collected from the participants' earlobe and analysed for [La] (Biosen S-Line, EKF Diagnostics, Barleben, Germany). At the end of each stage, ratings of perceived exertion (RPE) were recorded using the 6-20 Borg scale [5].

PPO was determined as the last completed stage plus the fraction of time spent in the final non-completed stage multiplied by 40 W [20]. VO_{2max} was determined as the highest 30-s mean value recorded, and HR_{max} as the highest individual value. The time course of [La] vs. work rates was graphically interpolated and LT_2 was determined using the IAT methodology, i.e. 1.5 mmol.L^{-1} above the point of minimum ratio between [La] and work rate [12]. The agreement between IAT and MLSS as well as IAT reliability has been described elsewhere [10,17]. HR, VO_2 and RPE at IAT were also identified by linear interpolation between two segments.

Time-trials

Cyclists performed two laboratory-simulated TTs (20- and 60-min) to determine FTP_{20} and FTP_{60}. For each test, the Velotron was connected to a laptop computer interfaced with a projector that displayed the computer-generated image of the 3D course profile in front of the cyclist (Interactive 3D, RacerMate, Seattle, USA). A flat terrain without wind was modelled and participants were able to view their progress over the course, with information on elapsed time and gear selection only.

Before the start of the 60-min TT, cyclists performed a 10-min self-selected warm-up. However, the 20-min TT was preceded by original warm-up procedures [2], as follows: 20 min at self-selected light intensity, 3 fast-pedalling accelerations (1 min at >100 rev.min^{-1}) with 1-min recovery between efforts, 5 min at self-selected light intensity, 5 min at maximal effort and 10 min at self-selected light intensity (46 min in total). Cyclists were oriented to produce the highest mean PO during the TTs. VO_2

and HR were continuously measured. [La] was collected during the warm-up after the 5-min maximal effort and before the start of the 20-min TT. [La] and RPE were then collected every 5 and 15 min during the 20- and 60-min TTs, respectively. FTP was identified as the mean PO during the 60-min TT (FTP_{60}) and 95% of the mean PO during 20-min TT (FTP_{20}) [2]. To analyse pacing, mean PO of each 10% of total duration was percentage normalised to the mean PO of the whole time-trial for each athlete [8].

Time-to-exhaustion at FTP_{20}

Prior to the test, cyclists performed a 10-min self-selected warm-up. The Velotron was set up with a pacer at each individual's FTP_{20} and participants were oriented to keep pedalling for as long as possible following the pacer. This approach was chosen in order to maintain the cycling conditions (i.e. self-selected gears and cadence). Cyclists watched their progress over the course on the screen but were blinded to all performance feedback. The test was interrupted when the cyclist could not follow the pacer for more than 10 s. VO_2 and HR were continuously measured; [La] and RPE every 5-min and at exhaustion.

Statistical analyses

Descriptive results are reported as mean ± standard deviation. The assumption of normality was verified using Shapiro-Wilk's test. One-way repeated measures ANOVA with Bonferroni pairwise comparisons were performed to test for differences in mean values of PO, HR, VO_2, [La] and RPE across conditions. Bland-Altman plots and 95% limits of agreement were employed to assess bias between PO, HR and VO_2 at IAT, FTP_{20} and FTP_{60}. Pearson product-moment correlations were used to test for significant relationships between FTP_{20} vs. FTP_{60} vs. IAT. Two-way repeated measures ANOVA with Bonferroni pairwise comparisons were performed to compare pacing, HR, VO_2, [La], and RPE across time points. Mauchly's test was used to test the assumption of sphericity and a Greenhouse-Geisser correction was applied when necessary. Statistical significance was accepted at $p \leq 0.05$. Interpretation of correlation coefficients was based on qualitative descriptors proposed by Hopkins et al. [19]: 0-0.09 trivial; 0.1-0.29 small; 0.30-0.49 moderate; 0.50-0.69 large; 0.70-0.89 very large; 0.90-0.99 nearly perfect; 1.00 perfect. Analyses were performed using SPSS statistical package (21.0, IBM, Armonk, USA).

Results

PO, HR, VO_2, [La], and RPE equivalent to IAT and mean values during the TTs and TTE are presented in Table 1. During the TTE, cyclists were able to sustain FTP_{20} for 50.9 ± 15.7 min. Mean PO of the 20-min TT was higher than FTP_{60} ($p < 0.001$). HR at IAT was lower than the mean value of the 20-min TT ($p < 0.001$). [La] was lower at IAT than the mean values of the 20-min TT, 60-min TT and TTE ($p < 0.001$, $p = 0.034$, $p = 0.004$, respectively). Moreover, mean [La] of the 20-min TT was higher than mean values of the 60-min TT and TTE ($p = 0.004$, $p = 0.029$, respectively). RPE was lower at IAT than the mean values of the 20-min TT, 60-min TT and TTE (all $p < 0.001$). Correlations between FTP_{20}, FTP_{60} and IAT are presented in Table 2.

[Table 1]

[Table 2]

Bland-Altman plots of FTP_{60} with FTP_{20} revealed a bias (95% limits of agreement) of -4 W (-40 to 32 W), -4 $b.min^{-1}$ (-12 to 21 $b.min^{-1}$) and 0.015 $ml.min^{-1}$ (-0.596 to 0.625 $ml.min^{-1}$) (Figure 1 – A, B, C). Plots of FTP_{60} with IAT revealed a bias of -5 W (-48 to 38 W), 2 $b.min^{-1}$ (-20 to 24 $b.min^{-1}$) and 0.129 $ml.min^{-1}$ (-0.823 to 0.565 $ml.min^{-1}$) (Figure 1 – D, E, F). Finally, plots of FTP_{20} with IAT revealed a bias of -1 W (-62 to 60 W), -2 $b.min^{-1}$ (-21 to 17 $b.min^{-1}$) and -0.144 $ml.min^{-1}$ (-0.928 to 0.641 $ml.min^{-1}$) (Figure – 1 G, H, I).

[Figure 1]

Figure 2 displays change over time of PO as absolute values and as percentages of final performance. Figure 3 shows HR (A), VO_2 (B), [La] (C) and RPE (D) during the 20-min TT, 60-min TT and TTE. We found a statistically significant main effect of time points for all variables and an interaction effect for PO and RPE only. During the warm-up of the 20-min TT, [La] was 10.3 ± 3.6 $mmol.L^{-1}$ after the 5-min maximal effort and 6.5 ± 2.9 $mmol.L^{-1}$ before the TT.

[Figure 2]

[Figure 3]

Discussion

To our knowledge, this is the first study to investigate the validity of FTP_{20} to predict FTP_{60} and IAT in trained cyclists. To do so, we included a graded exercise test to assess IAT, 20- and 60-min TTs, a TTE at FTP_{20}, and we measured physiological and perceptual responses during the TTs and the TTE to ascertain whether a steady state could be attained. According to our hypothesis, no significant differences were found between FTP_{20}, FTP_{60} and IAT for PO, HR and VO_2 values. In addition, Bland Altman plots presented minimal bias when comparing FTP_{20}, FTP_{60} and IAT for PO, HR and VO_2. The TTE performance at FTP_{20} fell within the expected range (i.e. 45–60 min) and large to very large correlations were found between FTP_{20}, FTP_{60} and IAT for PO, small to large correlations for HR, and large correlations for VO_2. However, despite the apparent validity of FTP_{20} to estimate IAT and FTP_{60} in the context of a group, caution must be exercised when performing these estimations on an individual basis as evidenced by large limits of agreement between variables.

The FTP_{20} concept has been developed to estimate the PO an athlete could sustain for approximately 60 min. This duration is similar to the time exercise is endured at LT_2 or MLSS [3,13]. Therefore, we hypothesised FTP_{20} could also represent IAT or MLSS, with the advantage of a field test easily implemented that does not involve invasive procedures or technical staff. Although we did not test MLSS directly, we have previously shown that IAT agrees more with MLSS than other LT methods [8] and presents high intraindividual reliability [14]. This choice was important to avoid excessive burden on research participants, given that several more visits would be necessary to assess MLSS. Our study might have also benefited from including familiarisation trials to rule out the possibility participants did not perform at their best [7]. The results presented here must be interpreted in light of these limitations.

That said, FTP_{20} (236 ± 38 W) or FTP_{60} (231 ± 33 W) were not different from IAT (237 ± 29 W) in our sample of trained cyclists. In addition, low bias and large to very large correlations were found between FTP_{20} vs. IAT (0.8 W, $r = 0.61$), FTP_{60} vs. IAT (5.8 W, $r = 0.76$) and FTP_{20} vs. FTP_{60} (-4.4 W, $r = 0.88$). Similarly, Gavin et al.

[14] found that FTP_8 (301 ± 13 W) was not different from LT_2 determined as [La] of 4 mmol.L^{-1} (293 ± 9 W). However, FTP_8 was higher than other LT methods: visual determination (LT_{visual}) (280 ± 15 W), 1 mmol.L^{-1} or greater than the previous stage ($LT_{\Delta 1}$) (268 ± 18 W), and 1 mmol.L^{-1} above baseline (LT_{+1}) (250 ± 24 W) [14]. Accordingly, Sanders et al. [25] found that FTP_8 overestimated several LT methods in well-trained cyclists, with mean differences ranging from 21 to 62 W. In contrast to Gavin et al. [14], Sanders et al. [25] reported FTP_8 was 6 ± 6% (21 ± 20 W) higher than [La] of 4 mmol.L^{-1}. Of note, the use of fixed [La] probably explains this inconsistency, as interindividual differences in lactate kinetics are not taken into account [13]. Moreover, the differences between FTP_8 and several LT approaches found by Gavin et al. [14] and Sanders et al. [25] are not surprising. For example, Gavin et al. [14] used LT_{+1} while Sanders et al. [25] used LT_{+1} and 2 mmol.L^{-1} [La] to compare with FTP_8. These methods represent LT_1 and not LT_2 [13]. Taken together, our data suggest FTP_{20} and FTP_{60} are more closely related to LT_2 than FTP_8. Therefore, 20- or 60-min TTs should be preferable over 8-min TTs to determine FTP. A higher correlation and smaller limits of agreement between FTP_{60} and IAT than between FTP_{20} and IAT corroborate our inference.

Nevertheless, it is difficult to accept FTP as a thoroughly valid concept. We found large limits of agreement between most variables, suggesting a high level of interindividual variability in the relationship between FTP_{20} vs. FTP_{60} and between both measures vs. IAT. Even though TTE performance at FTP_{20} fell within the expected range, the interindividual variability was higher (50.9 ± 15.7 min) than typically found at MLSS (55.0 ± 8.5 min [3] or 54.7 ± 10.9 min [15]). Researchers have investigated FTP predictive ability in diverse ways [11,14,21,25]. While some acknowledge interindividual differences in the applicability of these tests [14,25], we feel that the exact meaning of FTP as performance variable has not been established yet.

Interestingly, cyclists adopted a reverse J-shaped pacing during the 60-min TT while they adopted a negative pacing during the 20-min TT. For FTP_{20} determination, Allen and Coggan [2] recommend a 46-min warm-up that includes 3 fast-pedalling accelerations (1 min at >100 rev.min^{-1}) with 1-min recovery between efforts and a 5-min maximal effort. Our data revealed high [La] (6.5 ± 2.9 mmol.L^{-1}) immediately before the start of the TT, which may explain the differences in pacing. Importantly, this warm-up procedure is not in accordance with recommendations suggesting a duration of ~15 to 20 min and [La] < 3 $mmol.L^{-1}$ before the endurance performance [4]. Again, these results challenge the validity of the FTP concept. Interindividual differences in rate of recovery between high-intensity efforts [27] possibly increased the limits of agreement between FTP_{20}, FTP_{60} and IAT.

Therefore, we argue that the mean PO in a 20-min TT is used for training intensity prescription and regular performance monitoring. The obtained value might not necessarily represent the boundary between the heavy- and the severe-intensity domain [13,18], but this test is more practical than a 60-min TT and does not involve the burden of multiple MLSS assessments. Although our proposal does not solve the issue of training-zone systems that do not directly compare [26], 20-min TT performance is reliable [24], sensitive to training adaptations [22] and cycling ability [6]. Moreover, training zones derived from a 20-min TT are comprehensible enough to provide insights into the training strategies of elite cyclists without the need of a 5% subtraction [23]. To account for interindividual differences in endurance, TTEs could then be applied as indoor training sessions to establish the ideal volume of exercise targeting each intensity zone [18].

In summary, we have demonstrated that mean values of PO, HR and VO_2 at FTP_{20} were equivalent to values at IAT and FTP_{60} in trained cyclists. We also found low bias and large to very large correlations between FTP_{20}, FTP_{60} and IAT. Despite the apparent validity of FTP_{20} to estimate IAT and FTP_{60} in the context of a group, we found large limits of agreement between variables. Therefore, these measures should not be used interchangeably unless their relationship is tested on an individual basis. We propose the mean PO in a 20-min TT (without a 5% subtraction) is used for training intensity prescription and regular monitoring, as previous research has already ascertained its robustness as a performance test.

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Figure captions

Figure 1. Bland-Altman plots display bias and 95% limits of agreement (LoA) for power output, heart rate and oxygen uptake. FTP_{60} vs. FTP_{20} (A, B, C), FTP_{60} vs. IAT (D, E, F) and FTP_{20} vs. IAT (G, H, I).

Figure 2. Absolute power output (A) and pacing (B) across time points as percentages of total duration.

(A) * = TT_{20} different from TT_{60}; Main effect of time: a = different from 80% segment; b = different from 10, 20, 30, 40, 50, 60, 70, 80 and 90% segments. Interaction: TT_{20}: 1 = different from 80% segment; 2 = different from 10, 20, 30, 40, 50, 60, 70, 80 and 90% segments. TT_{60}: 3 = different from 80% segment; 4 = different from 20, 30, 40, 50, 60, 70, 80 and 90% segments.
(B) * = TT_{20} different from TT_{60}; Main effect of time: c = different from 80% segment; d = different from 10, 20, 30, 40, 50, 60, 70, 80 and 90% segments. Interaction: TT_{20}: 5 = different from 10, 20, 30, 40, 50, 60, 70, 80 and 90% segments. TT_{60}: 6 = different from 80% segment; 7 = different from 20, 30, 40, 50, 60, 70, 80 and 90% segments. Significance differences at $p < 0.05$.

Figure 3. Heart rate (A), oxygen uptake (B), blood lactate concentration (C) and ratings of perceived exertion (D) across time points as percentages of total duration.

(A) Main effect of time: a = different from 20, 30, 40, 50, 60, 70, 80, and 90% segments; b = different from 30, 40, 50, 60, 70, 80, and 90% segments; c = different from 50, 60, 70, 80, and 90% segments; d = different from 40, 50, 70 and 80, and 90% segments; e = different from 40, 50, 60, 70, 80 and 90% segments.
(B) Main effect of time- f = different from 10, 50, 60, 70 and 80% segments.
(C) Main effect of time- g = different from 50% segment; h = different from 25 and 75% segments. Main effect of trial: § = TT_{20} different from TT_{60} and TTE.
(D) # = TTE different from TT_{20} and TT_{60}; $ = TTE different from TT_{20}; Main effect of time- i = all segments different from each other. Significance differences at $p < 0.05$.