Functional threshold power is not a valid marker of the maximal metabolic steady state.

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Abstract

Purpose: Functional Threshold Power (FTP) has been considered a valid alternative to other performance markers that represent the upper boundary of the heavy intensity domain. However, such a claim has not been empirically examined from a physiological perspective.

Method: This study examined the blood lactate and $\dot{V}O_2$ response when exercising at and 15 W above the FTP (FTP_{+15W}). Thirteen cyclists participated in the study. The $\dot{V}O_2$ was recorded continuously throughout FTP and FTP_{+15W}, with blood lactate measured before the test, every 10 minutes and at task failure. Data were subsequently analysed using two-way ANOVA.

Results: The time to task failure at FTP and FTP_{+15W} were 33.7 ± 7.6 and 22.0 ± 5.7 minutes ($p < 0.001$), respectively. The $\dot{V}O_{2peak}$ was not attained when exercising at FTP_{+15W} ($\dot{V}O_{2peak}$: 3.61 ± 0.81 vs FTP_{+15W} 3.33 ± 0.68 $L \cdot min^{-1}$, $p < 0.001$). The $\dot{V}O_2$ stabilised during both intensities. However, the end test blood lactate corresponding to FTP and FTP_{+15W} was significantly different (6.7 ± 2.1 mM vs 9.2 ± 2.9 mM; $p < 0.05$).

Conclusion: The $\dot{V}O_2$ response corresponding to FTP and FTP_{+15W} suggests that FTP should not be considered a threshold marker between heavy and severe intensity.

Abbreviations

Amp	Amplitude
ANOVA	Analysis of variance
BLC	Blood lactate concentration
BLC_{FTP}	Blood lactate kinetics corresponding to FTP
$BLC_{FTP+15W}$	Blood lactate kinetics corresponding to FTP_{+15W}
$BLC_{\Delta 10end}$	The change of blood lactate concentration between the 10th minute and task failure
CV	Coefficient of variation
CP	Critical power
FTP	Functional threshold power
FTP_{20}	The FTP determined by 95% of the mean power output during a 20 minute time trial
FTP_{60}	The FTP determined by the mean power output during a 60 minute time trial
FTP_{+15W}	15 watts above the functional threshold power
MLSS	Maximal lactate steady state
RPM	The number of revolutions per minute
TTF	Time to task failure
TD	time delay
Tau	time constant
$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}_E$	Ventilation
$\dot{V}O_2$	Oxygen consumption
$\dot{V}O_{2base}$	The baseline $\dot{V}O_2$ measured during warm-up
$\dot{V}O_{2peak}$	Highest rate of oxygen consumption
$\dot{V}O_{2sc}$	$\dot{V}O_2$ slow component
W	Watts

Introduction

Over recent years, field-based testing methods for assessing athletic endurance performance potential have become more popular. This has been facilitated by the progress in micro-technologies such as the cycle computer and power meter, which are now essential components for most cyclists. One commonly used field-based test for assessing cycling performance potential is the Functional Threshold Power (FTP) test (Allen & Coggan, 2006; 2010). The FTP is the highest power output a cyclist can maintain in a quasi-steady state for one hour (Allen & Coggan, 2010). Determining the power output corresponding to FTP originally required cyclists to perform a maximal effort trial over one hour (FTP_{60}), but it was deemed impractical to conduct this test regularly. Thus, the determination protocol was modified to require an individual to perform a 20 minute maximal effort time trial (TT) and 95% of the mean power output subsequently calculated for the intensity corresponding to FTP (FTP_{20}) (Morgan et al., 2019; Inglis et al., 2019). Indeed, a strong correlation has been shown between the work rate corresponding to FTP_{20} and FTP_{60} (r=0.88; Borszcz et al., 2018). However, it has been questioned whether the power output from FTP_{20} and FTP_{60} can be considered interchangeable on an individual basis, despite no statistically significant differences between the two on a group basis (Borszcz et al., 2018). Moreover, previous research has shown that cyclists often fail to maintain the work rate corresponding to FTP_{20} for one hour (Borszcz et al., 2018; Sitko et al., 2022).

The FTP has also been proposed to be a surrogate of some well-known performance markers representing the maximal oxidative steady state or the maximal metabolic steady state (MMSS). For example, critical power (CP) (Jones et al., 2019) and maximal lactate steady state (MLSS) (Dotan, 2022a) because exercise sustained at intensities slightly greater than FTP (> 106 % of FTP) is suggested to result in $\dot{V}O_{2max}$ attainment (Allen & Coggan, 2010). However, unlike the aforementioned CP and MLSS, there is a paucity of research investigating the validity of FTP. The case for the use of FTP can be made based on findings from Coyle et al. (1991), who demonstrate that a 1-hour laboratory performance test was highly correlated with the actual road racing 40 km TT performance ($r = -0.88$. $p < 0.001$) (Coyle et al., 1991). Thus, a more rigorous scientific examination is required before making any meaningful conclusion between the FTP and MMSS.

The MMSS has been considered to represent an exercise intensity that can be sustained without a progressive loss of homeostasis and demarcates the heavy and severe exercise domains (Jones et al., 2010; 2019). The threshold between the heavy and severe intensity domains has significant value in sports science as it represents the upper boundary of whether the $\dot{V}O_2$ can remain in a steady state and the ability of the $\dot{V}O_2$ slow component ($\dot{V}O_{2sc}$) to stabilise. The amplitude of the $\dot{V}O_{2sc}$ is closely related to muscle fatigue development and exercise tolerance (Burnley & Jones, 2007; Colosio et al., 2020). In the heavy domain, the $\dot{V}O_{2sc}$ can stabilise, whereas when exercising within the severe intensity domain, the $\dot{V}O_2$ has been shown to project upwards, rising to $\dot{V}O_{2max}$ without a discernible steady state (Poole et al., 1988; Hill et al., 2002; De Lucas et al., 2013; Jones et al., 2019). Traditionally, the MMSS can be determined using MLSS (Billat et al., 2003; Faude et al., 2009) or the CP (Poole et al., 2021), both requiring individuals to undertake at least three to four short submaximal effort trials to determine the intensity corresponding to the threshold, which is a time consuming and labour-intensive process. Thus, a single 20-minute maximal effort TT for FTP determination (Morgan et al., 2019; Inglis et al., 2019) could efficiently determine the work rate corresponding to MMSS. However, previous studies have reported a low level of agreement between the measured power outputs associated with CP and FTP and should not be used interchangeably (Karsten, 2018; Morgan et al., 2019; Karsten et al., 2020; McGrath et al., 2021). Similarly, Inglis et al. (2019) reported that the power output corresponding to FTP was significantly higher than the MLSS; therefore, not a valid marker of the threshold between heavy and severe intensity domains. In short, previous research suggests that FTP should not be used interchangeably with CP and MLSS or as a marker of the MMSS. Nonetheless, the use of FTP to inform training and design training programs by coaches and athletes continues to grow (Allen & Coggan, 2010; Borszcz et al., 2018). A possible reason for this is that the little previous research that has been conducted investigating FTP has tended to focus on the statistical perspective (correlation and limits of agreement) with other well-known performance markers rather than the physiological basis of FTP itself (Borszcz et al., 2018; Inglis et al., 2019; Karsten et al., 2021; McGrath et al., 2021). Therefore, to determine the validity of FTP representing the MMSS, there is a need to examine the physiological responses to exercise at and above the FTP and identify whether they correspond to the heavy and severe intensity domain, respectively.

The present study aimed to investigate the validity of FTP being the threshold separating the heavy and severe intensity domains by examining the physiological response when exercising at and 15 W above FTP (FTP_{+15W}). Specifically, the study compared the $\dot{V}O_{2sc}$ response between exercising at and above FTP due to its ability to discriminate between heavy and severe exercise intensity domains (Burnley & Jones, 2007). The null hypothesis of the present study was that there would be no significant difference in $\dot{V}O_{2sc}$, $\%\dot{V}O_{2peak}$ and blood lactate when exercising at FTP and FTP_{+15W}.

Methods

Participants

Thirteen cyclists (male n = 11; Age = 23.5 ± 3.9 years; $\dot{V}O_{2peak}$ = 60.0 ± 4.7 $mL \cdot kg^{-1} \cdot min^{-1}$; female n = 2; Age = 26 ± 9.8 years; $\dot{V}O_{2peak}$ = 48.0 ± 4.0 $mL \cdot kg^{-1} \cdot min^{-1}$) were recruited for this study. Participants were classified into four categories based on their relative and absolute $\dot{V}O_{2peak}$ (De Pauw et al., 2013; see Table 1). The inclusion criteria were 1) at least three years of cycling experience, 2) a minimum of four hours of training per week, and 3) previous experience with the FTP determination test. Participants were fully informed about the nature of the study, all associated risks, and their right to withdraw at any time before providing written consent. The study was ethically approved by the Human Research Ethics Committee at the Education University of Hong Kong (E2021-2022-0003) in line with the requirements of the declaration of Helsinki.

Table 1 Characteristics of the participants

Participant	Height (cm)	Mass (kg)	Relative $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	Absolute $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	Performance Level (Relative/Absolute)
1	177	70	64	4.49	T / T
2	177	56	60	3.36	T / RT
3	180	65	61	3.95	T / RT
4	173	63	65	4.07	WT / RT
5	176	68	57	3.89	T / RT
6	170	62	64	3.97	T / RT
7*	164	53	51	2.68	RT / UT
8	174	63	55	3.44	T / RT
9	170	58	62	3.59	T / RT
10*	162	42	45	1.89	UT / UT
11	171	53	50	2.66	R / UT
12	180	63	64	4.04	T / RT
13	177	83	58	4.84	T / T

UT = Untrained; RT = Recreationally Trained; T = Trained; WT = Well Trained; *Female participant

Study Design

As shown in Figure 1, the study comprised four laboratory visits separated by 24 to 48 hours. During the first visit, participants were required to undertake a ramp incremental exercise test to determine their maximal oxygen uptake ($\dot{V}O_{2peak}$). Visit 2 was conducted to determine the participant's FTP, which was subsequently used in visits 3 and 4, the main experimental trials. The order of the 3rd and 4th visits was randomised and required the participant to cycle for 40 minutes or to task failure, whichever occurred first, either at an exercise intensity equivalent to their FTP or FTP_{+15W}.

Participants were asked not to engage in strenuous exercise 24 hours before testing and were required to avoid adding new training to their habitual routine during the testing period. They were required to maintain the same diet 24 hours before each test and arrive at the laboratory hydrated without consuming food and caffeine in the preceding three hours. The incremental ramp test and constant intensity tests at FTP and FTP_{+15W} were performed on a laboratory cycle ergometer (Lode Excalibur Sport, The Netherlands). The ergometer was calibrated according to the manufacturer's recommendations and adjusted for participant comfort before every use. The FTP determination trial was performed on the participants' bike attached to a stationary bike trainer (Wahoo KICKER v.5; Wahoo Fitness, Atlanta, GA), which was previously shown to possess a high level of accuracy and reliability (Hoon et al., 2016). The pedal frequency was set at the participants' preferred rate between 80 and 90 rpm and held constant throughout the ramp incremental and constant intensity tests (± 2 rpm). Pulmonary gas exchange was measured on a breath-by-breath basis using Cortex Metalyzer 3B (Cortex, Leipzing, Germany).

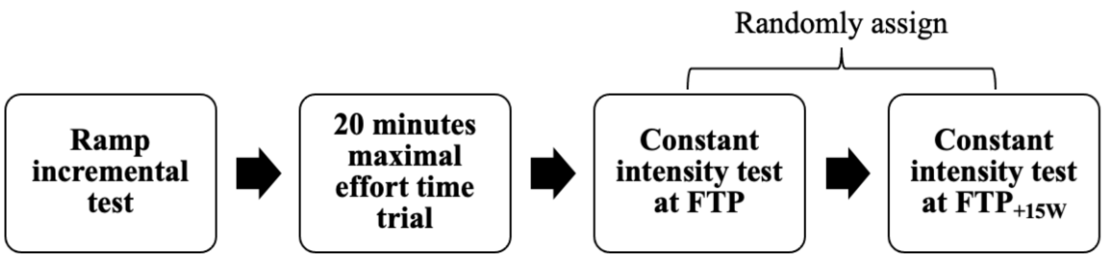

Figure 1. Study Design Schematic

Incremental ramp test

The incremental ramp test commenced with a warm-up at 50 W for four minutes. The work rate was increased by 30 W.min^{-1} for male participants and 25 W.min^{-1} for female participants until volitional exhaustion. Breath-by-breath $\dot{V}O_2$ data were subsequently averaged in the 30s to determine the $\dot{V}O_{2peak}$ (Nixon et al. 2021).

Determination of the FTP

The FTP test started with five minutes of baseline pedalling at 100 W using the preferred cadence, followed by a 20-minute maximal, self-paced TT. The aim of the TT was for the participant to achieve the highest mean power output possible across the 20 minutes with no verbal encouragement from the researcher. Participants were allowed to see the time and cadence to support appropriate pacing (Morgan et al., 2019; Inglis et al., 2019). Indoor cycling training software (Zwift, v1.0.85684, Zwift Inc, US) was used to record PO from all FTP determination trials.

Constant intensity trials equivalent to FTP and FTP_{+15W}

The objective of these visits was to determine the participant's $\dot{V}O_2$ and blood lactate responses when exercising at the intensity corresponding to FTP and FTP_{+15W}. A change in work rate of ± 15 W was selected due to previous research that examined similar threshold markers such as CP and MLSS using incremental rates such as 10 W (Maturana et al., 2016; Iannetta et al., 2021) and 5% of $\dot{V}O_{2max}$ (Dekerle et al., 2003), were suggested to be too low to provide conclusive changes in BLC and $\dot{V}O_2$ response (Jones et al., 2019). Tests began with a five-minute warm-up at 100 W using the participant's preferred cadence. Participants were then required to cycle at a constant intensity, either equivalent to their FTP or FTP_{+15W}, for 40 minutes or until task failure, whichever occurred first. The intensity for the first trial (FTP or FTP_{+15W}) was randomly assigned using a website (https://www.random.org/lists/). Task failure was defined as the point at which the participant could no longer maintain a cadence of at least 50 rpm for more than five consecutive seconds despite strong verbal encouragement (Murgatroyd et al., 2011). Blood lactate samples were collected in duplicate from their fingertip before the test (baseline), every 10th minutes throughout the test session, and upon task failure (Biosen C-Line, EKF Diagnostics, GmbH, Barleben, Germany).

Data Analysis

The $\dot{V}O_2$ data were edited to eliminate the effects of coughs or swallows on the measurement. Only those data points beyond the three standard deviations of the mean value were excluded (Burnley et al., 2006). The first 20 s of the $\dot{V}O_2$ data following the onset of exercise were removed to eliminate the phase I component from the analysis. The first 2 minutes of the $\dot{V}O_2$ data (20 to 120 s) were then analysed using the monoexponential model (Rossiter et al., 2001; Burnley et al., 2005; 2006):

$$\dot{V}O_2(t) = \dot{V}O_{2base} + amp*(1 - e^{-(t-TD/tau)})$$

Where $\dot{V}O_2(t)$ = $\dot{V}O_2$ at time, $\dot{V}O_{2base}$ = the baseline $\dot{V}O_2$ measured in the four minutes before the transition in work rate, amp = amplitude, TD = time delay, and tau = time constant of the primary (phase II) response. The amplitude of the $\dot{V}O_{2sc}$ was determined by the highest $\dot{V}O_2$ value achieved during the constant intensity trial and subtracting the "absolute" primary amplitude ($\dot{V}O_{2base}$ + amp) (Burnley et al., 2005; 2006). The monoexponential model was chosen because a more complex model will significantly degrade the confidence intervals and create a lot of parameter interdependence (Burnley et al., 2005). Given that the time to task failure (TTF) at FTP and FTP_{+15W} varied between participants, the $\dot{V}O_2$ data were analysed using the individual isotime method and expressed in relative time (baseline, 25, 50, 75 and 100%) to avoid any data loss (Nicolò et al., 2019). The $\dot{V}O_2$ corresponding to the desired time points was determined by the average $\dot{V}O_2$ over the prior 60 s. The mean of the last two segments (75% and 100%) was considered the $\dot{V}O_2$ corresponding to each trial.

Two sets of blood lactate samples were collected before the test, at every 10th minute and task failure. The mean of the two blood lactate samples was used for subsequent analysis. The blood lactate kinetic response was interpolated with a linear function using Microsoft Excel (Excel, Microsoft, Redmond, Washington) and represented as BLC_{FTP} and $BLC_{FTP+15W}$. The estimated blood lactate concentration (BLC) corresponding to 25, 50, 75 and 100% of the test duration were used to represent the blood lactate kinetics corresponding to FTP (BLC_{FTP}) and FTP_{+15W} ($BLC_{FTP+15W}$) (Nicolo et al., 2019). The actual difference in BLC between the 10^{th} minute and end test ($BLC_{\Delta 10end}$) and the actual end test value corresponding to FTP and FTP_{+15W} trials were also calculated and subsequently used for statistical analysis purposes.

Statistical Analysis

Prior to analysis, data were checked for normality of distribution using a Shapiro-Wilk test. The $\dot{V}O_2$ data were subsequently analysed using two-way ANOVA with repeated measures across two tests (FTP vs FTP_{+15W}) and five time points (Baseline, 25%, 50%, 75% and 100% of the total test duration). The estimated blood lactate kinetics data interpolated with a linear function was analysed using two-way ANOVA with repeated measures across two tests (BLC_{FTP} vs $BLC_{FTP+15W}$) and five time points (Baseline, 25%, 50%, 75% and 100% of the total test duration). The significant interaction and main effects were determined using LSD post hoc tests. When sphericity was violated, the F value was adjusted using Greenhouse-Geisser. The end test $\dot{V}O_2$, the $BLC_{\Delta 10end}$ and the end test BLC corresponding to FTP and FTP_{+15W} were analysed using paired t-tests. Analyses were performed using IBM SPSS statistics 26.0 (Chicago, IL, USA). Data are reported as mean ± SD unless otherwise stated.

Results

The mean cycling power output was 222 ± 51 W and 237 ± 51 W at FTP and FTP_{+15W}, respectively. Only seven out of thirteen participants were able to sustain exercise at FTP for 40 minutes. The mean TTF at FTP and FTP_{+15W} was 33.7 ± 7.6 and 22.0 ± 5.7 min ($p < 0.05$), respectively. There was a small but significant difference between the end test $\dot{V}O_2$ (calculated using the average of 75% and 100% of the total duration) corresponding to FTP and FTP_{+15W} (2.97 ± 0.66 vs 3.13 ± 0.67 $L \cdot min^{-1}$, respectively; $p < 0.05$). The highest $\dot{V}O_2$ achieved during both intensities in 10 s average was significantly lower than the $\dot{V}O_{2peak}$ measured during the incremental ramp test ($\dot{V}O_{2peak}$: 3.61 ± 0.81 vs FTP: 3.21 ± 0.69, $p < 0.001$ and FTP_{+15W} 3.33 ± 0.68 $L \cdot min^{-1}$, $p < 0.001$).

$\dot{V}O_2$ response *when exercising at FTP and FTP_{+15W}*

The $\dot{V}O_2$ kinetics analysed using the individual isotime method demonstrated a significant interaction effect between test and time for $\dot{V}O_2$ response ($F = 2.827$, $p < 0.05$), the main effect of the test ($F = 19.015$, $p < 0.001$) and time ($F = 85.535$, $p < 0.001$). The $\dot{V}O_2$ was significantly different at all time points between the two intensities ($p < 0.05$), except for baseline. Post hoc analysis showed a significant difference in $\dot{V}O_2$ between the baseline and the rest of the time points ($p < 0.001$) during both FTP and FTP_{+15W}. The $\dot{V}O_2$ did not change significantly between 25% of the total duration and the end of the exercise during both FTP and FTP_{+15W} ($p > 0.05$) (see Figure. 2). There was no significant difference in the magnitude of the $\dot{V}O_{2sc}$ when exercising at FTP and FTP_{+15W} (399 ± 177 $mL \cdot min^{-1}$ vs 409 ± 185 $mL \cdot min^{-1}$, $p > 0.05$).

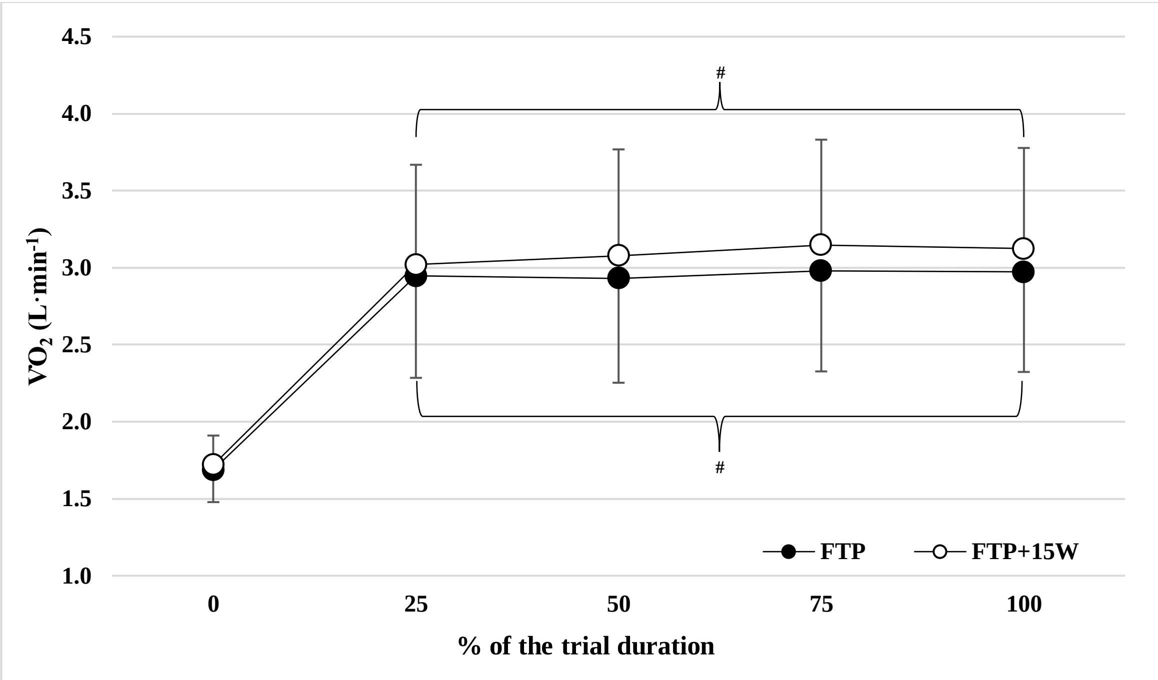

Figure 2. The $\dot{V}O_2$ response as a percentage of trial duration when exercising at the intensities corresponding to FTP and FTP_{+15W}. #no significant difference ($p > 0.05$)

Blood lactate response when exercising at FTP and FTP_{+15W}

For the blood lactate kinetics estimated using linear regression, there was a significant interaction between test and time ($F = 12.871$, $p < 0.001$), a significant main effect of time ($F = 88.110$, $p < 0.001$) and for test ($F = 3.12$, $p = 0.09$). Post hoc analysis showed a significant difference between every timepoint for BLC_{FTP} and $BLC_{FTP+15W}$ ($p < 0.05$), except for baseline. There was also a significant difference in the BLC from 50% of the test duration to the end test between BLC_{FTP} and $BLC_{FTP+15W}$ ($p < 0.05$; see Figure. 3). The estimated BLC_{FTP} and $BLC_{FTP+15W}$ at each time point were 1.6 ± 0.6, 5.6 ± 2, 6.0 ± 2.0, 6.4 ± 2.0, 6.8 ± 2.1 mM and 1.5 ± 0.5, 6.2 ± 2.0, 7.3 ± 2.2, 8.3 ± 2.5 and 9.3 ± 3.0 mM, respectively. The blood lactate difference between 50% and 100% of the test duration was 0.8 ± 0.7 and 2.0 ± 1.4 mM for FTP and FTP_{+15W}, respectively. The actual end test BLC (FTP: 6.7 ± 2.1 vs FTP_{+15W}: 9.2 ± 2.9 mM, $p < 0.05$) and the $BLC_{\Delta 10end}$ between two intensities were significantly different (FTP: 1.1 ± 0.9 vs FTP_{+15W}: 2.8 ± 2.3 mM, $p < 0.05$) between two intensities.

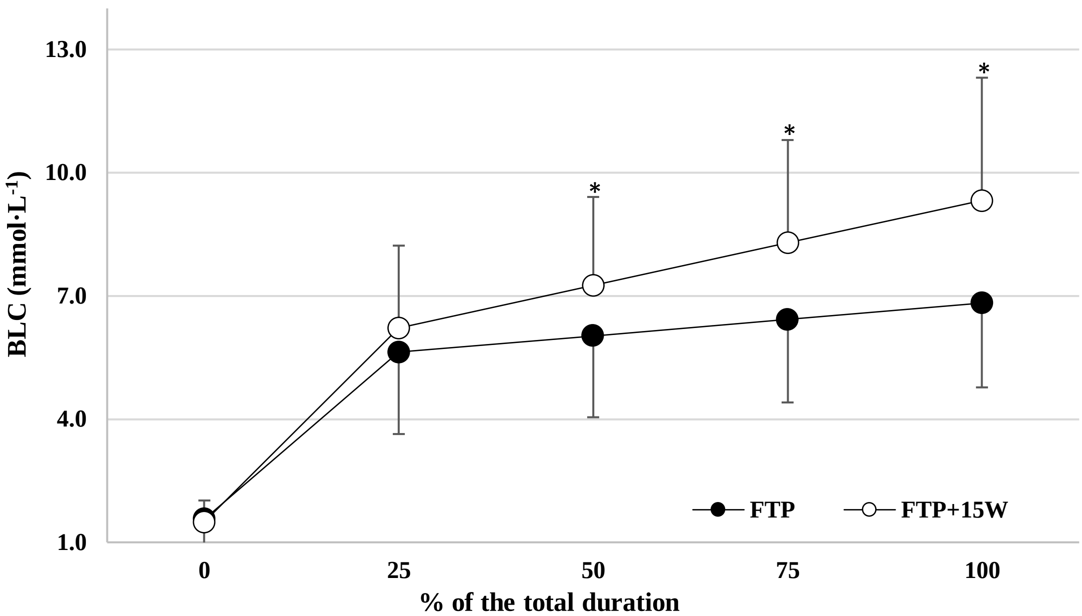

Figure 3. The blood lactate response as a percentage of trial duration when exercising at intensities corresponding to FTP and FTP_{+15W}. *significantly different from FTP ($p < 0.05$)

Discussion

In this study, we examined the physiological response when exercising at and above FTP to determine whether it is a valid representation of the threshold between the heavy and severe intensity domains. The key findings were that i) $\dot{V}O_{2peak}$ was not reached at both intensities; ii) $\dot{V}O_2$ stabilised at both intensities; iii) there was no significant difference in the amplitude of the $\dot{V}O_{2sc}$ between two intensities; iv) the actual end test BLC and the $BLC_{\Delta 10end}$ were both significantly higher during FTP_{+15W}; v) 46% of the participants reached task failure before 40 minutes when exercising at FTP. Therefore, although the present study did not set out to examine the validity between FTP and hour performance, the results demonstrated that the FTP determined using 95% of a 20-minute TT performance is not a valid estimation of maximal hourly performance. The present study also demonstrated that FTP and FTP_{+15W} are within the heavy intensity domain and, therefore, should not be used to represent the physiological threshold between the heavy and severe intensity domains.

The validity of FTP

The FTP is suggested to represent the maximal power output that a cyclist can sustain for an hour (Allen & Coggan, 2006; 2010). Although the original goal of the present study was not to examine the TTF of FTP, the results were in line with previous studies (Borszcz et al., 2018; Sitko et al., 2022). In the present study, only seven out of thirteen participants were able to complete 40 minutes at FTP, the mean TTF for the six participants who reached TTF before 40 minutes was 26 ± 4 minutes demonstrating that FTP is not a valid estimation of the one-hour maximal performance. Contrary to previous research (McGrath et al., 2019) reported that 89 % of the participants sustained 60 minutes when exercising at an intensity equivalent to FTP. A possible explanation is that they recruited highly trained subjects therefore with a higher pain/fatigue tolerance ($\dot{V}O_{2max}$: Male 66.3 ± 5.5 mL·kg·min^{-1}; Female 59.3 ± 6.9 mL·kg·min^{-1}), whereas the participants in the present study have a lower mean

$\dot{V}O_{2peak}$ (Male 60.0 ± 4.7; Female 48.0 ± 4.0 mL·kg·min^{-1}). However, according to Sitko et al. (2022), even professional cyclists with a $\dot{V}O_{2max}$ of 74.3 ± 3.9 mL·kg·min^{-1} and more than 15 years of cycling experience were unable to sustain 60 minutes at the intensity corresponding to the traditionally determined FTP (mean TTF: 51 minutes, ranged from 44 to 59 minutes). Therefore, the FTP should not be considered a valid representation of what it originally proposed, even when accounting for variables such as cyclists' performance level, experience, and aerobic fitness level (i.e., $\dot{V}O_{2max}$). Although the fatigue development in the heavy intensity domain is complex (Burnley & Jones, 2018), future studies could explore why cyclists reach task failure before the 60 minutes mark when exercising at FTP.

Oxygen kinetics when exercising at FTP and FTP_{+15W}

The threshold between the heavy and severe intensity domain separates whether the $\dot{V}O_2$ can remain in a steady state or cannot stabilise and rise towards the $\dot{V}O_{2max}$ (Hill et al., 2002). Therefore, in our view, the question of whether FTP represents the upper boundary of the heavy intensity domain is best assessed by the physiological characteristics, specifically the $\dot{V}O_2$ response. In the present study, the $\dot{V}O_2$ was not significantly different between 25 % of the total duration and the end test when exercising at FTP and FTP_{+15W}, indicating a clear $\dot{V}O_2$ steady state during both intensities. Contrary to the results reported by Nixon et al. (2021), in which the $\dot{V}O_2$ changed significantly between the 5th minute and at task failure when exercising slightly above critical speed (CS), the representation of the threshold between the heavy and severe domain in running (Jones et al., 2019). Consistent with our hypothesis, the amplitude of $\dot{V}O_{2sc}$ was not significantly different between the two intensities, indicating that FTP and FTP_{+15W} are the same intensity. It has been previously demonstrated that the $\dot{V}O_{2sc}$ is significantly lower during the heavy intensity domain compared to the severe intensity domain (Pringle et al., 2003) because the $\dot{V}O_{2sc}$ cannot be stabilised and rise towards $\dot{V}O_{2max}$ in the severe domain (Burnley & Jones, 2007). Another result from the present study is that FTP should not be considered as the threshold between heavy and severe because the highest $\dot{V}O_2$ in 10 s average when exercising at FTP and FTP_{+15W} was significantly different to $\dot{V}O_{2peak}$, which means $\dot{V}O_2$ was not reached at both intensities. Although the increment rate was fixed to 15 W in the present study, it was equivalent to a 9% to 12% increase for 3 participants. The percentage of $\dot{V}O_{2peak}$ corresponding to the FTP_{+15W} remained below 90% for these 3 participants, whereas when exercising within the severe intensity domain until task failure, the $\dot{V}O_2$ should theoretically rise inexorably towards $\dot{V}O_{2max}$ (Poole et al., 1988; De Lucas et al., 2013; Nixon et al., 2021). Moreover, the results of the present study also suggest that the training intensity zones e.g. > 106% of FTP would train $\dot{V}O_{2max}$ (Allen and Coggan, 2006; 2010) might not be valid because the highest $\dot{V}O_2$ value remains below 90% $\dot{V}O_{2max}$ when exercising at as high as 112% of FTP. Therefore, based on both the overall $\dot{V}O_2$ kinetics and the inability to attain $\dot{V}O_{2max}$, the power output corresponding to FTP_{+15W} does not appear to represent the severe intensity domain. In fact, the intensity corresponding to FTP and FTP_{+15W} may be within the heavy intensity domain (Hill et al., 2002; Burnley & Jones, 2007). Additionally, the intensity corresponding to the FTP is not appropriate to use as a reference for designing training programs as it has a high chance of overestimating the $\dot{V}O_2$ response (i.e., unable to reach the $\dot{V}O_{2max}$ even when the intensity corresponding to 112% of FTP was prescribed).

Lactate kinetics of FTP and FTP_{+15W}

Allen & Coggan (2012) suggested that the FTP could be used interchangeably with the MLSS. Three studies have examined the validity between MLSS and FTP (Borszcz et al., 2019; Lillo-Bevia et al., 2019; Inglis et al., 2019), and the results of which are in line with Allen & Coggan's suggestion (2012). However, results of the current study demonstrated that the difference in the actual BLC from the 10^{th} to 30^{th} minute for those who sustained the FTP intensity for at least 30 minutes was 1.1 ± 0.2 mM (n = 9), which exceeds the suggested conventional criterion for the determination of the conventional MLSS (change in BLC < 1.0 mM between the 10^{th} and 30^{th} minute). Therefore, using the conventional determination criterion for MLSS suggested that the power output corresponding to FTP is not a valid surrogate of MLSS as the BLC_{FTP} was not in a steady state. However, a paper recently published by Nixon et al. (2021) proposed that the criterion for BLC should be 2 mM between 10 to 20 minutes instead of the conventional criterion because the MLSS determined using this protocol eliminated the difference with Critical Speed (CS). When adopting this modified approach, the FTP examined in the present study fulfilled the criterion for being accepted as MLSS (0.8 ± 0.6 mM) for all thirteen participants. Similarly, Iannetta et al. (2021) also proposed a modified MLSS criterion of using data from the time window of 20 to 30 minutes instead of the conventional method because it has a higher agreement with MMSS. In the present study, for those who cycled for at least 30 minutes when exercising at FTP (n = 9), the actual BLC difference between 20 to 30 minutes was 0.3 ± 0.6 mM, which also meets the modified criterion for MLSS proposed by (Iannetta et al., 2021). Therefore, the ability of FTP to provide an approximation of the MLSS appears to be influenced by the criterion used to determine the MLSS. On the other hand, the blood lactate data estimated using the linear function showed a clear dissociation between blood lactate and $\dot{V}O_2$ kinetics. Therefore, it could be argued that relying solely on blood lactate to provide an indication of a given level of systemic homeostasis and the threshold between heavy and severe intensity domains might be inappropriate as it does not reflect the $\dot{V}O_2$ kinetics. As such, there is a need for scientific validation of the criterion for determining MLSS and blood lactate steady state, and it is premature to conclude whether FTP can be used to represent MLSS.

Conclusion

The present study demonstrated that FTP should not be considered a marker of the threshold separating the heavy and severe domains for cyclists. Therefore, not a valid representation of the MMSS. The conclusion from the present study is based on the $\dot{V}O_2$ response when exercising at FTP and FTP_{+15W}. There was no significant difference in the $\dot{V}O_{2sc}$, and a clear $\dot{V}O_2$ steady state was shown when exercising at both intensities. Most importantly, the $\dot{V}O_2$ did not project towards $\dot{V}O_{2max}$ when exercising at FTP and FTP_{+15W}. Future studies should examine the value of FTP, other than a valid 20-minute TT indicator, and whether it can be used as an alternative to conventional and modified MLSS.

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Figure Captions

Figure 1. Study Design Schematic

Figure. 2. The $\dot{V}O_2$ response as a percentage of trial duration when exercising at the intensities corresponding to FTP and FTP_{+15W}. #no significant difference ($p > 0.05$)

Figure. 3. The blood lactate response as a percentage of trial duration when exercising at intensities corresponding to FTP and $FTP_{+15W.}$ *significantly different from FTP ($p < 0.05$)