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The Power Profile Predicts Road Cycling MMP

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Key words
- maximum mean power
- critical power
- self-selected cadence

Abstract

Laboratory tests of fitness variables have previously been shown to be valid predictors of cycling time-trial performance. However, due to the influence of drafting, tactics and the variability of power output in mass-start road races, comparisons between laboratory tests and competition performance are limited. The purpose of this study was to compare the power produced in the laboratory Power Profile (PP) test and Maximum Mean Power (MMP) analysis of competition data. Ten male cyclists (mean ± SD: 20.8 ± 1.5 y, 67.3 ± 5.5 kg, $\dot{V}O_{2max}$ 72.7 ± 5.1 mL·kg^{-1}·min^{-1}) completed a PP test within 14 days of competing in a series of road races. No differences were found between PP results and MMP analysis of competition data for durations of 60–600 s, total work or estimates of critical power and the fixed amount of work that can be completed above critical power (W'). Self-selected cadence was 15 ± 7 rpm higher in the lab. These results indicate that the PP test is an ecologically valid assessment of power producing capacity over cycling specific durations. In combination with MMP analysis, this may be a useful tool for quantifying elements of cycling specific performance in competitive cyclists.

Introduction

Numerous authors have established strong relationships between physiological fitness parameters ($\dot{V}O_{2max}$, lactate kinetics, threshold power, economy, etc) and cycling time-trial performance [2,14,15]. In addition, the average power produced during laboratory time-trials has been shown to be a valid predictor of cycling time-trial performance [5,19] and not different to the power output produced during an actual time-trial in the field [21]. While the relationship between physiological fitness assessed in the laboratory and performance during a cycling time-trial have been investigated, due to a number of confounding factors, there is little published data comparing the results of existing laboratory tests to performance or power output produced during mass-start cycling road races.

Unlike many other endurance-based events where physiological variables are the primary determinants of performance, the impact of drafting and team tactics inherent in road racing can significantly alter the relationship between traditional markers of physiological fitness and finishing position. In addition, while road racing is often described as steady-state exercise, unlike a cycling time-trial, it is a dynamic event characterised by periods of sustained power output with alternating periods of high- and low-intensity; the combination of which can be infinitely variable [20]. As a result, the cyclist who has the highest $\dot{V}O_{2max}$, or greatest sustainable power output is not necessarily the most likely to succeed in a road race. Due to its tactical nature and the influence of drafting and terrain, the results of a mass start road race are typically determined at a critical period(s) during the race. These critical periods require the competitors to produce maximal power output for a race-specific period of time. Therefore, depending on the nature of the race, the winner can potentially be the cyclist who produces the lowest average power over the whole duration, only producing a maximal effort that is greater than their competitors at a critical moment(s).

Due to the variable nature of power output during road racing and the now common use of mobile ergometers, an increasingly popular method of assessing a cyclist's capacity to produce power during competition is maximum mean power (MMP) analysis [1,6,7,23]. During a

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road race, periods of high and low intensity can be sub-divided into efforts of various durations (5–600 s) and the MMP produced for each of these epochs can be identified. Consequently, a laboratory test that evaluates the maximum capacity to produce power over similar durations may provide a basis for the evaluation of physiological performance during a road race.
The Power Profile (PP) is a laboratory test that assesses a cyclist's maximum capacity to produce power over durations that are typically encountered during road races. Consequently, the PP test may provide a platform for the evaluation of power producing capacity of cyclists that can be directly compared to the power that they produce during competition. However, the PP requires only 1 h to be completed, is conducted in standard laboratory conditions and the cyclist is typically well hydrated and not fatigued at the time of the test. In contrast, cycling competitions are competed over durations ranging between 2–6 h, can take place in a variety of environmental conditions, and the cyclist may become glycogen depleted and/or dehydrated. Thus, the powers produced during a laboratory PP test may differ from those produced in competition. In addition, given the tactical nature and influence of race format and terrain on the types of efforts made by cyclists during a given road race [7], the likelihood of a given cyclist providing maximal efforts across the range of durations assessed in the PP test in a single race may be relatively low. As a consequence, MMP was analysed across a series of road races (1–10) that were all completed within 14 days of the laboratory PP test. The inclusion of multiple races that are composed of various race formats and are competed over various types of terrain is likely to improve the likelihood that each of the cyclists provides maximal efforts across a range of durations.
The purpose of this investigation was to evaluate the ecological validity of the PP test; in particular, to assess whether the power produced over durations of 5–600 s in the laboratory Power Profile test were similar to the MMP produced over these same durations during a series of road races.

Methods

Ten experienced male cyclists (mean ± SD: age 20.8 ± 1.5 y, mass 67.3 ± 5.5 kg, $\dot{V}O_{2max}$ 72.7 ± 5.1 $mL \cdot kg^{-1} \cdot min^{-1}$) completed a PP test within 14 days of competing in a mass start cycling road race. Prior to participating in any testing sessions, each subject provided written informed consent in accordance with the institutional Human Research Ethics Committee and the study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [13].
The PP test was completed on a custom-built wind-braked ergometer (AIS, Canberra, Australia) fitted with the cyclists' own pedal system and adjusted to replicate their individual riding position. The ergometer consisted of a stainless steel frame that supported a 15 kg fly-wheel with 18 fan blades providing resistance. The mass of the wheel and gearing system were designed to replicate the kinetic energy and crank inertial load typically encountered during road cycling (2 000–8 000 J and 30–150 $kg.m^2$ respectively). Cyclists accelerated the fly-wheel via an intermediate drive and gearing system (14 gears) that could be adjusted by the cyclist while riding. Power output was recorded at a sampling rate of 5 Hz with a dynamically-calibrated scientific version (8 strain-gauge) SRM power meter (Schoberer Rad Messtechnik, Germany). A 5 min warm up consisted of riding between 100 and 250 W with two short efforts (3 s) at 70 and 90 % of maximal effort, respectively. The PP test protocol consisted of seven maximal efforts (6, 6, 15, 30, 60, 240 and 600 s) with active recovery periods of 54, 174, 225, 330, 480 and 600 s, respectively. The first two efforts (2 × 6 s sprints) were completed in gears 1 (peak rpm ~160 rpm) and 4 (peak rpm ~140 rpm), from a standing start and the remaining efforts were completed from a rolling start between 70–80 rpm. Cyclists were able to adjust the gear ratio at any time and were instructed to produce as much power as possible for each effort. The shorter efforts (6–30 s) were typically an all-out sprint; however for the longer efforts (60–600 s) the athletes were required to pace their effort. During the recovery periods, cyclists were instructed to continue to pedal at a light/comfortable intensity (typically ~100 W). The power output produced during the test was analysed with custom software (AIScycle, KPT, Canberra, Australia) which automatically identified the MMP for each of the efforts in the PP test. From the two 6 s efforts, the MMP over 5 s was recorded and the total work completed during the six maximal efforts was calculated by summing the work produced (kJ) during each (5, 15, 30, 60, 240 and 600 s). In addition, the power produced during the 60, 240 and 600 s efforts were used to estimate critical power (CP) and the fixed amount of work that can be completed above CP (W'). The hyperbolic power-time relationship was converted into a straight line using the linear model:

$$P = W' \cdot (1/t) + CP$$

where P = power output (W), W' = the fixed amount of work (kJ) that can be completed above CP, t = time (s) and CP = critical power (W) [9].While no familiarisation test was completed *per se*, each of the cyclist's were familiar with the test protocol having completed the test on a number of previous occasions. The typical error of power output for each of the effort durations is 3.6 ± 0.8 % (2.3–4.5 %) (unpublished observations).
The mass start cycle races that were included in the analysis were the 2006 Tour Down Under, Australia (UCI Category-2.HC; 6 stages; n = 4), 2006 Tour of Canberra, Canberra, Australia (UCI Category – NE; 3 stages; n = 1), 2007 Tour of Langkawi, Malaysia (UCI Category – 2.HC; 10 stages; n = 4) and the 2007 Australian National Road Championships, Buninyong, Australia (UCI Category – CN; 1 road race; n = 1). These races were contested over a range of distances (80–180 km), topography (flat, rolling and mountainous) and format (criterium, circuit and point-to-point races). Each subject completed their event with a dynamically-calibrated Professional model (4 strain-gauge) SRM power meter (Schoberer Rad Messtechnik, Germany) attached to their bicycle. The power meters were "zeroed" in accordance with the manufacturer's instructions prior to the start of each race and power output was recorded at a frequency of 1 Hz. Following each race, the data were downloaded to a laptop computer using SRM software (v6.33.11, Schoberer Rad Messtechnik, Germany) and transferred to CyclingPeaks software for analysis (WKO+ Unlimited Edition, v2.1, Peaksware, CO, USA). For each race, this software was used to identify the MMP and the associated average cadence over the same durations (5–600 s) that were assessed in the PP test. As cyclists competed in multiple races within 14 days of completing the PP test, only the highest individual MMP for each of the assessed durations was included. This resulted in a single pair of PP and MMP data for each of the 10 subjects retained for statistical analysis. Total work was calculated by summing the work produced (kJ) during each duration (5, 15, 30, 60, 240 and 600 s). In addition, the MMP produced

Table 1 Maximum mean power (MMP) for durations of 5–600 s, total work, critical power (CP) and W' determined during the laboratory PP test and field MMP analysis of power output during competition; n = 10.

		PP Test		MMP Analysis		Difference					TEE	90 % CI	
	Units	Mean	SD	Mean	SD	Absolute	Relative	Effect Size		r_s	%	Lower	Upper
5 s	W	986	125	1071	134	−85	−8.6 %	0.68	moderate	0.95*	3.2	2.3	5.5
15 s	W	798	114	830	111	−32	−4.1 %	0.26	small	0.97*	3.0	2.1	5.5
30 s	W	642	74	661	77	−19	−2.9 %	0.25	small	0.88*	5.1	3.6	8.9
60 s	W	529	42	532	43	−4	−0.7 %	0.08	trivial	0.93*	2.4	1.7	4.2
240 s	W	393	26	397	24	−4	−1.0 %	0.17	trivial	0.93*	2.7	1.9	4.7
600 s	W	346	25	348	26	−2	−0.6 %	0.08	trivial	0.92*	3.1	2.2	5.3
Total Work	kJ	368.4	26.8	372.0	27.0	−3.6	−1.0 %	0.13	trivial	0.97*	1.7	1.2	3.0
CP	W	334	23	337	24	−3	−0.8 %	0.11	trivial	0.86*	2.6	1.8	4.5
W'	kJ	11.7	1.9	12.0	2.1	−0.3	−2.6 %	0.04	trivial	0.69*	8.6	6.1	15.2

r_s = Spearman's rank correlation; * = p < 0.05. TEE = typical error of the estimate and represents the relative (%) typical magnitude of error if predicting the MMP in competition from the results of the PP test

over 60, 240 and 600 s was used to estimate CP and W' using the equation described above.

Prior to the start of this study, the SRM power meters on both the laboratory ergometer and each of the cyclists' bicycles were dynamically calibrated using a calibration rig following the procedures outlined by Gardner et al. [11].

Statistical analysis

Data in figures and text are presented as mean ± standard deviation (± SD) unless indicated otherwise. The distribution of each variable was examined with the Kolmogorov-Smirnov normality test. Total work, CP and W' results were analysed using a single factor (location) repeated measures ANOVA. Cadence data were analysed using a 2-factor repeated measures ANOVA with one between factor (location) and one within factor (duration). Pairwise comparisons were made using the Bonferroni correction procedure. As both raw and log transformed power data showed a non-Gaussian distribution, a Kruskal-Wallis' test was used to asses power output in the laboratory PP test and MMP analysis of competition data. In addition, Spearman's rank correlation (r_s) was also calculated for each parameter.

Post-hoc analysis of the statistical power of this study design revealed a large chance of type II error (average statistical power of each comparison = 0.31 ± 0.34), consequently the magnitude of differences between the PP test and MMP analysis were also expressed as standardised mean differences (Cohen effect sizes, ES). The criteria to interpret the magnitude of the ES were: < 0.2 trivial, 0.2–0.5 small, 0.5–0.8 moderate, > 0.8 large [4]. Significance was set at < 0.05 and all statistical analyses were carried out using the statistical analysis software package Minitab 14.1 (Minitab Inc. Paris, France). In addition, the typical error of the estimate (TEE), which is the typical magnitude of the error if you are predicting the MMP produced in competition from the results of the PP test, was determined for each variable. This value is calculated via linear regression from the standard error of the log transformed data using the spreadsheet "Analysis of validity by linear regression" available at www.sportsci.org/resource/stats/xvalid.xls and is presented as a coefficient of variation (%) with 90 % confidence intervals.

Results

The MMP for durations of 5–600 s during the laboratory PP test and field MMP analysis are presented in ▶ **Table 1**. The relative difference in power output between the PP test and MMP analysis for each cyclist over each of the assessed test durations are presented in a Bland-Altman plot (▶ **Fig. 1**). Results of the Kruskal-Wallis test indicated that there were no differences between the power produced in the laboratory PP test and MMP analysis of race data (p = 0.69). Results of the analysis of Cohen's effect sizes are also presented in ▶ **Table 1**. The rank order for power output produced over each duration during both laboratory and field analysis were significantly correlated (r_s > 0.69; p < 0.05, ▶ **Table 1**). The single factor repeated measure ANOVA revealed no effect of "location" on total work completed and estimations of CP and W' calculated from the PP test and MMP analysis (p = 0.09, 0.32 and 0.85, respectively). In addition, analysis of standardised mean differences indicated a 'trivial' effect of location on each of these variables (▶ **Table 1**). The TEE for each of the PP test parameters are presented in ▶ **Table 1**.

The average cadence during each maximal effort in the laboratory and field are presented in ▶ **Table 2**. The repeated measures ANOVA revealed "duration" and "location" main effects (p < 0.001) as well as "duration" x "location" interaction (p < 0.001). Results of pairwise comparisons and Spearman's rank order correlations are presented in ▶ **Table 2**. Across each of the assessed durations, cadence in the field was on average 15 ± 7 rpm (13 ± 5 %) less than cadence in the laboratory PP test.

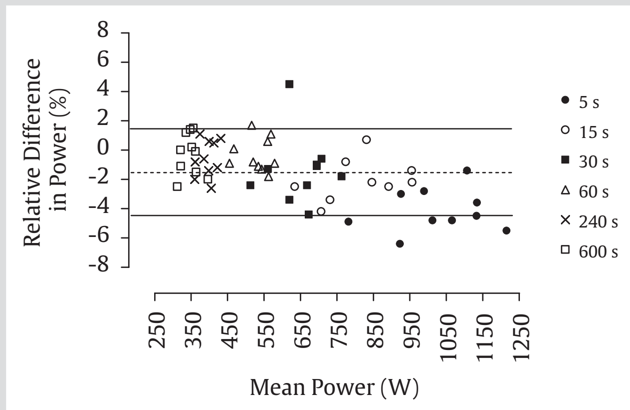

Fig. 1 Bland-Altman plot of the relative difference (%) in power output for the Power Profile test and Maximum Mean Power analysis for each sprint duration; n = 10. Dashed line is the mean bias and solid lines are the 95 % limits of agreement.

Table 2 Average cadence (rpm) during maximal sprints of 5–600 s duration recorded from the laboratory PP test and MMP analysis of power output data during competition; n = 10.

	PP Test		MMP Analysis		Difference				Effect Size	
	Mean	SD	Mean	SD	Absolute	Relative	p	r_s		
5 s	119	6	102	7	17	14 %	< 0.001	0.45	2.7	large
15 s	126	9	99	6	27	21 %	< 0.001	− 0.39	2.9	large
30 s	116	6	99	7	17	15 %	< 0.001	0.37	3.0	large
60 s	108	3	96	8	12	11 %	0.001	− 0.27	3.8	large
240 s	105	4	94	6	11	10 %	0.002	− 0.33	3.1	large
600 s	102	5	95	4	7	7 %	0.510	0.38	1.3	large

r_s = Spearman's rank correlation

Discussion

Previously, factors such as drafting, team tactics and the variability of power output during mass start cycle races has limited the ability to make meaningful comparisons between laboratory tests of cycling fitness and competition performance. The results of this study indicate that the maximal power produced over durations of 60–600 s during a series of mass start cycle races is similar to the power produced over the same durations in the laboratory PP test in male cyclists. In addition, estimates of total work, CP and W' are also similar between the laboratory and the field. These findings indicate that the PP is a valid assessment tool of maximal power producing capacity in competitive male cyclists.

It should be noted that the relatively low subject numbers in this study and the resultant low statistical power increases the likelihood of a type II error. However, the trivial effect size for durations of 60–600 s as well as total work, CP and W' indicate that these variables are similar between the laboratory PP test and MMP analysis of competition data (**Table 1**). In contrast, the small to moderate effect sizes shown for the 5, 15 and 30 s duration sprints indicate that there may be a difference over these shorter durations between the two tests that could not be detected in this study (**Table 1**). Bertucci et al. [3] reported similar findings over short duration sprints with 6 % higher peak power outputs recorded during field compared to stationary ergometer sprinting (~5 s sprints). The authors attributed this difference to decreased lateral oscillations of the bicycle in the laboratory and the associated reduction in the cyclist's ability to apply a perpendicular force to the pedals while accelerating. In contrast, Gardner et al. [10] found no difference in the maximum power output or the power- and torque-pedalling rate relationships during a maximal 6 s laboratory test and a 65 m field test in world-class sprint cyclists. However, both of these studies examined the ability to produce power in the lab and field during a maximal acceleration. When performing the 5, 15 and 30 s sprints in the PP test, cyclists maximally accelerate the flywheel from a standing start (5 s) or from 70–80 rpm (15 and 30 s) to cadences greater than 140 rpm. However during a road race, while maximal accelerations that begin at a low cadence and progress to a high cadence may occur, given the confounding influence of speed, grade and the ease and rapid ability to change between a range of gear ratios, it is unlikely that maximal efforts occur while the cyclist's pedalling rate is accelerating through such a large range of cadences.

While the power outputs achieved in the lab and field in this study were similar, the cadence that was selected to produce these maximal efforts was different between lab and field conditions (**Table 2**). Various factors have been reported to influence self-selected cadence, including relative fitness level, experience, power output, drafting, duration of the effort and road gradient [12]. Given that: 1) the participants in this study were of similar levels of fitness and experience, 2) the power output between the lab and field conditions were the same and 3) the unlikely scenario that the cyclists produced a maximal effort while drafting, where the power required to ride at a given speed can be reduced anywhere from 20–50 % [8]; the duration of the race and the variable gradient experienced during road cycling were the most likely contributors to the differences in self-selected cadences reported here. Self-selected cadence has previously been reported to decrease by an average of 7–18 rpm over 1–5 h of prolonged cycling; a reduction associated with neuromuscular fatigue [16,17,22]. Given that the cyclists in this study completed the 1 h PP test in a rested state and that the typical duration of the races ranged between 2 and 4 h, the lower cadences associated with the MMP's in the field may be the result of fatigue induced by the race. Alternatively, the variable gradient encountered during the road races in the present study may have influenced the self-selected cadence, as has previously been reported [18,23]. It is recommended that future research begins to assess where in a mass start road race maximal efforts tend to occur and the potential impact of fatigue and gradient on the self-selected cadence as well as the power and torque-pedalling rate relationships during competition.

In addition to producing maximal efforts with a lower cadence in the field, an interesting finding in this study was that despite the large range and combination of speed, cadence, gear ratio, slope, wind direction and drafting conditions these cyclists experienced during the course of each of the races that they contested, the cadence range in which these cyclists achieved their MMP in the field was consistently between 95 and 100 rpm for each of the durations examined (**Table 2**). Given that we have no information about the conditions under which these athletes achieved each MMP in the field, it is not apparent from this study whether these cyclists self-selected this cadence range to produce maximum efforts or whether the race conditions required the cyclists to produce maximal efforts under these cadence conditions. The difference in the self-selected cadence between the lab and field conditions and the consistency of the self-selected cadence during maximal efforts in the field suggest that performing the PP test isokinetically and limiting the cadence to 95–100 rpm, may be advantageous.

While the results of this study indicate that the power produced in the PP test are comparable to MMP analysis of a series of road races, this relationship may not hold true when evaluating only a single road race. Due to the tactical nature of mass start road races, the likelihood of a given cyclist providing a maximum effort may be relatively low. In addition, as the format and terrain that the race is competed over can also influence the types of efforts that are made [7], it is unlikely that a rider will give a maximal effort across each of the durations examined in the PP test. Consequently, it may be more appropriate, particularly for professional cyclists who compete regularly within a short period of time, to examine the MMP across a series of races. The various tactical scenarios, race formats and types of terrain encountered over multiple races are likely to result in a number of maximal efforts across a range of durations, as shown by the results in this study.

In conclusion, the variability of power output and the confounding influence of drafting and team tactics during mass start cycle races have previously limited the ability to make meaningful comparisons between laboratory tests and road cycling performance. However, the results of this study indicate that with the use of competition MMP analysis, it is possible to directly compare a cyclist's capacity to produce power during the PP test and the actual power produced during a series of road races. Consequently, this test protocol in combination with field MMP analysis may provide coaches with a useful tool for the quantification of changes in road cycling performance capacity in competitive cyclists.

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