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MLSS vs the 20-minute FTP test in well-trained individuals: "Watts" the big deal?

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Abstract

PURPOSE This study aimed to i) compare the power output (PO) for both the 20-minute functional threshold power (FTP_{20}) field-test and the calculated 95% ($FTP_{95\%}$) with power at maximal lactate steady state (MLSS); and ii) evaluate the sensitivity of $FTP_{95\%}$ and MLSS to training induced changes.

METHODS

Eighteen participants (12 males- 37± 6 years; 6 females- 28 ± 6 years) performed a ramp-incremental cycling test to exhaustion, 2 to 3 constant load MLSS trials, and a FTP_{20} test. 10 participants returned to repeat the test series after 7-months of training.

RESULTS

PO at FTP_{20} and $FTP_{95\%}$ was greater than that at MLSS (p=0.00), with the PO at MLSS representing 88.5 ± 4.8% and 93.1 ± 5.1% of FTP and $FTP_{95\%}$, respectively. MLSS was greater POST compared to PRE training (12 ± 8 W) (p=0.002). No increase was seen in mean PO at FTP_{20} and $FTP_{95\%}$ (p=0.75).

CONCLUSIONS

The results indicate that the PO at $FTP_{95\%}$ is different to MLSS, and that changes in MLSS PO after training were not reflected by $FTP_{95\%}$. Even using an adjusted percentage (i.e., 88% rather than 95% of FTP_{20}), the large variability in the data is such that it would not be advisable to use this as a representation of MLSS.

Introduction

Identifying the critical intensity of exercise is a crucial aspect for predicting performance, prescribing exercise training, and evaluating the effectiveness of training interventions[1,2]. This critical intensity is thought to represent the upper boundary of sustainable performance (i.e., the boundary separating tolerable and non-tolerable exercise) and is often identified by measures including the maximal lactate steady state (MLSS) or critical power (CP)[3]. While the accuracy for determining this intensity is best obtained in a laboratory setting, this is not always feasible due to cost, accessibility, and time constraints. Thus, field-test protocols are popular amongst cyclists as they are easily conducted with minimal equipment. Given the practical nature of field-tests, they do not entail direct measurement of the physiological responses normally used to confirm the level of exertion (e.g., blood lactate concentration ([BLa]), oxygen uptake ($\dot{V}O_2$)), instead they rely on the maximal voluntary performance.

In cycling, power meters are commonly used for monitoring the cyclist's work rate and can be used to measure performance during field-test protocols. Specifically, a popular approach amongst cyclists is to determine their functional threshold power (FTP_{60}), which is defined as the highest mean power output (PO) that can be achieved during a 60-minute time-trial[4]. FTP_{60} PO is then used as the basis for prescribing training intensities. Because of the length of this test, a more commonly used protocol is the 20-minute FTP test (FTP_{20}), from which 95% ($FTP_{95\%}$) of the mean FTP_{20} power is calculated as a prediction of FTP_{60}[4].

With the increased popularity of the FTP test, comparison has been made between the various time-trials and other markers of performance. Specifically, MacInnis et al.[5] found that the 20-minute time-trial (i.e. FTP_{20}) is a reliable test with a strong association with the 60-minute time trial (i.e. FTP_{60}) and suggested that it may be an appropriate tool for performance assessment and tracking. However, these authors concluded that the use of 95% could result in an overestimation of FTP_{60} and suggested that a reduction in the percentage of the $FTP_{95\%}$ - from 95% to 90% - might be a better predictor of this intensity[5]. In contrast, others have found no difference between the $FTP_{95\%}$ and the lactate threshold [6], nor between the $FTP_{95\%}$ and the individual anaerobic threshold[7]. Moreover, a comparison between $FTP_{95\%}$ and CP (also closely related with the anaerobic threshold[8]) found a strong correlation and no difference[9] between the two variables. However, large limits of agreement were reported and it was concluded that CP and $FTP_{95\%}$ should not be considered equivalent nor used interchangeably[9].

According to Allen & Cogan[4], FTP_{60} and $FTP_{95\%}$ represent the highest PO that can be maintained for an extended period of time (~1 hour), a duration that very closely resembles that reported for exercising at MLSS (~55 min)[10]. Despite this claim, no study has experimentally investigated whether $FTP_{95\%}$ is equivalent to MLSS. This is pertinent as many regard MLSS to be the criterion measure for tolerable exercise[2]. Furthermore, although cross-sectional comparisons between $FTP_{95\%}$ and other markers of performance have been made[5–7,9], no study has evaluated the ability or sensitivity of the $FTP_{95\%}$ test to track changes in fitness level on a longitudinal basis.

Thus, the aims for this study were to assess whether $FTP_{95\%}$ PO is similar to that at MLSS and whether the FTP_{20} is sensitive to changes in fitness status over a 7-month training period. Based on the fact that i) the FTP is a performance-based test that could be subject to external factors; ii) the $FTP_{95\%}$ is a fixed percentage that does not consider inter-individual variations; and iii) it has previously been shown to be an overestimation of FTP_{60}, we hypothesized that $FTP_{95\%}$ PO would be different to PO at MLSS. Additionally, we hypothesized that PO at $FTP_{95\%}$ would be sensitive to changes in fitness level.

Methods

Participants

Eighteen participants (12 males – mean ± SD; 37 ± 6 years; 180 ± 6 cm; 79 ± 8 kg; 6 females – mean ± SD; 28 ± 6 years; 171 ± 6 cm; 68 ± 9 kg) volunteered and provided written informed consent to participate in this study. Participants ranged from trained to well-trained athletes. $\dot{V}O_{2max}$, self-reported training volume and years of training experience were used to categorize participants with reference to previously established guidelines[11]. All procedures were approved by the Conjoint Health Research Ethics Board at the University of Calgary and complied with the latest version of the Declaration of Helsinki.

Protocol

All testing sessions were performed on an electromagnetically braked cycle ergometer (Velotron Dynafit Pro, Racer Mate, Seattle, WA, USA) in an environmentally controlled laboratory (i.e., temperature ~21°C, relative humidity ~36%) over the span of 4-5 sessions. For each participant the time of day was kept consistent and each session was separated by at least 48 hours and no longer than 72 hours. Participants were asked to refrain from performing vigorous intensity exercise the day before each session while also maintaining a similar diet over the course of the testing. Testing sessions included a ramp-incremental test, constant-load trials and a maximal effort 20-minute time trial (see below for details).

The study was separated into two separate parts with identical testing procedures. The first part included all participants (n=18) whereas the second part included 10 returning participants (9 males, 1 female-mean ± SD; 39 ± 5 years; 178 ± 8 cm; PRE 76 ± 10 kg, POST 76 ± 11 kg). For these ten participants the first and second parts corresponded to before (PRE) and to the end (POST) of a seven-month cycling season[12]. Additionally, for these ten participants PRE-season testing corresponded to the 2-months prior to the start of racing season (a period of time during which training consisted predominantly of prolonged endurance sessions). Over the course of the cycling season these ten participants trained on average 5-6 days per week, for ~1.5-4 hours per session. The necessary sample size for sufficient statistical power was n=10 and was calculated based on the observed differences in a similar study[5].

Ramp-incremental test. The initial visit consisted of a ramp-incremental test to exhaustion to determine maximal oxygen uptake ($\dot{V}O_{2max}$) and to predict the initial load for determination of MLSS[13]. The ramp-incremental test began with a 4-min baseline at 50W followed by a 30W·min^{-1} ramp for males and a 25W·min^{-1} for females.

Constant-load trials. The successive visits after the ramp-incremental test included 30-min constant-PO trials for the determination of MLSS. Participants were instructed to cycle at their preferred cadence which was recorded and kept consistent for the constant-PO trials. MLSS was defined as the highest PO at which a stable blood lactate concentration ([BLa]) ($\Delta \leq 1.0$ mmol·L^{-1}) was measured between the 10th and 30th minute of the constant-PO trial[14]. Multiple trials were performed until this criterion was satisfied. Prior to the MLSS trial a 4-minute baseline ride was performed at 80W before PO was instantaneously increased to a predetermined value. Throughout all the testing sessions the participants were blinded to PO and elapsed time.

20-minute Functional Threshold Power Test. The Velotron 3D software (Racer Mate, Seattle, WA, USA) was used for the FTP_{20} during which the participants controlled the gearing of the ergometer. Participants were familiarized with the gearing system prior to the test. The test was preceded by an 8-minute baseline at 80W. For the FTP_{20} test the participants were familiar with the goal of achieving the highest average PO possible across the 20-minutes and no verbal encouragement was provided. During the test, participants were blinded to PO but were allowed to see time and cadence to allow for individual pacing strategies.

Measurements

A metabolic cart (Quark CPET, Cosmed, Rome, Italy) measured breath-by-breath gas exchange and ventilatory variables. Expired gases were sampled at the mouth and analyzed for fractional concentrations of oxygen (O_2) and carbon dioxide (CO_2) and a low-dead space turbine assessed inspired and expired flow rates. Gas and flow calibrations were performed prior to each testing session as per manufacturer recommendations. Heart rate was continuously monitored (Garmin, Chicago, USA).

[BLa] was measured with a portable device (Lactate Scout, LS, SensLab, GmbH, Germany) from a finger prick during baseline and at 5-minute increments during the 30-minute constant-load trials and the FTP_{20} test.

Psychological measures including the feeling scale (FS) for measures of "affect" and the felt arousal scale (FAS) for "arousal" level were administered before and after each testing session, while a rating of perceived exertion (RPE) scale (0-10) was administered at the same 5-minute intervals as [BLa] was measured.

Data and Analysis

Gas exchange and ventilatory variables

Breath-by-breath $\dot{V}O_2$ data from each test was processed (aberrant data points that were >3 SD from the local mean were removed), time-aligned (such that time "zero" represented the onset of the ramp- or constant-load exercise) and then linearly interpolated to 1s intervals.

Ramp-Incremental test. The highest $\dot{V}O_2$ computed from a 30 s rolling average was defined as $\dot{V}O_{2max}$, while peak PO was the highest PO value achieved at the end of the ramp-incremental test.

MLSS & FTP. $\dot{V}O_2$ at MLSS was determined from the average of the last 10 minutes of the constant-load trial. FTP_{20} PO was calculated as the average of the entire 20-minute test from which the $FTP_{95\%}$ was derived (95% of the 20-minute average). PO was interpolated into 1 s intervals and to 5 min bins for statistical comparison (i.e. PRE vs POST).

HR, RPE, FS, FAS, [BLa]. HR was taken as the average of the last two minutes of exercise and the RPE collected during the final minute of exercise was used for comparison of PRE to POST. Pre-session FS and FAS measurements were used for analysis. End [BLa] represents the sample taken in the 30th minute and 20th minute for MLSS and FTP_{20}, respectively.

Pacing. Changes in pacing strategy were evaluated PRE to POST by finding the average PO within 5-minute segments during the FTP_{20}.

Statistics

All data processing and modelling were performed with a commercially available computer software (OriginLab, Northhampton, MA) and statistical analysis was performed using SPSS version 23 (SPSS, Chicago, USA) with statistical significance set at a $P < 0.05$. Descriptive data are presented as mean ± SD. Paired samples t-tests were used to evaluate differences in PO at FTP_{20} and $FTP_{95\%}$ compared to MLSS, in addition to differences in physiological and psychological measures (HR, [BLa], RPE, FS and FAS) from MLSS and FTP_{20} within the same testing period. A repeated measures ANOVA was used to evaluate these difference PRE-POST. Bland-Altman analyses were used to test for agreement between PO at MLSS and $FTP_{95\%}$ while the association between values of $\dot{V}O_2$ and PO were tested by linear regression analysis and Pearson's product moment correlations. Paired samples t-tests were used to evaluate changes in pacing strategy from PRE to POST at each 5-minute segment.

Results

Full group PRE

Overall $\dot{V}O_{2max}$ was 4.00 ± 0.68 L/min with a peak PO of 394 ± 67W. PO at FTP_{20} and $FTP_{95\%}$ was greater than that at MLSS ($p<0.05$; Table 1), with PO at MLSS representing 88.5 ± 4.8% and 93.1 ± 5.1% of FTP and $FTP_{95\%}$, respectively. There was a strong correlation between MLSS and $FTP_{95\%}$ (Figure 1, right panel), with a significant mean difference (i.e., bias) between the PO observed at MLSS compared to $FTP_{95\%}$ (Figure 1, left panel). Mean HR and RPE was 162 ± 8 bpm and 5.0 ± 1.7 at MLSS and 175 ± 8 bpm and 8.4 ± 1.4 at FTP_{20}, respectively. Mean change in [BLa] for MLSS was 0.7 ± 0.3 $mmol·L^{-1}$. Mean end [BLa] was 4.3 ± 1.2 $mmol·L^{-1}$ for MLSS and 12.3 ± 2.6 $mmol·L^{-1}$ for FTP_{20}.

PRE to POST responses

For the 10 participants that completed both phases of the study, no increase in $\dot{V}O_{2max}$ was seen from PRE (4.32 ± 0.53 $L·min^{-1}$, 56.6 ± 4.3 $ml·kg·min^{-1}$) to POST (4.37 ± 0.60 $L·min^{-1}$, 57.7 ± 7.9 $ml·kg·min^{-1}$) ($p=0.45$). Mean change in [BLa] for the MLSS trials (Δ [BLa] from the 10th to 30th minute) was 0.7 ± 0.3

mmol·L^{-1} PRE and 0.7 ± 0.3 mmol·L^{-1} POST. Table 2 displays mean HR, end [BLa], RPE, FS and FAS for MLSS and FTP_{20} at PRE and POST.

Table 3 displays PRE and POST values of MLSS, FTP_{20} and $FTP_{95\%}$. MLSS was greater at POST compared to PRE for both PO (+12 ± 8W; range +2 to 28W) (p=0.00) and $\dot{V}O_2$ (PRE 3.63 ± 0.51 L·min^{-1}, POST 3.77 ± 0.51 L·min^{-1}; +0.14 ± 0.13 L/min; range -0.01 to + 0.37 L·min^{-1}) (p=0.01). No increase was seen in mean PO at FTP_{20} (range -18 to +26W) and $FTP_{95\%}$ (-17 to +25W) (p=0.75). Bland-Altman and a correlation analysis of changes in PO at MLSS and $FTP_{95\%}$ from PRE to POST are shown in Figure 2. At PRE, $FTP_{95\%}$ represented 88 ± 6% of PO at MLSS (range: -8 to +51W; bias = -20W) whereas at POST, $FTP_{95\%}$ values represented 92 ± 5% of PO at MLSS (range: -31 to +28W; bias -9W). No difference in PO was found at any of the 5-minute segments from PRE-POST (p=0.48-0.96) (Figure 3).

Discussion

The main goal of this study was to evaluate the ability of the 20-minute FTP test to predict PO associated with MLSS. As hypothesized, despite a strong correlation between PO at $FTP_{95\%}$ and MLSS, the calculated $FTP_{95\%}$ overestimated PO corresponding to MLSS (i.e., bias = -17W) with large variability between the measures (i.e., differences ranging from -8 to +51W for $FTP_{95\%}$). A second goal of this study was to evaluate the ability of the $FTP_{95\%}$ to reflect changes in fitness on a longitudinal basis. Contrary to our hypothesis, the results of this study indicate that the PO at $FTP_{95\%}$ was not sensitive to changes in MLSS, as improvements in this marker were not reflected in the $FTP_{95\%}$.

Relevance of FTP_{20} *testing from PRE training data:* The $FTP_{95\%}$ derived from the FTP_{20} test has recently become a widespread approach thought to be able to estimate PO associated to the critical intensity of exercise. This study compared the $FTP_{95\%}$ PO derived from the FTP_{20} test to that at MLSS, which represents the upper limit for metabolic steady-state during continuous exercise[2]. The results of this study demonstrate that a PO lower than the recommended 95% of the FTP_{20} was associated MLSS. While the results of this study indicate that 88.5% (± 4.8%) of the FTP_{20} is more likely to reflect PO at MLSS, the large amount of variability in the agreement for these measures (LOA = 9 to -44W) prevents the use of this percent value with any confidence, as a superior approximation of MLSS. In this regard, MacInnis et al. [5] previously reported that $FTP_{95\%}$ exceeds PO for the FTP_{60} test and that the FTP_{60} PO represented 90% (CI 88-92%) of that achieved during a FTP_{20} test, which is in good agreement with the present study. Taken together, these data are in accordance with our hypothesis, and indicate not only that using a PO of 95% of the FTP_{20} seems to be an overestimation of the actual PO associated to MLSS, but also that even by using a lower percentage of the FTP_{20}, there is large inter-individual variability inherent in this prediction. This may be partly related to the fact that both oxidative and non-oxidative energetic pathways contribute to the overall FTP_{20} performance but that their proportional contributions may vary between individuals. In this context, the discrepancy between these measures is concerning if trying to use $FTP_{95\%}$ as a proxy for MLSS, as previous research has demonstrated that exercising at only 10 W above MLSS profoundly reduces subsequent performance ability (i.e. time to task failure) is substantially reduced[15]. Furthermore, inaccurate estimations of this intensity could change prescription of intended training intensity zones.

While the present study adopted MLSS as the criterion measure for the upper limit of metabolic stability and compared this with the $FTP_{95\%}$, other studies have investigated the correspondence between FTP tests and different markers of critical intensity. For example, Morgan et al.[9], found a close relationship between CP (275 ± 42W) and $FTP_{95\%}$ (278 ± 42W). However, similar to our results, they found that the corresponding limits of agreement (+10.9% to 13.1%) exceeded those that would allow the two measures to be used interchangeably with a high level of confidence. Additionally, in the previously mentioned study of MacInnis et al.[5] the authors found that 95% of the FTP_{60} (CI 92-98%) was equal to CP. Although this may be in contrast to our results, it should be noted that the authors utilized a two-trial linear model (including a four-minute trial) which might have overestimated PO at CP[16]. It is important to highlight that, although CP and MLSS share a similar definition, they reflect two different methods to derive PO at critical intensity[17,18]. As briefly mentioned, estimates of CP are affected by the testing protocol, the mathematical model used, and the data fitting strategy[16,19] and in some circumstances have been shown to elicit POs greater than that at MLSS[20]. Thus, caution is warranted when comparing POs at MLSS and CP in relation to that derived from FTP testing. Given the great variability in measures of FTP compared to other markers of critical intensity, caution should be exerted before using $FTP_{95\%}$ as one size fits all approach to predicting critical intensities of exercise[7].

Effects of training on FTP and MLSS: This study found that PO at MLSS was greater at POST compared to PRE. Surprisingly, the increase in PO associated with MLSS did not translate into an improvement in the FTP_{20} test, as evidenced by the fact that the improvements in MLSS from PRE to POST correlated poorly to changes (or the lack thereof) for FTP_{20} from PRE to POST, and did not translate to improvements in $FTP_{95\%}$. This is an important finding as it would be expected that a greater PO from MLSS, a physiologically validated test that determines the highest intensity corresponding with stable metabolic responses, should be related to performance improvements during a similarly challenging FTP test. Given that it is important that measurements are sensitive to small but meaningful changes in performance, as well as valid and reliable[21,22], the present data question the ability of the FTP_{20} test to accurately track those changes. It could be argued that the average increase of MLSS was relatively small (i.e., 12W) however it is likely that well-trained populations have a smaller opportunity for improvement and that changes are of a smaller magnitude compared to untrained populations[23,24]. From this perspective, it could be possible that individuals of lower fitness level undergoing training programs, may display greater changes in MLSS that may also better relate to performance changes in FTP_{20}, as in this population greater relative improvements in aerobic fitness can be expected[25]. Therefore, the results of the present study indicate that the $FTP_{95\%}$ may not be sensitive enough to detect small physiological training adaptations occurring in well-trained individuals. Alternatively, improvements in MLSS may solely indicate changes in physiology which may not encompass all components of performance, which however seems unlikely given the tight association between MLSS and exercise capacity[2].

Although the reasons why the increase in PO at MLSS did not translate into an improvement in the FTP_{20} test cannot be fully elucidated from this study, it should be acknowledged that the $FTP_{95\%}$ itself is a performance-based test and the ability of the test to track the actual changes in performance relies upon participants exerting maximal effort. In this context, it is important to consider that this performance may be influenced by other factors[26]. While laboratory-based testing procedures ensure that tests are performed in standardized and well-controlled conditions for the majority of factors that might influence performance, the psychological state of the participants (e.g., motivation) cannot be controlled. Even though there were no differences PRE to POST in the FS and FAS measures, no direct measures of motivation were taken in this study and thus it is possible that motivation to provide a maximal effort changed towards the end of the season. This may be a limitation of FTP testing as, in addition to the possibility that small changes in fitness are not detected with the test, other factors such as motivation are more likely to jeopardize a performance-based protocol compared to a laboratory-based test (i.e., MLSS). Additionally, it has been showed that in some circumstances experience and training status also can influence the reliability of a time-trial test[27]; however, it is unlikely that this played a role in our study as the cyclists involved in the post-measurements were the most familiar with the FTP_{20} test and were also among the individuals in this study with the highest training status. In fact, in well-trained cyclists time-trial performance is reported to be highly reproducible, despite the fact that pacing strategy can be subject to variability[28]. Furthermore, it has been shown that even if the time-trials performed differ in duration, when the absolute PO and overall pacing strategy are expressed against relative exercise duration, well-trained athletes show minimal differences between conditions[29]. Regardless, we did not find differences in the pacing strategy employed by the participants between PRE and POST measurements of the FTP_{20}, thus it is unlikely that this played a role.

As MLSS testing is not readily and easily accessible to every individual and discrepancies in the predictive ability of the $FTP_{95\%}$ have been shown in our results and those presented by others[5], there may be the need to develop an alternative approach to the $FTP_{95\%}$ that is reliable, valid and convenient for cyclists. Based on these data, it could be suggested that the use of the $FTP_{95\%}$ on its own does not closely estimate the critical intensity of exercise and does not seem to effectively monitor changes in performance. Thus, future studies are warranted to develop alternative field-test protocols that produce a closer approximation of PO at MLSS.

Conclusions

The results from this study indicate that the $FTP_{95\%}$ does not provide an accurate representation of PO at MLSS. Even with an adjusted percentage (i.e., 88% rather than 95% of FTP_{20} representing a value for FTP_{60}), the large variability in the data is such that it would not be advisable to use the $FTP_{95\%}$ test to estimate MLSS. Furthermore, the results demonstrated that POs from the $FTP_{95\%}$ are not sensitive to small but meaningful and significant changes in fitness level and thus its use as a tool for monitoring training may be limited.

Disclosure of interest

The authors report no conflict of interest.

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References

1. Poole DC, Burnley M, Vanhatalo A, Rossiter HB, Jones AM. Critical Power: An Important Fatigue Threshold in Exercise Physiology. *Med Sci Sport Exerc*. 2016;48(11):2320-2334. doi:10.1249/MSS.0000000000000939.Critical

2. Billat VL, Sirvent P, Py G, Koralsztein J-P, Mercier J. The Concept of Maximal Lactate Steady State. *Sport Med*. 2003;33(6):407-426. doi:10.2165/00007256-200333060-00003

3. Keir DA, Fontana FY, Robertson TC, et al. Exercise intensity thresholds: Identifying the boundaries of sustainable performance. *Med Sci Sport Exerc*. 2015;47(9):1932-1940. doi:10.1249/MSS.0000000000000613

4. Allen H, Coggan A. *Training and Racing with a Power Meter*. Boulder, CO: Velopress; 2006.

5. Macinnis MJ, Thomas ACQ, Phillips SM. The Reliability of 4-Minute and 20-Minute Time Trials and Their Relationships to Functional Threshold Power in Trained Cyclists. *Int J Sports Physiol Perform*. 2018;Ahead of P:1-9.

6. Valenzuela PL, Morales JS, Foster C, Lucia A, de la Villa P. Is the functional threshold power (FTP) a valid surrogate of the lactate threshold? *Int J Sports Physiol Perform*. 2018;Ahead of P.

7. Borszcz FK, Tramontin AF, Bossi AH, Carminatti LJ, Costa VP. Functional Threshold Power in Cyclists: Validity of the Concept and Physiological Responses. *Int J Sports Med*. 2018:737-742. doi:10.1055/s-0044-101546

8. Moritani T, Nagata a, deVries H a, Muro M. Critical power as a measure of physical work capacity and anaerobic threshold. *Ergonomics*. 1981;24(January):339-350. doi:10.1080/00140138108924856

9. Morgan PT, Black MI, Bailey SJ, et al. Road cycle TT performance : Relationship to the power-duration model and association with FTP. *J Sports Sci*. 2018;00(00):1-9. doi:10.1080/02640414.2018.1535772

10. Baron B, Noakes TD, Dekerle J, et al. Why does exercise terminate at the maximal lactate steady state intensity ? *Br J Sports Med*. 2008;42:828-833. doi:10.1136/bjsm.2007.040444

11. Pauw K De, Roelands B, Geus B De, Meeusen R. Guidelines to classify subject groups in sport-science research. *Int J Sports Physiol Perform*. 2013;8:111-122. doi:10.1123/ijspp.8.2.111

12. Inglis EC, Iannetta D, Keir DA, Murias JM. Training-Induced Changes in the RCP, [HHb] BP and MLSS: Evidence of Equivalence. *Int J Sports Physiol Perform*. 2019;In Press:1-23. doi:10.1123/ijspp.2019-0046

13. Iannetta D, Fontana FY, Maturana M, et al. An equation to predict the maximal lactate steady state from ramp incremental exercise test data in cycling. *J Sci Med Sport*. 2018:1-7. doi:10.1016/j.jsams.2018.05.004

14. Beneke R. Methodological aspects of maximal lactate steady state—implications for performance testing. *Eur J Appl Physiol*. 2003;89(1):95-99. doi:10.1007/s00421-002-0783-1

15. Iannetta D, Inglis EC, Fullerton C, Passfield L, Murias JM. Metabolic and performance-related consequences of exercising at and slightly above MLSS. *Scand J Med Sci Sports*. 2018;(August):2-5. doi:10.1111/sms.13280

16. Mattioni Maturana F, Fontana FY, Pogliaghi S, Passfield L, Murias JM. Critical power: How different protocols and models affect its determination. *Journal of Science and Medicine in Sport*. 2017:1-6.

17. Keir DA, Mattioni Maturana F, Murias JM. When is it appropriate to compare critical power to maximal lactate steady-state? *Appl Physiol Nutr Metab*. 2017.

18. Jones AM, Vanhatalo A, Burnley M, Morton RH, Poole DC. Critical Power: Implications for Determination of VO2max and Exercise Tolerance. *Med Sci Sport Exerc*. 2010;42(10):1876-1890. doi:10.1249/MSS.0b013e3181d9cf7f

19. Bishop D, Jenkins DG, Howard A. The critical power function is dependant on the duration of predictive tests chosen. *Int J Sports Med*. 1998;19:125-129.

20. Mattioni Maturana F, Keir DA, McLay KM, Murias JM. Can measures of critical power precisely estimate the maximal metabolic steady-state? *Appl Physiol Nutr Metab*. 2016;41(11):1197-1203. doi:10.1139/apnm-2016-0248

21. Hopkins WG. Measures of Reliability in Sports Medicine and Science. *Sport Sci Rev*. 2000;30(1):1-15.

22. Hopkins WG, Schabort EJ, Hawley JA. Reliability of Power in Physical Performance Tests. *Sport Med*. 2001;31(3):211-234.

23. Sjodin B, Jacobs I, Svedenhag J. Changes in Onset of Blood Lactate AccUmulation (OBLA) and Muscle Enzymes After Training at OBLA *. *Eur J Appl Physiol Occup Physiol*. 1982;49:45-57.

24. Denis C, Fouquet R, Poty P, Geyssant A, Lacourt J. Effect of 40 weeks of endurance training on the anaerobic threshold. *Int J Sports Med*. 1982;3:208-214.

25. Hickson RC, Bomze HA, Holloszy JO. Linear increase in aerobic power induced by a strenuous program of endurance exercise. *J Appl Physiol*. 1977;42(3):372-376. doi:10.1152/jappl.1977.42.3.372

26. Faria EW, Parker DL, Faria IE. The Science of Cycling Factors Affecting Performance – Part 2. *Sport Med*. 2005;35(4):313-337.

27. Zavorsky GS, Murias JM, Gow J, et al. Laboratory 20-km cycle time trial reproducibility. *Int J Sports Med*. 2007;28(9):743-748. doi:10.1055/s-2007-964969

28. Thomas K, Stone MR, Thompson KG, St Clair Gibson A, Ansley L. Reproducibility of pacing strategy during simulated 20-km cycling time trials in well-trained cyclists. *Eur J Appl Physiol*. 2012;112(1):223-229. doi:10.1007/s00421-011-1974-4

29. Nicolò A, Marcora SM, Sacchetti M. Respiratory frequency is strongly associated with perceived exertion during time trials of different duration. *J Sports Sci*. 2016;34(13):1199-1206. doi:10.1080/02640414.2015.1102315

Figure 1. Bland-Altman plot analysis *(left)* showing differences in power output at maximal lactate steady state (MLSS) and 95% of the 20-minute functional threshold power test ($FTP_{95\%}$) for all subjects. Correlation graph *(right)* between power output at MLSS and $FTP_{95\%}$ (dashed grey line indicates line of identity).

Figure 2. Bland-Altman plot analysis *(left)* showing changes in power output PRE to POST at maximal lactate steady state (MLSS) and 95% of the 20-minute functional threshold power test ($FTP_{95\%}$). Correlation graph *(right)* between change in power output at MLSS and $FTP_{95\%}$ (dashed grey line indicates line of identity).

Figure 3. Power output during the 20-minute functional threshold power test (FTP_{20}) at PRE (grey circles, positive SD) and POST (white circles, negative SD).