Title: A field-based cycling test to assess predictors of endurance performance and establishing training zones.

Running head: Field-based cycling test

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ABSTRACT

This study evaluates the relationship between a field-based 8-min time trial (8MTT) and physiological endurance variables assessed with an incremental laboratory test. Secondly, lactate thresholds assessed in the laboratory were compared to estimated functional threshold power (FTP) from the 8MTT. Nineteen well-trained road cyclists (aged 22 ± 2 yr, height 185.9 ± 4.5 cm, weight 72.8 ± 4.6 kg, VO_{2max} 64 ± 4 $ml \cdot min^{-1} \cdot kg^{-1}$) participated. Linear regression revealed that mean 8MTT power output (PO) was strongly to very strongly related to PO at 4 $mmol \cdot L^{-1}$, PO at initial rise of 1.00 $mmol \cdot L^{-1}$, PO at D_{max} and modified (mD_{max}) (r = 0.61 – 0.82). Mean 8MTT PO was largely to very largely different compared to PO at fixed blood lactate concentration (FBLC) of 2 $mmol \cdot L^{-1}$ (ES = 3.20) and 4 $mmol \cdot L^{-1}$ (ES = 1.90), PO at initial rise 1.00 $mmol \cdot L^{-1}$ (ES = 2.33), PO at D_{max} (ES = 3.47) and mD_{max} (ES = 1.79) but only trivially different from maximal power output (W_{max}) (ES = 0.09). The 8MTT based estimated FTP was moderate to very largely different compared to PO at initial rise of 1 $mmol \cdot L^{-1}$ (ES = 1.37), PO at D_{max} (ES = 2.42), PO at mD_{max} (ES = 0.77) and PO at 4 $mmol \cdot L^{-1}$(ES = 0.83). Therefore, even though the 8MTT can be valuable as a performance test in cycling shown through its relationships with predictors of endurance performance, coaches should be cautious when using FTP and PO at laboratory-based thresholds interchangeably to inform training prescription.

Keywords: endurance training, cycling, lactate threshold, power output

INTRODUCTION

Conducting exercise tests is an essential part of the training monitoring process of athletes as it allows coaches to track the effectiveness of different training programs or strategies and to determine whether progress has been made. Additionally, exercise tests are used to define individual training intensity zones that are subsequently used for the design of training sessions in a training plan (34). The availability of mobile power meters has enabled cyclists to track power output along with heart rate continuously in the field during training and competition. Furthermore, given the intrusiveness of laboratory testing on the cyclist's training or competition program, more and more research is focusing on testing the validity of field-based tests to track and monitor performance changes (11, 24, 30, 33). A field-based test provides coaches with an easy-to-implement tool to track and monitor changes in performance during different training phases. Most field-based tests designed for cyclists consist of all-out time trials of different durations (e.g. 20-min time trial (1)). Power output is measured during such time trials to assess the performance level of the cyclist. Secondly, based on the mean power output and heart rate during the time trials, training intensity zones can be defined (1, 14, 25).

Even though power output during time trials of 60-90min closely relate to markers of endurance performance (5, 18), shorter tests are easier to integrate in to a training plan on a regular basis and are less physically and mentally demanding. Allen and Coggan (1) proposed the 20-min functional threshold power (FTP) test, where 95% of the average power over the 20-min time trial was used to estimate FTP. The FTP was defined as the highest average power that a rider can maintain for 60 min and serves as an individual's estimated power output at lactate threshold (defined as 1 $mmol \cdot L^{-1}$ increase above baseline) (17, 18). This is based on the strong relationship between mean power output achieved during 60-90min time trials and lactate threshold (5, 18). The training intensity zones are based on percentages of that FTP or mean power output during the test. Carmichael and Rutberg (14) described an 8-min FTP estimation test (8MTT), where 90% of the average power during the maximal effort was used to estimate FTP. However, there is still little scientific evaluation of these field-based cycling tests, FTP estimation and their relationship with endurance variables.

Klika et al. (25) showed that the average power during the 8MTT was ~7.5% higher than lab-tested power output at lactate threshold (determined by increase of 1 $mmol \cdot L^{-1}$ above baseline) in 56 cyclists ranging from novice cyclists to master athletes. Based on anecdotal evidence and the fact that the Klika et al. (25) study was conducted at altitude (2400m), Carmichael and Rutberg (14) defined a practical 10% conversion factor to estimate FTP (FTP = 0.90 x 8MTT mean power output). Gavin et al. (21) evaluated the 8MTT in estimating FTP using this conversion factor. They showed that the estimated FTP using the 8MTT (301 ± 13 W) was not different than power output at a fixed blood lactate concentration of 4 $mmol \cdot L^{-1}$ (303 ± 23 W) but greater than power output at lactate threshold defined as the point at which blood lactate values increases 1 $mmol \cdot L^{-1}$ (264 ± 9 W) greater above that of the previous stage. Therefore, it is important to consider between-method differences to determine lactate threshold and how these compare to estimated FTP. Even though these studies show promising results of using the 8MTT as a performance measure or to estimate FTP, there are some limiting factors with regards to these studies. Klika et al. (25) used a relatively large sample of 56 participants, however the participants were considered recreational cyclists, making it questionable if these results can be transferred to well-trained cyclists. In contrast, Gavin et al. (21) used well-trained cyclists (VO_{2max} of 65.3 ± 1.6 $ml \cdot min^{-1} \cdot kg^{-1}$) but with a limited sample size (n = 7) against 4 common methods to identify a lactate threshold. Therefore, the evaluation of the relationship of the 8MTT to additional submaximal physiological variables based on the blood lactate response to exercise such as the D_{max} method (15) or modified D_{max} method (mDmax) (9) may provide additional insight.

As such, building on the promising results of the 8MTT in previous research (21, 25) this study will evaluate the relationship between the 8MTT performed in the field and different laboratory based physiological endurance variables previously assessed in trained cyclists (5, 9, 10) to assess the applicability of the 8MTT as a measure of fitness. In line with previous research, it is expected that strong relationships with indices of aerobic fitness will be observed. Secondly, it will be evaluated how lactate thresholds determined by different methods in the laboratory will compare to 8MTT estimations of FTP to assess the 8MTT's ability to inform training prescription.

METHODS

Experimental Approach to the Problem

This study compares the field-based 8MTT with physiological measures obtained using a laboratory incremental cycling test. Firstly, we evaluated how power output during the 8MTT relates to predictors of endurance cycling performance obtained with the laboratory test such as power output at fixed blood lactate concentrations (FBLC) of 2 and 4 $mmol \cdot L^{-1}$, D_{max}, mD_{max} and maximal power output (W_{max}). Previous research has shown that such submaximal and maximal markers are able to distinguish endurance capacity and cycling specialty between elite cyclists with similarly high VO_{2max} (16, 27, 31) and are related time trial performance of longer durations (20-90 min) (5, 18). Secondly, an evaluation was made into how estimated FTP by the 8MTT compares to commonly used lactate thresholds assessed in a laboratory setting to evaluate if field-based and laboratory based thresholds can be used interchangeably.

Subjects

Nineteen competitive male road cyclists (aged 22 ± 2 yr, height 185.9 ± 4.5 cm, weight 72.8 ± 4.6 kg, VO_{2max} 64 ± 4 $ml·min^{-1}·kg^{-1}$) (mean ± SD) volunteered to participate in the study. All participants were well-trained competitive cyclists active in national and international competitions. Participants reported to be healthy and free of injury when starting the study. Participants were informed of the benefits and risks of the prior to signing an institutionally approved informed consent. Institutional ethical approval was granted prior to the commencement of the study, and in agreement with the Helsinki Declaration

Procedures

Laboratory test

Participants performed an incremental exercise test in the laboratory with lactate measures. The incremental test started at 100 W and increased with 40 W every 4 minutes until voluntary exhaustion or when the pedalling cadence fell below 70 $rev·min^{-1}$ and the cyclists was not able to increase the cadence. The cyclists' own bikes were placed on an ergometer (Cyclus2 ergometer, RBM Electronics, Leipzig, Germany). All tests were performed under similar environmental conditions (17-18 ºC, 45–55% relative humidity). Five common lactate landmarks were measured: FBLC at 2 $mmol·L^{-1}$ and 4 $mmol·L^{-1}$, initial rise of 1 $mmol·L^{-1}$ above baseline, D_{max}(15) and mD_{max} (9). A publically available spreadsheet was used to calculate power output at the different lactate landmarks (29). W_{max} was computed as follows: $W_{max} = W_f + [(t/D \times P)]$, where W_f is the power output during the last completed stage, *t* is the duration of the last uncompleted stage, *D* is the duration of each stage in seconds (=240 s) and *P* is the incremental increase in power output with every stage (26).

8MTT test

The 8MTT test was performed on the cyclists' own bike with power output measured using a mobile power meter system. Participants were encouraged to reach the highest mean power output during the time trial. The 8MTT was performed directly after a controlled warm-up (10-20min <60% power output at FBLC of 4 $mmol \cdot L^{-1}$, 5min 90% power output at of FBLC 4 $mmol \cdot L^{-1}$, 5min <60% power output at FBLC of 4$mmol \cdot L^{-1}$) in the field with the intensity for the warm-up being determined by the laboratory test. Participants monitored the power output during the warm-up and 8MTT test using mobile power meters, owned by the cyclists: SRM system (n = 2) (SRM, Jülich, Welldorf, Germany), Power2max (n = 8) (Power2max, Chemnitz, Germany), PowerTap (n = 2) (CycleOps, Madison, USA) (7), SRAM Quarq (n = 1) (SRAM, Chicago, Illinois, USA), Rotor (n = 2) (Rotor bike components, Madrid, Spain), Stages powermeter (n= 2) (Stages Cycling, Saddleback LTd., UK) and Pioneer power meter (n = 2) (Pioneer, Kawasaki, Kanagawa, Japan). Validity of the crank based mobile power meters was assessed by comparing the measured power output by mobile power output to the set power output by the Cyclus2 ergometer during every stage of the incremental test (Table 1). The power meters were calibrated prior to testing according to the manufacturer's instructions. FTP was estimated using the following conversion (14, 21): FTP = mean power output during the 8MTT x 0.90

TABLE 1 ABOUT HERE

Statistical analyses

A one-way repeated measures analysis of variance (ANOVA) was used to compare the power output at different lactate markers obtained by the laboratory test and the mean power output measured during the 8MTT. Prior to analysis the assumption of normality was verified by using Shapiro-Wilk W test. When a significant *F* ratio was observed, a Bonferroni post hoc analysis was used to do pairwise comparisons. Standardised effect size (ES) is reported as Cohen's *d*, using the pooled standard deviation as the denominator. A magnitude based inferences approach was used to evaluate the magnitude of the ES and relationships between variables (4, 23). Qualitative interpretation of *d* was based on the guidelines provided by Hopkins et al. (23): 0 - 0.19 trivial; 0.20 – 0.59 small; 0.6 – 1.19 moderate; 1.20 – 1.99 large; ≥ 2.00 very large. The association between power output at different lactate markers and during the 8MTT was determined using Pearson's product moment correlation coefficients. Uncertainties in the correlation coefficients are presented as 95% confidence intervals. Interpretations on the strength of the correlation coefficients were based on guidelines provided by Hopkins et al. (23): 0-0.09 trivial; 0.1-0.29 weak; 0.3-0.49 moderate; 0.50-0.69 strong; 0.70-0.89 very strong; 0.90-0.99 nearly perfect; 1.00 perfect.

RESULTS

Relationship with endurance performance determinants

A total of 19 laboratory and field-tests were analysed. The correlations (± 95% confidence intervals) between the different lactate markers and W_{max} assessed with the incremental exercise test and mean power output during the 8MTT are presented in Table 2. Linear regression revealed strong relationships between mean power output during the 8MTT and power output at FBLC 2 mmol·L^{-1} and power output at initial rise of 1 mmol·L^{-1}. Very strong relationships were observed for power output at FBLC 4 mmol·L^{-1}, D_{max}, mD_{max} and W_{max}. Mean power output during the 8MTT (378 ± 37 W) was very largely different compared to power output at FBLC of 2 mmol·L^{-1} (278 ± 26 W) (ES = 3.20, $p < 0.001$), power output at initial rise of 1 mmol·L^{-1} (300 ± 30 W) (ES = 2.33, $p < 0.001$) and power output at D_{max} (279 ± 20 W) (ES = 3.47, $p < 0.001$). Large differences were found between mean power output during the 8MTT compared to power output at 4 mmol·L^{-1} (319 ± 25 W) (ES = 1.90, $p < 0.001$) and power output at mD_{max} (319 ± 29 W) (ES = 1.79, $p < 0.001$). A trivial difference (ES = 0.09, $p = 1.00$) was observed between W_{max} (381 ± 30 W) and mean power output during the 8MTT.

TABLE 2 ABOUT HERE

FIGURE 1 ABOUT HERE

Comparison of estimated FTP and lactate thresholds

The different lactate landmarks assessed in the laboratory in comparison to the estimated FTP by the 8MTT are presented in Figure 1. Absolute and percentage differences between estimated FTP and the different lactate landmarks are presented in Table 3, mean and individual differences between estimated FTP and the lactate landmarks are presented in Figure 2. Even though strong to very strong associations between 8MTT and physiological variables were observed, estimated FTP (341 ± 33 W) was very largely different than power output at FBLC of 2 $mmol \cdot L^{-1}$ (ES = 2.20, $p < 0.001$) and D_{max} (ES = 2.42, $p < 0.001$), largely different than power output at initial rise of 1 $mmol \cdot L^{-1}$ above baseline (ES = 1.37, $p < 0.001$) and moderately different than power output at FBLC of 4 $mmol \cdot L^{-1}$ (ES = 0.83, $p = 0.009$) and mD_{max} (ES = 0.77, $p < 0.001$). W_{max} was largely different than the estimated FTP based on the 8MTT (ES = 1.21, $p < 0.001$).

FIGURE 2 ABOUT HERE

TABLE 3 ABOUT HERE

DISCUSSION

This study demonstrates that mean power output during a field-based 8MTT exhibits a strong to very strong association with physiological determinants of endurance performance assessed in the laboratory. Therefore, this study suggests that an easy-to-implement short field test such as the 8MTT could be considered as an useful test to monitor performance in well-trained cyclists. However, even though large to very large associations with predictors of endurance performance were shown, differences between estimated FTP based on the 8MTT and power output at all the lactate markers were moderate to very large.

It has previously been demonstrated that submaximal parameters such as lactate or ventilatory thresholds are key determinants of endurance performance as they can distinguish endurance capacity between athletes with similarly high VO_{2max} values (18, 19, 28). Therefore, providing evidence of the relationship between field-based tests and these endurance performance determinants shows the validity for such a test as a predictor of endurance performance. This study demonstrates that mean power output during the 8MTT has strong to very strong relationships (r= 0.61 – 0.82) with physiological determinants of endurance performance. The results of this study are in line with the study performed by Klika et al. (25) who reported nearly perfect correlations (r = 0.98) between power output during the 8MTT and power output at lactate threshold (+1 $mmol \cdot L^{-1}$ above baseline). Additionally, they showed that mean power output during the 8MTT was very strongly related to W_{max} and VO_{2max} (r = 0.76 – 0.90). Gavin et al. (21) also reported a very strong relationship (r = 0.80) between PO during the 8MTT ($W \cdot kg^{-1}$) and VO_2max. However, even though these results are promising for the 8MTT test to monitor performance in cycling, the optimal duration for an all-out field-based cycling test remains debatable. Previous research has shown strong relationships between time trials ranging from 20-90 min and endurance performance variables (3, 5). However, a field-based time trial of 4-min has also been shown to relate very strongly to two lactate turn points based on a first and second nonlinear increase in lactate versus power output (r = 0.87, 0.90) and the ventilatory threshold (r = 0.77) and respiratory compensation point (r = 0.78) (30). Similar relationships are observed for a 20-min time trial in the field, performed either uphill or on flat or slightly undulating roads (11, 30). Nevertheless, based on strong relationships observed between endurance performance determinants in this study and previous research, short all-out time trials (e.g. 4 – 8min) can be considered as useful tests to track performance in trained road cyclists. Such short tests are relatively easy to integrate in to the training plan of cyclists on a regular basis and are less physically and mentally demanding compared to tests of longer durations.

In most endurance sports, training intensity zones are based on ranges of heart rate, speed or power output relative to a range of blood lactate concentration or %VO_{2max}, typically defined using incremental laboratory exercise tests (34). However, field-based cycling tests (e.g. the 8MTT) provide a more easily administered and repeatable method to define training zones, which are defined relative to an estimated lactate threshold or FTP (1, 14, 21). Providing scientific evidence on the accuracy of these field-tests in estimating power output at lactate threshold provides valuable information for coaches and practitioners implementing these tests (21, 25). These results suggest that estimated threshold power using an 8-min time trial (i.e. FTP) may not be used interchangeable with laboratory based lactate thresholds. To the best of our knowledge, Gavin et al. (21) is the only other study that evaluated estimated FTP of the 8MTT with lactate markers. They reported that PO at estimated FTP was very largely different than the PO at the point at which blood lactate values increase 1 $mmol \cdot L^{-1}$ or greater above that of the previous stage. Even though slightly different methods have been used in this study (e.g. rise of 1 $mmol \cdot L^{-1}$ above baseline) we found similar results with estimated FTP being largely different. Furthermore, they reported that the estimated FTP (301 ± 13 W) was moderately different from power output at FBLC of 4 $mmol \cdot L^{-1}$ (293 ± 9 W). We also observed a moderate difference with estimated FTP being 21 ± 20 W and 6 ± 6% higher compared to power output at 4 $mmol \cdot L^{-1}$ lactate. In some individuals this would lead to substantially different training zones when the lab-based and field-based thresholds would be used interchangeably. It must be noted however that it remains questionable if these differences in training intensity zones and subsequent training prescription would lead to clear physiological differences in training adaptation. However, we would still suggest that it is important for coaches and practitioners to consider these differences when defining training intensity zones based on an estimated FTP in the field or in a laboratory interchangeably.

When establishing training zones based on a threshold measured in the laboratory or using a field-based threshold estimation, it is important to consider the influence of the test protocol. Bentley et al. (6) suggested that it is necessary to use stage lengths of 3-6min during incremental laboratory exercise test to obtain precise lactate measurements to determine desired metabolic inflection points. Modification of stage duration will influence the lactate threshold with shorter stages causing the lactate threshold to occur at a higher power output or heart rate (6). These differences must be acknowledged since differences in protocol might lead to differences in prescribed training intensity zones and potential differences in adaptations. Additionally, it is important to consider between-individual differences in the comparison between field-based and laboratory based assessments. For example, our results show that estimated FTP by the 8MTT was 21 ± 20 higher compared to power output at FBLC of 4 mmol·L^{-1}. However, for some individuals a difference of <10 W between FTP and FBLC of 4 mmol·L^{-1} was shown while for other individuals there was a difference of >30 W (Figure 2). A potential factor contributing to these differences is the between-individual differences in time to exhaustion at the intensity of maximal aerobic power (8, 22). Especially, since our study shows a trivial difference between W_{max} assessed in the laboratory and mean power output during the 8MTT, suggesting the intensity of the 8MTT being similar or close to power output at VO_{2max}. The individual differences in time to exhaustion at VO_{2max} could potentially lead to increased between-individual variability during short time trials of a duration of ~4-8 min (8). This similarity also opens the avenue for the 8MTT to be used as a surrogate measures of PO at VO_{2max} which may be considered important for the implementation of some high intensity training protocols (13).

One limitation of the present study is that different power meters are used to evaluate and collect power output data during the 8MTT. Differences between power meters can potentially contribute to increased variability in the results. However, the power meters have been tested for concurrent validity by comparing the power output measured by the mobile power meters to the Cyclus2 ergometer (Table 1). Since the bicycles are placed on the ergometer without wheels we could not performance a similar analysis for the PowerTap power meter which is based on the hub of the back wheel. However, previous research has shown the validity of this specific power meter (7, 12, 20). Furthermore, there is additional research validating the Stages and SRM power meter systems which are also used in this study (2, 32). Additionally, the 8MTT is a self-paced time trial performed in the field. Using such a field-based approach makes the collection of data less controlled compared to laboratory settings. However, this adds a degree of external validity as it relates more closely to a field-based elite-sporting environment.

In conclusion, this study shows that mean power output during an 8-min time trial demonstrates strong to very strong associations with physiological determinants of endurance performance and could therefore be considered as an useful test to track and monitor changes in performance in well-trained cyclists. However, these results suggest that estimated threshold power using field-based tests (i.e. FTP) may not be used interchangeably with laboratory based threshold makers based on lactate. Future research should assess other field-tests and their relationship with indices of endurance performance to validate these practical tests for coaches and practitioners.

PRACTICAL APPLICATIONS

Laboratory tests provide valuable information about the fitness and performance potential of athletes. However, implementing frequent laboratory tests during the season is not practical in a sport as road cycling because of the high number of competition days. Field-based tests to track performance changes and establish training zones are valuable for coaches as they are easy to implement in to the training plan of the cyclist. The findings of this study provides evidence to support the use of an 8MTT to track and monitor changes in performance in well-trained cyclists as mean power output during the 8MTT was strongly to very strongly related to key determinants of endurance performance. However, since we observed that estimated FTP based on the 8MTT is different to power output at lactate markers observed in a laboratory test, coaches and practitioners working with cyclists should be cautious when using FTP and power output at laboratory-based thresholds interchangeably to inform training prescription.

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TABLES

Table 1: Comparison between the Cyclus2 ergometer and the different mobile power meters used in this study.

		Comparison with Cyclus2 Ergometer			
Power meter	**Number of participants with power meter**	**Mean and % difference**	**Standard error estimate**	**Bland Altman 95% Limits of Agreement**	**Intraclass correlation coefficient**
SRM System	2	9 W, 4.3%	3 W	±8 W	0.99
Power2max	8	6 W, 4.2%	3 W	±8 W	0.99
PowerTap	2	N/A*	N/A	N/A	N/A
Quarq	1	9 W, 3.9%	2 W	±17 W	0.99
Rotor	2	6 W, 2.7%	2 W	±6 W	1.00
Stages	2	7 W, 3.4%	8 W	±15 W	1.00
Pioneer	2	7 W, 2.8%	6 W	±13 W	0.99

[1]Since the bicycles are placed on the ergometer without wheels we could not performance a similar analysis for the PowerTap power meter which is based on the hub of the back wheel.

Table 2: Relationships between different lactate markers and peak power output of an incremental exercise test and mean power output during an 8-minute field time trial

	PO at 8MTT		
	Correlation coefficient (r)	95% confidence intervals	*p*
PO at FBLC 2 mmol·L^{-1}	0.65	0.28 – 0.85	< 0.001
PO at FBLC 4 mmol·L^{-1}	0.81	0.55 – 0.92	< 0.001
PO at IR of 1 mmol·L^{-1}	0.61	0.21 – 0.83	< 0.001
PO at D_{max}	0.76	0.47 – 0.90	< 0.001
PO at mD_{max}	0.82	0.57 – 0.93	< 0.001
W_{max}	0.81	0.56 – 0.92	< 0.001

Abbreviations: PO, power output; FBLC, fixed blood lactate concentration; IR, initial rise of blood lactate increase; 8MTT, 8-min time trial.

Table 3: Differences between estimated FTP by the 8-min field time trial and physiological lactate markers measured during a laboratory incremental test.

	Difference with estimated FTP (W) (mean ± SD)	**Difference with estimated FTP (%)** (mean ± SD)
Lactate markers		
PO at FBLC 2 mmol·L^{-1}	-62 ± 26	-18 ± 7
PO at FBLC 4 mmol·L^{-1}	-21 ± 20	-6 ± 6
PO at IR of 1 mmol·L^{-1}	-50 ± 28	-14 ± 8
PO at D_{max}	-61 ± 22	-18 ± 5
PO at mD_{max}	-21 ± 19	-6 ± 6
W_{max}	+41 ± 20	+12 ± 6

Abbreviations: PO, power output; FBLC, fixed blood lactate concentration; IR, initial rise of blood lactate increase; 8MTT, 8-min time trial; FTP, functional threshold power.

FIGURES

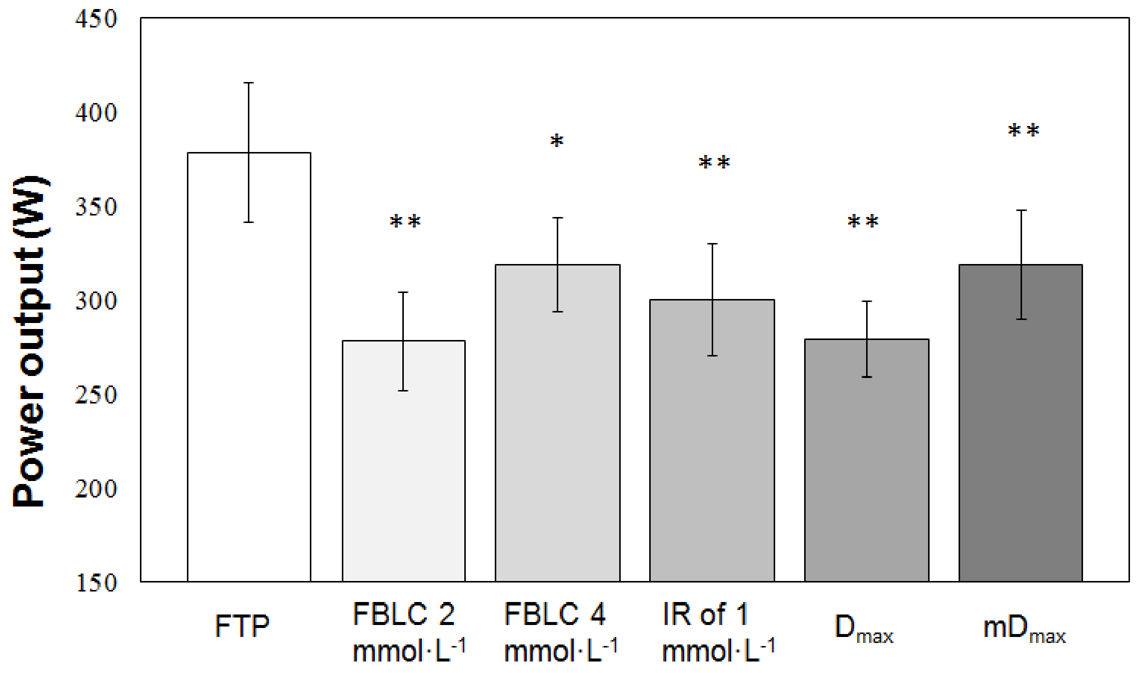

Figure 1. Estimated functional threshold power (FTP) by the 8MTT in comparison to lactate landmarks assessed during an incremental laboratory cycling test. *Significantly different from FTP ($p < 0.01$).**Significantly different from estimated FTP ($p < 0.001$).

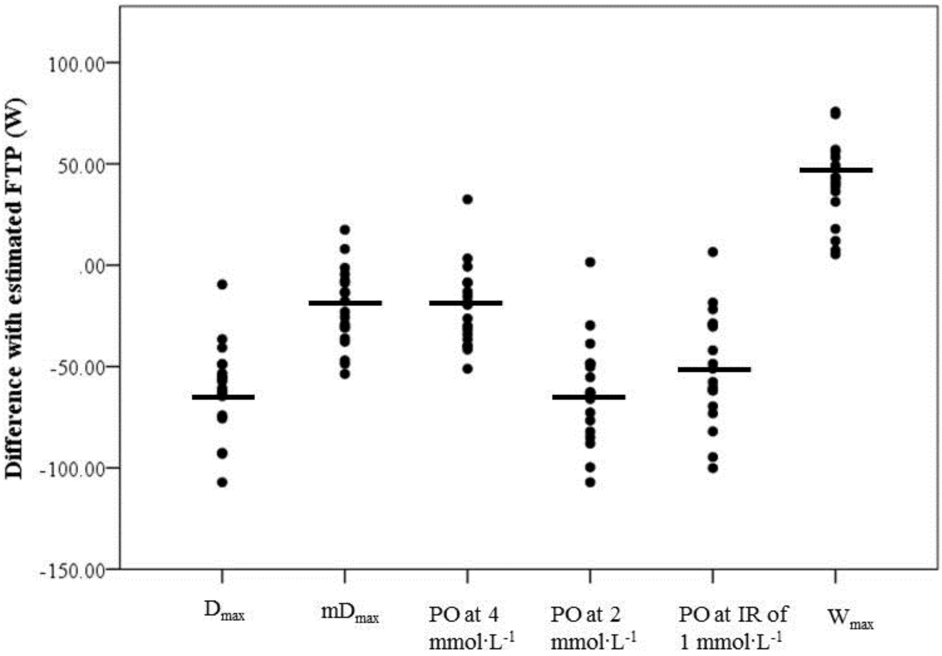

Figure 2. Mean and individual differences between estimated FTP by the 8MTT and physiological lactate markers measured during the laboratory incremental cycling test.