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Prediction of Rowing Functional Threshold Power Using Body Mass, Blood Lactate and GxT Peak Power Data

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ABSTRACT

International Journal of Exercise Science 16(4): 31-41, 2023. Functional Threshold Power (FTP) is a validated index of a maximal quasi steady-state cycling intensity. The central component of the FTP test is a maximal 20-min time-trial effort. A model to predict FTP from a cycling graded exercise test (m-FTP) was published that estimated FTP without the requirement of the exhaustive 20-min time-trial. The predictive model (m-FTP) was trained (developed to find the best combination of weights and bias) on a homogenous group of highly-trained cyclists and triathletes. This investigation appraised the external validity of the m-FTP model *vis-à-vis* the alternate modality of rowing. The reported m-FTP equation purports to be sensitive to both changing levels of fitness, and exercise capacity. To assess this claim, eighteen (7 female, 11 male) heterogeneously-conditioned rowers were recruited from regional rowing clubs. The first rowing test was a 3-min graded incremental test with a 1-min break between increments. The second test was a rowing adapted FTP test. There were no significant differences between rowing FTP (r-FTP) and m-FTP (230 ± 64 versus 233 ± 60 W, respectively, F = 1.13, P = 0.80). Computed Bland-Altman 95% LoA between r-FTP and m-FTP were (-18 W to + 15 W), $s_{y.x}$ was 7 W, and 95 %CI of regression were 0.97 to 0.99. The r-FTP equation was demonstrated to be effective in predicting a rowers 20-min maximum power; further appraisal of the physiological response to rowing for 60-min at the corresponding calculated FTP requires investigation.

KEY WORDS: Load at FBLC-4, FTP predictive equation, club-level rowers, heterogeneously-trained

INTRODUCTION

Functional Threshold Power (FTP) is the uppermost bicycling power sustainable for 60-min in a quasi-steady state (1) and has been demonstrated to be valid and reliable (16). Undoubtedly, one advantage of the FTP test (Table 1) is its simplicity and accessibility (8). The creators of the test, Hunter Allen and Dr Andrew Coggan, published the FTP test with details on the testing protocol, directions as to how to implement the test result into a training plan, clear strata to identify energy systems, tabulated power profile data to identify performance level, and highlight the scope of using FTP to monitor changes in fitness. Furthermore, the authors developed software that could be used by the athlete to record their training, retain archives, highlight personal bests and measure of exercise stress. The inference here being, perhaps the test attributes extend beyond the FTP tests simplicity. However, it should be highlighted that these functions do not appear to have been validated in peer-reviewed scientific literature to date.

Comparisons have been made between the intensity associated with FTP and alternate endurance tests. The interchangeability of FTP and Critical Power (CP) was investigated as a consequence of similar physiological identifiers, most notably that both CP and FTP demark the boundary between steady- and non-steady-state cycling (1, 26). However, a comparison of FTP and CP in a trained cohort of cyclists concluded that the tests could not be used interchangeably, although a correction factor between the indices appeared effective in predicting one test measure from the alternate test measure (17). Maximum lactate steady-state (MLSS) is the maximum intensity that BLa concentration increases by < 1 $mmol.L^{-1}$ over a 20-min epoch (2). Investigators have suggested MLSS could be used interchangeably with FTP (3). However, the MLSS marker is not frequently used in the field because of the number of discrete test sessions required (12), a problem perhaps overcome by using the FTP test.

Table 1: Protocol used for performing the rowing FTP (r-FTP) test

	Time	Description	Intensity
Warm-up	10-min	Endurance pace	65 % Dmax
	3 by 1-min, rest 1-min	Race cadence	2000-m race-rate
	5-min	Easy rowing	65% Dmax
	20-min	Time-trial	Maximum effort
	10 to 15-min.	Easy rowing	65% Dmax

FTP = Functional threshold power; Dmax = an index of blood lactate threshold

The graded exercise test (GxT) has maintained a prevalent position for the assessment of aerobic exercise fitness. There are reported variations in the GxT protocols according to the researchers needs or leanings. These variations include: the number of incremental steps, the duration of discrete steps, and the magnitude of the increase in load (W) (5). The garnered raw data are routinely collated, and an array of computerized metrics ensue (16). There have been attempts to identify an equivalent of FTP derived from a GxT, but without success (16).

Recently, an equation to predict FTP (m-FTP) from GxT data was constructed and reported consequently (15), furnishing another GxT-derived metric. The m-FTP equation was trained and tested on highly-trained cyclists, and reported: favorable root mean square of the error ($s_{y.x}$) of 15 W, a strong r^2 (0.89), and r^2adj remaining unchanged to two decimal places. The stability of r^2adj indicates that the increased error accounted for by the model was not a consequence of overfitting. The m-FTP equation was reportedly identified from a list of alternate predictive models for FTP on the basis of having the lowest error associated with future (unseen) predictions of FTP from GxT data, identified using a Leave One Out (LOO) cross-validation technique. In LOO cross-validation, for each observation (athlete) in the dataset, say the *i*th observation, the same model is fitted keeping aside the *i*th observation and using the remaining observations (athletes) to train the model. The MSE is then calculated from the model prediction for the *i*th observation. Finally the average of the individual MSE is calculated, which corresponds to the LOO cross- validation metric (15). The m-FTP variables were: power output (W) at an affixed blood lactate concentration of 4 mmol.L^{-1} BLa (FBLC-4), maximum power output (W) achieved during the GxT (Pmax), and body mass (BM in kg), as seen Equation 1 below (15). The m-FTP equation was derived from cycling data in highly-trained cohort of cyclists and triathletes. The null hypothesis for the current investigation was that the m-FTP equation could accurately predict rowing FTP (r-FTP) data in a more heterogeneous cohort of club-level male and female rowers.

Equation 1: m-FTP = -6.6 + 0.32 FBLC-4 + 0.42 BM + 0.46 Pmax

Where m-FTP = Functional Threshold Power modelled, 6.6 = Y-intercept, FBLC-4 = power output (W) at an affixed blood lactate concentration of 4 mmol.L^{-1}, BM = body mass (kg), Pmax = maximum 3-min power completed during the GxT.

METHODS

Participants

The current study obtained ethical approval from the Faculty of Health Sciences Research Ethics Committee in Trinity College Dublin and was performed in accordance with the ethics standards of the International Journal of Exercise Science (19). Initially, nineteen (n = 8 female, n = 11 male) club rowers were recruited by poster advertisement and email correspondence to the regional club gatekeepers. The participant information leaflet highlighted the inclusion of rowers from novice, club, intermediate, senior, and lightweight categories. A medical examination was performed on potential participants by a registered medical practitioner, including: spirometry, blood pressure, and the determination of injury free status. Inclusion criteria also included being aged 18 to 35 years and competing in rowing for a minimum of 1-yr. Exclusion criteria included the following: high blood pressure or found to have high blood pressure during pre-screening assessment, a bleeding or clotting disorder, any previous history of cardiopulmonary disease, respiratory difficulties or symptoms of colds/influenza on the day of testing, acute or chronic musculoskeletal injury limiting exercise capacity, or a disease that would prevent participation in a maximal exercise test. Other exclusion criteria included the following: having diabetes, hypertension, heart defects, metabolic disorders or other contraindications to maximal exercise. The mean VO_2peak (mL.kg^{-1}.min^{-1}), body mass (kg), body mass index (kg.m^{-2}), % body fat and age (yr) of enlisted rowers are presented in Table 2.

Protocol

Participants attended the laboratory on two separate occasions having abstained from alcohol and caffeine for the 24-h prior to testing. The rowers were required to attend test days in a rested, carbohydrate replete, and euhydrated state. A 24-h food diary completed prior to the first trial

(3-min GxT) identified that enlisted participants were consuming a standard training load adjusted isocaloric diet (macronutrient breakdown; ≥ 60% carbohydrate, ≤ 20% fat and ≤ 20% protein) to control for dietary induced elevations or reductions in BLa data (14). Each participant was requested to replicate their food intake prior to the r-FTP test, or if different, to consume comparable carbohydrate quantities. Trials were separated by a minimum of 4 and maximum of 10-days.

Table 2. Mean (± SD) VO_2peak, mass, BMI, % body fat, and age of enlisted participants.

	GxT VO_2peak ($mL.kg^{-1}.min^{-1}$)	Mass (kg)	BMI ($kg.m^{-2}$)	Body fat (%)	Age (yr)
Female (*n* = 7)	52.0 ± 7.7	71.3 ± 11.7	23.4 ± 3.5	25.3 ± 5.6	22.6 ± 3.2
Male (*n* = 11)	55.6 ± 9.9	85.6 ± 11.6	24.5 ± 2.4	13.8 ± 5.8	25.5 ± 6.5

(SD) – standard deviation, (BMI) – Body mass index, (GxT VO_2peak) – Peak maximum oxygen uptake during graded incremental test, ($mL.kg^{-1}.min^{-1}$) - milliliter of Oxygen consumed per kilogram body mass per minute, (kg) – kilogram, ($kg.m^{-2}$) – kilogram divided by metre squared, (yr) – year.

The c-FTP equation was developed using cycle ergometry (13). In this investigation, the Concept2 rowing ergometer (model D, VT, USA) was used throughout. Unlike the cited cycling investigation ergometers (15), the Concept2 rowing ergometer does not have a calibrating option. The rowing power output display is coded internally and generic among all Concept2 ergometers (13). The drag factor was set for each participant according to their weight category or fitness: 130 W for heavyweight (> 72.5 and > 59-kg for the male and female rowers respectively), 120 W for lightweight (< 72.5 and < 59-kg for the male and female rowers respectively) (13). The drag factor sets the rate of deceleration of the flywheel after each drive phase of the rowing stroke is completed (13). The foot-stretcher was adjusted appropriately for each participant for both tests. The first test was a 3-min graded incremental test (GxT) with a 1-min break between increments to facilitate collection of earlobe blood samples for lactate analysis. The load commenced at 100 and 120 W for the lightweight and heavyweight rowers, respectively, or on the basis of their anticipated fitness. The load increased by 20 W and 30 W every 3-min in the respective groups. To minimize measurement error on the ergometer for each 3-min segment, each rower took their initial 3 to 5 strokes to accelerate the flywheel prior to the commencement of each stage (4, 25). Collected earlobe blood samples were processed using an Arkray Lactate Pro 2 (Arkray, Shiga, Japan), which required 0.3 µL whole blood samples and had an operating range of 0.5 to 25 $mmol \cdot L^{-1}$. During the GxT, breath-by-breath ventilatory (VE, VO_2 and VCO_2) data were recorded using a calibrated cardio-metabolic cart (CPET; Cosmed, Rome, Italy). Heart rate (HR) data were recorded by radio-telemetry using a Cardiosport GT1 HR monitor (Cardiosport, Hampshire, UK), consisting of a coded transmitter belt and monitor.

The second test completed by each rower was the rowing FTP (r-FTP) test, adapted from the original cycling protocol (1) to rowing, see Table 1. The test order was not randomized as the warm-up intensity for the FTP test was set using fractions of load at Dmax calculated from the GxT (16). The instruction given to participants for the 20-min FTP time-trial was the same as that recommended for the cycling test: "A strong, steady effort for the entire 20-min. Do not start out too hard! Get up to speed (power) and then try to hold that speed (power). Your goal is to achieve the highest average wattage over the entire period" (1). Throughout the 20-minute r-FTP test, HR data were recorded and the mean and maximum data noted. An earlobe blood sample for BLa analysis was collected at baseline (pre-test), prior to commencing the 20-min trial, and having completed the 20-min time-trial. Peak BLa was compared with peak GxT data to ensure the 20-min effort was maximal. The power data was recorded on the ergometer monitor throughout each test and transmitted via Bluetooth to Concept2 Software. On an air-damped ergometer, the rower determines the accuracy of the targeted mechanical output via stroke force, rate, and length (25). Consequently, the actual power rather than the anticipate power output at each stage was used for all calculations. Breath-by-breath ventilatory (VE, VO_2 and VCO_2) and HR data were averaged across the final minute of each 3-min increment. Blood samples for lactate analysis were collected immediately following each 3-min increment.

Lactate E software was used to interpolate the power associated with FBLC-4 and the threshold index Dmax (21). The power associated with FBLC-4 was identified from a third order polynomial line of best fit using least squares regression. The load (W) at Dmax was identified as the maximum perpendicular distance to the straight line between the lowest and highest exercise BLa (5). Pmax was identified at the final 3-min average load completed during the GxT. Each participant's VO_2peak was determined as the highest consecutive 60-second average during the final test increment. The description "VO2peak" is distinct from "VO2max" on the basis of the GxT test construct was selected to derive steady-state data, thereby exceeding 10-min in total duration, which has been demonstrated to significantly impact on the magnitude of the measured VO_2 data (7). The FTP warm-up intensity was set at 65% of Dmax as a proxy for 65% FTP (16), see Table 1. The load (W) for the 3 by 1-min intervals (Table 1) required by the FTP test (1) were adapted to rowing using race stroke rate as the controller. All participants were fully familiarized with 20-min time-trials prior to testing. The load at r-FTP was calculated by reducing the mean power sustained during the 20-min time-trial by 5% (1).

Statistical Analysis

An *a priori* power test was conducted for highly correlated variables with expected outcomes of a Type 1 error probability of 0.05, a power of 0.95 and a projected effect size 0.1. This analysis indicated that n = 19 would provide a statistical power of 95% (G*Power v3.0.10 free software, Institute of Experimental Psychology, Heinrich Heine University, Dusseldorf, Germany). All data were checked for normality using the D'Agostino and Pearson Omnibus normality test. Comparisons between m-FTP versus r-FTP were made using repeated measures ANOVA test with significant differences set at $P < 0.05$, intra-class correlation (ICC), standard deviation of the residuals ($s_{y.x}$), coefficient of determination (r^2) and the computed 95% confidence intervals of r (95% CI) were also computed. For the purpose of comparing m-FTP with r-FTP a Bland-Altman plot was constructed and the acceptable 95% LoA were set *a priori* as ± 20 W (16). All analyses were performed using Prism 9 (Graph Pad, CA, USA) and group data are presented as mean and standard deviation (SD).

RESULTS

Data checks using the D'Agostino and Pearson Omnibus normality test classified that all data were normal distributed. One of the nineteen study participants was unable to complete the second trial due to an illness; a *post-hoc* power analysis indicated an amended overall power of 94.6%. The mean power at m-FTP, r-FTP and the predictive parameters body mass (kg), FBLC-4 (W), and Pmax (W) for the female, male, and grouped cohorts are presented in Table 3. The results of comparisons between m-FTP (W) vs. r-FTP (W) including the computed 95% LoA (W), mean bias (W), relative technical error of the measurement (% TEM), ICC, r^2, 95% CI of regression, and $s_{y.x}$ (W) are presented in Table 4. Computed variables m-FTP and r-FTP were highly correlated ($r = 0.99$, $P < 0.0001$, see Figure 1a) and no significant difference was detected between them ($F = 1.13$, $P = 0.80$, repeated measures ANOVA). The computed 95% LoA were – 18 to + 15 W with a mean bias of 2 W, see Figure 1b, and an associated $s_{y.x}$ of 7 W. There were no significant differences detected comparing BLa data on cessation of the 20-min r-FTP test time-trial and Pmax (12.4 ± 2.7 versus 11.5 ± 3.7 mmol.L^{-1}, $F = 1.84$, $P = 0.22$) or HR data (190 ± 9 versus 183 ± 8 beats.min^{-1}, $F = 1.35$, $P = 0.63$).

Table 3. Mean power at m-FTP, r-FTP, and the predictive parameters body mass (kg), FBLC-4 (W) and Pmax (W) for female ($n = 7$), male ($n = 11$) and grouped ($n = 18$) cohorts.

	r-FTP (W)	m-FTP (W)	Body mass (kg)	FBLC-4 (W)	Pmax (W)
Female	176 (± 24)	182 (± 23)	71 (± 12)	181(± 30)	224 (± 27)
Male	265 (± 57)	265 (± 54)	86 (± 12)	260 (± 68)	331 (± 70)
Grouped	230 (± 64)	233 (± 60)	80 (± 13)	226 (± 67)	286 (± 77)

r-FTP = Rowing FTP determined from a 20-min time-trial, m-FTP = FTP estimated from GxT data, FBLC-4 = the power associated with 4-mmol.L^{-1} blood lactate; (W) = Watt, kg = kilogram, Pmax = the average power on the final 3-min of the GxT.

Table 4. Results of comparisons using regression analysis between m-FTP (W) vs. r-FTP (W) computed 95% LoA (W), mean bias (W), % TEM, ICC, r^2, 95% CI of r and $s_{y.x}$ (W).

	95% LoA (W)	Mean bias (W)	% TEM (%)	ICC	r^2	95% CI of r	$s_{y.x}$ (W)
m-FTP vs. r-FTP	-18 to + 15	-2	2	0.99	0.98	0.97 to 0.99	7

m-FTP = Functional threshold power derived from the predictive equation, r-FTP = rowing Functional threshold power derived from the 20-min test, LoA = limits of agreement, % TEM = Relative technical error of measurement, ICC = Inter-class correlation coefficient, r^2 = Coefficient of determination, CI = confidence interval, $s_{y.x}$ = Standard deviation of the residuals, W = Watt.

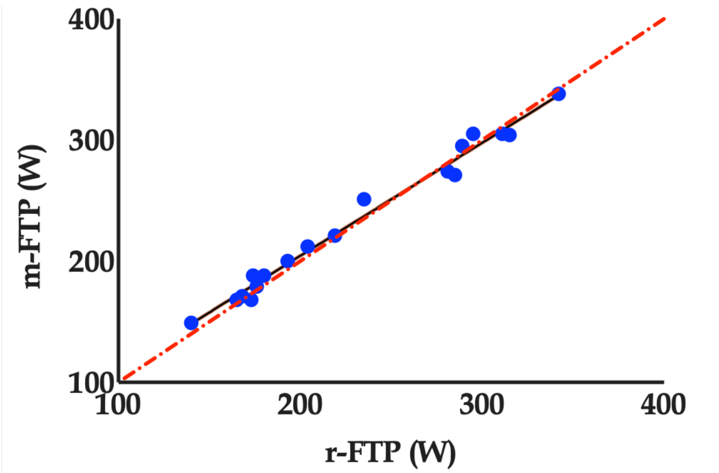

Figure 1a. Regression analysis of m-FTP (W) versus r-FTP (W) data. Dashed red line represents line of equality.

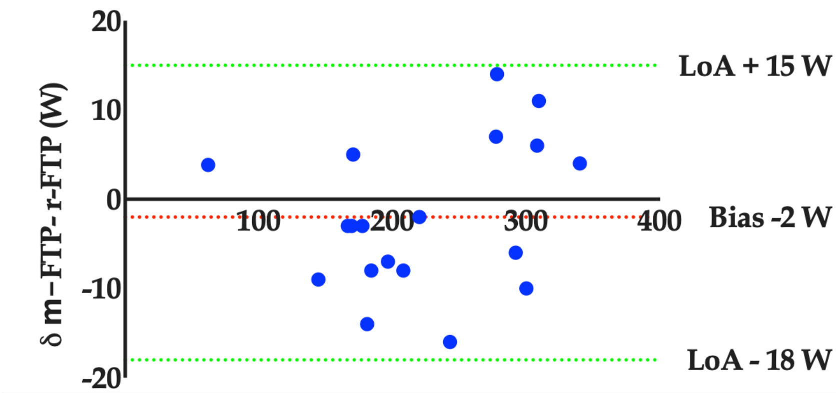

Figure 1b. Bland-Altman plot for m-FTP (W) versus r-FTP (W) identifying mean bias (dashed red line) and upper and lower 95 % LoA (dashed green line).

DISCUSSION

The computed m-FTP from GxT data and the measured r-FTP were highly correlated (r^2 = 0.98). More insightfully, the 95 % LoA (-18 W to + 15 W) between m-FTP and r-FTP were comparable to those associated with repeating the same cycling FTP test on two occasions; namely, -17 to + 13 W (16). Furthermore, the 95 % LoA were found to be narrower than the limits set *a priori*, therefore supporting usage of the cycling trained m-FTP equation to accurately predict r-FTP on a rowing ergometer. A comparison of the $s_{y.x}$ determined from the rowers data (7 W) compared favorably (15 W) with the original cycling validation study reported by McGrath *et al*. (16). Lastly, the 95 % CI of regression in the current rowing investigation were much tighter than those previously derived from the determination of the repeatability of FTP testing when cycling: 0.97 to 0.99 versus 0.87 to 1.11. These results as a whole may be interpreted as there being equivalence in completing or repeating an FTP test versus predicting FTP from GxT data. Practically, however, in a circumstance where a rower only wishes to determine their FTP, there is an argument for choosing the r-FTP test rather than using m-FTP equation derived from GxT data.

The determination of the external validity of the cycling m-FTP was feasible as the analogue power is used on both cycling and rowing ergometers. Rowing ergometers are widely used by recreational to elite-level rowers (18). The Concept2 rowing ergometer used in the current investigation is air-braked and resistance is created by a flywheel that is accelerated during the drive-phase and decelerated during the subsequent recovery phase of a stroke. The flywheel decelerates due to the resistance provided by the circulating air but it does not stop immediately due to the rotating mass of the flywheel and the energy stored therein (25). The ergometer determines resistance via stroke force, rate and length (25) using the following equation (4);

$$P_{ergo} = \frac{\int_{t_1}^{t_2} C_1 \dot{\theta}^3 dt + \frac{1}{2} J(\dot{\theta}_3^2 - \dot{\theta}_1^2)}{t_3 - t_1}$$

Where θ: angular position of the flywheel (rad), J: moment of inertia of the flywheel ($kg.m_2$), t1: starting time of the rowing cycle, namely the catch (s), t2: end of the pull phase; namely the finish (s), t3: end of the rowing cycle; namely, the next catch, C1: constant ($kg.m^2$) calculated for each stroke on the previous recovery phase (4).

$$C_1 = -\frac{\int_{t_2}^{t_3} \frac{J\ddot{\theta}}{\dot{\theta}^2}}{t_3 - t_2}$$

The power at the level of the flywheel is considered to be the power dissipated by air resistance and the power developed to accelerate the flywheel between two successive strokes (4).

Peak rowing power outputs during a GxT have been reported to be significantly lower ($p < 0.00$) when rowing versus cycling (13). The associated VO_2 at a fixed load (W) has been demonstrated to be higher when rowing versus cycling (23). Moreover, when power is expressed as a percentage of VO_2peak, power output on a rowing ergometer has been shown to be consistently lower than on a cycling ergometer (13). The dissimilar metabolic strain between these modalities is in part due to the activated muscle mass and diverging physiological requirements (23). Another furnished explanation for the variance in metabolic strain is the different duty cycle associated with rowing versus cycling, particularly when rowing with a low stroke-rate where the drive time to recovery phase ratio is high (13). One final conjectured explanatory factor is that the power required during the recovery phase of the rowing stroke is not accounted for by the rowing ergometer (13). Given that the predictive equation m-FTP comprises the parameter Pmax, the impact of a lower Pmax on a rowing ergometer versus a cycle ergometer was identified as a possible influence on the equations efficacy. However, this risk was considered low as Pmax and FBLC-4 are both contained in the predictive equation and the relative relationship between the indices was anticipated to be more important than the independent parameters (Equation 1). Previous research has argued that Pmax could be used as a standalone marker of performance. Pmax has been demonstrated to be a more stable marker than VO_2max for predicting performance as a consequence of a lower coefficient of variation (4.99 versus 7.89

%, respectively) (10). However, there is a reported lack of a consistency between Pmax versus both peak blood lactate and VO_2max (10), which may limit the insight derived from Pmax as a stand-alone index of performance. FTP represents a change in the upper-limit quasi-steady-state intensity an athlete can sustain for 60-min, whereas the insight derived from Pmax (10) is that performance has changed with the absence of any insight as to the mechanistic basis. The argument for a single parameter model for FTP has been argued previously on the basis of parsimony (15). However, the authors conceded that the addition of a second parameter reflecting the more oxidative energetics was worthwhile (15).

McGrath *et al*. (15) reported that the inclusion of FBLC-4 in their m-FTP equation was questionable as a consequence of high correlation of FBLC-4 with Pmax (r = 0.90). The premise for retaining the parameter (FBLC-4) was that the relationship between FBLC-4 and Pmax varies with fitness, and therefore both indices provide unique predictive capacity. The current investigation findings appear to support this argument where FBLC-4 expressed as a fraction of Pmax ranged between 60 and 93% (mean 78 ± 7%). As it stands, the identification of the m-FTP equation was based on its predictive capacity and minimizing of errors (15). Other investigators surmise that the errors associated with the parameter FBLC-4 versus a "turning point" (Dmax, Tvent and T_{Lac}) could be theoretically lower as a consequence of the calculation design (9). An elevated baseline BLa could impact on the identification of a turning point as this initial datum point is included in the calculation. Given that FBLC-4 is not impacted by baseline BLa data, it is insusceptible to this particular source of error. The magnitude of the errors in BLa at FBLC-4 versus "a turning point" should also be smaller as FBLC-4 is positioned on the steeper region of the BLa curve (9). The premise of this conjecture is that changes in the Y-coordinate decrease relative to the independent X-coordinate as a consequence of the exponential relationship between BLa and load (W).

The third equation parameter; namely BM, has been demonstrated to have a meaningful impact on both cycling (11) and rowing (20), as both modalities require the athlete to carry only a portion of their mass. As such, both modalities have been scaled using a variety of models including: simple ratio, linear regression, and a power function (20, 24). The weighting of the individual predictive parameters can be identified by the product of the coefficient and the magnitude of the parameter. Consequently, the m-FTP equation can be considered most heavily weighted to Pmax, followed sequentially by FBLC-4 and BM.

In conclusion, the power output associated with r-FTP in a heterogeneous cohort of female and male club-level rowers can be accurately derived from GxT rowing data. Further investigation is required to determine the limits of tolerance to rowing a r-FTP and the associated physiological response are consistent with cycling (16). The application of the m-FTP to alternate fully weight-bearing sports is possibly limited as a consequence of the coefficient of BM but this conjecture requires further investigation.

REFERENCES

1. Allen H, Coggan A. Training and racing with a power meter. Colorado, USA: VeloPress; 2010.

2. Beneke R, Leithauser R, Hutler M. Dependence of the maximum lactate steady state on the motor pattern of exercise. Br J Sports Med 35: 192-196, 2001.

3. Borszcz R, Tramontin A, Costa V. Is the Functional Threshold Power interchangeable with maximal lactate steady-state in trained cyclists. Int J Sports Physiol Perform 14(8): 1029-1035, 2019.

4. Boyas S, Nordez A, Cornu C & Guevel. Power responses of a rowing ergometer: mechanical sensors vs. Concept2 measurement system. Int J Sports Med 27: 830-833, 2006.

5. Cheng B, Kuipers H, Snyder A, Keizer H, Jeukendrup A, Hesselink M. A new approach for the determination of ventilatory and lactate thresholds. Int J Sports Med 13: 518-522, 1992.

6. Cunningham D, Goode P, Critz J. Cardiorespiratory response to exercise on a rowing and bicycle ergometer. Med Sci Sports Exerc 7: 37-43, 1975.

7. Denham J, Scott-Hamilton J, Hagstrom A, Gray A. Cycling power outputs predict Functional Threshold Power and maximm oxygen uptake. J Strength Cond Res 34: 3489-3497, 2017.

8. Gavin T, van Meter J, Brophy P, Dubis G, Potts K, Hickner R. Comparisons of a field-based test to estimate Functional Threshold Power output at lactate threshold. J Strength Cond Res 26(2): 416-421, 2012.

9. Heck H, Mader G, Hess G, Mucke S, Muller R, Hollmann W. Justification of the 4-mmol$\cdot$L^{-1} lactate threshold. Int J Sports Med 6: 117-130, 1985.

10. Kuipers H, Verstappen F, Keizer H, Geurten P, van Kranenburg G. Variability of aerobic performance in the laboratory and its physiologic correlates. Int J Sports Med 6: 197-201, 1985.

11. Lamberts R, Lambert M, Stewart J, Noakes T. Allometric scaling of peak power output accurately predicts time-trial performance and maximal oxygen consumption in trained cyclists. B J Sports Med 46: 36-41, 2012.

12. Lillo-Beviá J, Courel-Ibáñez J, Cerezuela-Espejo V, Morán-Navarro R, Martínez-Cava A, Pallarés J. Is the functional threshold power a valid metric to estimate the maximal lactate steady state in cyclists? J Strength Cond Res 36: 167-173, 2022.

13. Lindenthaler J, Rice A, Versey N, McKune A, Welvaert M. Differences in physiological responses during rowing and cycle ergometry in elite male rowers. Front Physiol 9: 1-10, 2018.

14. Maassen N, Busse M. The relationship between lactic acid and workload: A measure for endurance capacity or an indicator of carbohydrate deficiency? Eur J Appl Physiol Occup Physiol 58: 728-737, 1989.

15. McGrath E, Mahony N, Fleming N, Benavoli A, Donne B. Prediction of Functional Threshold Power from graded exercise test data in highly-trained individuals. Int J Exerc Sci 15(4): 747-759, 2022.

16. McGrath, Mahony N, Fleming N, Donne B. Is the FTP test a reliable, reproducible and functional assessment tool in highly trained athletes? Int J Exerc Sci 12(4): 1334-1345, 2019.

17. McGrath, Mahony N, Fleming N, Raleigh C, Donne B. Do critical and functional threshold power equate in highly-trained athletes? Int J Exerc Sci 14(4): 45-59, 2021.

18. Mentz L, Engleder T, Schulz G, Winkert K, Steinacker J, Treff G. The mechanical rower: construction, validity, and reliability of a test rig for wind braked rowing ergometer. J Biomech 106, 2020. Doi:10.1016/j.jbiomech.2020.109833

19. Navalta J, Stone W, Lyons T. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12: 1-8, 2019.

20. Nevill A, Ramsbottom R, Williams C. Scaling physiological measurements for individuals of different body size. Eur J Appl Physiol 65: 110-117, 1992.

21. Newell J, Higgins D, Madden N, Cruickshank J, Einbeck J, Mc Millan K, Mc Donald R. Software for calculating blood lactate endurance markers. J Sports Sci 25(12): 1403-1409, 2007.

22. Smith T, Hopkins W. Variability and predictability of final times of elite rowers. Med Sci Sports Exerc 43: 2155-2160, 2011.

23. Steinacker J, Marx T, Marx U, Lormes W. Oxygen consumption and metabolic strain in rowing ergometer exercise. Eur J Appl Physiol 55: 240-247, 1986.

24. Swain D, Coast R, Clifford P, Milliken M, Stray-Gunderson J. Influence of body size on oxygen consumption during bicycling. J Appl Physiol 62: 668-672, 1987.

25. Treff G, Mentz L, Mayer B, Winkert K, Engleder T, Steinacker J. Initial evaluation of the Concept 2 rowing ergometer's accuracy using a motorised test rig. Front Sports Act Living 3: 801617, 2022. doi: 10.3389/fspor.2021.801617

26. Vanhatalo A, Jones A, Burnley M. Application of critical power in sport. Int J Sports Physiol Perform 6: 128-136, 2011.