Peak power predicts performance power during an outdoor 16.1-km cycling time trial

JAMES BALMER, R. C. RICHARD DAVISON, and STEVE R. BIRD

Department of Sport Science, Canterbury Christ Church University College, Canterbury, CT1 1QU, UNITED KINGDOM

ABSTRACT

BALMER, J., R. C. R. DAVISON, and S. R. BIRD. Peak power predicts performance power during an outdoor 16.1-km cycling time trial. *Med. Sci. Sports Exerc.,* Vol. 32, No. 8, pp. 1485–1490, 2000. **Purpose:** To assess i) the reproducibility of peak power output recorded during a maximal aerobic power test (MAP), and ii) its validity to predict endurance performance during a field based 16.1-km time trial (16.1-km TT). **Methods:** Two studies were completed: for part I, nine subjects performed three MAP tests; for part II, 16 subjects completed a MAP test and 16.1-km TT. Power output was recorded using an SRM^{TM} power meter and was calculated as peak power output (PPO) recorded during 60 s of MAP and mean power output for the 16.1-km TT (16.1-km TT_{PO}). **Results:** There was no difference between PPO recorded during the three MAP trials, mean coefficient of variation for individual cyclists was 1.32% (95%CI = 0.97–2.03), and test-retest reliability expressed as an intraclass correlation coefficient was 0.99 (95%CI = 0.96–1.00). A highly significant relationship was found between PPO and 16.1-km TT_{PO} ($r = 0.99$, $P < 0.001$) but not for PPO and 16.1-km TT time ($r = 0.46$, $P > 0.05$). **Conclusion:** The results show that PPO affords a valid and reliable measure of endurance performance which can be used to predict average power during a 16.1-km TT but not performance time. **Key Words:** SRM POWER METER, REPRODUCIBILITY, VALIDITY, PERFORMANCE

A laboratory-based test that measures exercise performance capacity must be both reliable and valid. Reliability is essential when athletes are required to perform repeated tests and validity is a critical issue when data collected in the laboratory is compared between athletes or used to predict field based performance. A measure of maximal muscle power (W_{peak}) achieved during progressive exercise to exhaustion has been used on several occasions to assess the exercise performance capacity of racing cyclists (5,11,16,23,24) to investigate the effects of training on endurance performance (12,24) and to predict time to complete a cycling time trial (5). Furthermore, Lindsay et al. (12) and Westgarth-Taylor et al. (23) have calculated that the mean ± SD coefficient of variations (CV%) for W_{peak} are relatively low (1.14 ± 0.65 and 1.5 ± 1.3%, respectively), and Hawley and Noakes (5) found that the correlation coefficient for W_{peak} and 20 km cycling time was high ($r = -0.91$, $P < 0.001$).

Various testing methods have been developed to assess the maximal muscle power of endurance cyclists and the Kingcycle^{TM} (High Wycombe, UK) maximal aerobic power test (MAP) has been used by several authors (3,6,17–19) to investigate cycling performance. This test involves a ramp exercise protocol to exhaustion with peak power output (PPO) recorded as the highest average power during 60 s of the test. Although a test retest correlation of $r = 0.98$ for PPO has been reported in abstract format (10), very little information has been published concerning the reliability (CV%) of PPO and its relationship with endurance performance.

To investigate the relationship between physiological variables measured during a laboratory test with field based cycling performance, studies have used average speed or time to complete field based time trials as the criterion measure (1,5,15,17). However, with the development of the SRM power meter, it is now possible to record power output in the field (8). Although recent studies (9,13) have found that the SRM ergometry system provides a reliable and valid measure of power output when compared with a Monark ergometer, there is surprisingly little information available concerning power outputs recorded using SRM.

The purpose of this study was to assess the reproducibility of peak power output achieved during a MAP test and to investigate the relationship between a laboratory based measure of maximal muscle power and power output recorded during a field based cycling time trial.

METHODS

This study was completed in two parts: for part I, nine cyclists (characteristics described subsequently) completed three MAP tests, and for part II of the study, 16 cyclists (see

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TABLE 1. Subject characteristics and individual performance during 16.1-km TT.

Subject	Age (yr)	Height (m)	Mass (kg)	PPO (W)	16.1-km TT (W)	Speed ($km \cdot h^{-1}$)	Time (min:s)
1	25	1.82	76.5	484	368	44.00	21:49
2	25	1.79	71.0	432	341	46.01	20:52
3	25	1.84	82.5	457	353	39.72	24:10
4	29	1.87	73.0	453	348	45.46	21:07
5	30	1.91	73.5	403	325	42.11	22:48
6	30	1.78	66.5	425	338	45.35	21:10
7	31	1.91	75.5	423	337	40.85	23:30
8	42	1.75	73.6	378	296	44.31	21:40
9	46	1.81	76.5	454	357	43.15	22:15
10	52	1.78	71.5	368	307	43.70	21:48
11	55	1.76	71.5	348	283	41.62	23:04
12	56	1.76	72.5	360	292	43.37	22:08
13	58	1.84	86.0	339	292	39.40	24:22
14	60	1.80	79.5	280	224	38.30	25:07
15	61	1.77	79.0	304	251	41.50	23:08
16	63	1.73	80.5	324	270	43.80	21:55
Mean	43	1.81	75.6	390	311	42.67	22:34
SD	15	0.05	5.0	61	41	2.28	1:14

Table 1) performed a MAP test and an outdoor 16.1-km time trial race.

Before testing, each volunteer gave written informed consent when the nature and purpose of the tests had been fully explained and completed a habituation MAP to familiarize themselves with the testing procedure. Laboratory-based tests were conducted at the same time of day, and environmental conditions were maintained during testing (ambient temperature 18–22°C, relative humidity 45–55%). During the field-based time trial races, environmental conditions varied due to changes in the weather. Wind direction was relatively consistent and resulted in a tail wind for the outward bound section of the course, and wind speed varied between ~10 and 32 $km \cdot h^{-1}$. Ambient temperature and barometric pressure varied between 15–23°C and 745–775 mm Hg, respectively.

For each laboratory-based test subjects used their own racing bicycle (fitted with SRM) attached to a Kingcycle air braked ergometer (EDS Portaprompt Ltd., High Wycombe, UK). Immediately before testing, the Kingcycle rig and SRM power meter (Jülich, Welldorf, Germany) were calibrated according to the manufacturer's recommended procedure. The calibration procedure and technical aspects of each ergometry system have been previously described by Palmer et al. (17) for the Kingcycle and by Jones and Passfield for the SRM power meter (9). During tests, gear ratio and pedal cadence ($rev \cdot min^{-1}$) were self-selected. Throughout each test, power output (W) was averaged at 1-s intervals by either a 4 or 20 strain gauge SRM.

Part I

Subjects. Nine endurance trained male cyclists who regularly competed in local cycling time trial races participated in this part of the study. Each subject completed three MAP tests, which were performed on three separate occasions (at the same time of day) separated by at least 1 wk. Subject characteristics were (mean ± SD) age 32 ± 5 (yr), height 1.79 ± 0.04 (m), and body mass 71.1 ± 4.7 (kg).

Maximal aerobic power test. On arrival at the laboratory, bicycle rear tire pressure was standardized at 100 psi using a track pump with tire pressure gauge (Silca, Italy). Before each test, an additional stabilizing kit was fitted to the Kingcycle rig; this consisted of a strap fed through the rails of the subject's bicycle saddle and secured firmly to the frame of the Kingcycle ergometer (the stabilizing kit was used to reduce changes in resistance between the tire of the bicycle and the roller of the air-braked flywheel during the MAP test). Immediately thereafter, the Kingcycle was calibrated according to the manufacturers guidelines. After the calibration procedure, subjects warmed-up at a self-selected intensity that was repeated for each trial this was followed by 5 min of cycling at the starting power of the MAP test. For MAP, work rate was increased per minute by 5.0 ± 0.2% of PPO achieved during the habituation test and starting power output was calculated for subjects to reach volitional exhaustion between 10–12 min. For subsequent trials, the protocol used during the first MAP trial was repeated and peak power output (PPO) was calculated as the highest average power recorded during any 60-s period of the test. Power output was recorded using SRM; however, subjects were required to complete the ramp test provided by the Kingcycle computer software. Subjects were not informed of their performance until all three MAP tests had been completed.

Part II

Subjects. Sixteen endurance-trained male racing cyclists completed i) a MAP test and ii) a field based 16.1-km time trial (TT). Tests were performed at the same time of day (early evening) separated by at least 1 wk, and each subject competed in a separate 16.1-km time trial race, which was completed on the same time trial course. Data for the whole group were collected over a period of about 4 months (June to September). All subjects had extensive experience of competitive cycling and during the period of the study were regularly participating in local time trial races. The physical characteristics of the subjects are shown in Table 1.

Maximal aerobic power test. All subjects completed a maximal aerobic power test as described previously.

Time trial performance ride. Each rider had previous experience of racing on the 16.1-km time trial course used for the study. Each 16.1-km time trial race was completed under Road Time Trials Council regulations (20). During each separate time trial, competitors started the race at 1-min intervals, and ~30 riders raced against each other to complete the 16.1-km distance in the fastest time. Before the ride a SRM power meter was fitted to the subject's racing bicycle and calibrated. During the ride, subjects were unable to see power output but were able to observe time elapsed (min:s) and heart rate response ($b \cdot min^{-1}$). For the completed 16.1-km TT; total time (min:s) and averages for power output (W) and speed ($km \cdot h^{-1}$) were calculated.

Statistical Analyses

Measures of reproducibility (mean CV) and intraclass correlation coefficient (ICC) for PPO were derived by two-

TABLE 2. PPO (W) achieved by individual subjects in the three MAP trials.

Subject	Trial 1	Trial 2	Trial 3	Mean	SD	CV (%)
1	386	378	377	380	4.9	1.30
2	434	449	437	440	7.9	1.80
3	310	325	324	320	8.4	2.62
4	406	408	408	407	1.2	0.28
5	421	421	419	420	1.2	0.27
6	432	428	427	429	2.6	0.62
7	410	407	399	405	5.7	1.40
8	404	404	407	405	1.7	0.43
9	324	324	320	323	2.3	0.72
Mean	392	394	391	392		1.32
SD	45	44	43	43		

way analysis of variance (ANOVA) as described by Schabort et al. (21), and the 95% confidence interval (95%CI) for CV and ICC were calculated by the methods of Tate and Klett (22) and McGraw and Wong (14), respectively. For comparisons with the CV in the present study, unbiased estimates of published CVs were obtained using the method proposed by Schabort et al. (21). CVs for individual riders were calculated by dividing each cyclist's SD by their mean PPO.

The relationship between PPO and time to complete 16.1-km TT was assessed using linear and log-linear models (25). The log-linear model described a curvilinear relationship between variables and assumed a multiplicative error term, which controlled for spread in the data (heteroscedasticity). Statistical analyses were completed using Microsoft Excel (Bellevue, WA) and Minitab (State College, PA). Values in the text for standard error of estimate (SEE) are for the 68% confidence interval.

RESULTS

Part I

Table 2 shows the PPO recorded during the three MAP trials. The differences between PPO recorded during each MAP trial were not statistically significant ($P = 0.5$). The mean coefficient of variation (CV%) for MAP achieved during the three trials was 1.32% (95%CI = 0.90–1.89) and the intraclass correlation coefficient (ICC) was 0.99 (95%CI = 0.96–1.00). There was an increase in reproducibility for trials 2 to 3 alone (CV = 0.76, 95%CI = 0.52–1.09, correlation = 0.99) when compared with that of trials 1 and 2 alone (CV = 1.54, 95%CI = 1.05–2.21, correlation = 0.98).

Part II

Table 1 shows the individual data for PPO, average power output (16.1-km TT_{PO}) and performance time (16.1-km TT_{TIME}) recorded during the 16.1-km time trial and Figure 1 shows the relationship between 16.1-km TT_{PO} and PPO. A very strong relationship was found between PPO and 16.1-km TT_{PO} using linear (r = 0.97; $P < 0.001$, 95%CI = 0.91–0.99; SEE of 7 W) and log-linear models (r = 0.99; $P < 0.001$, 95%CI = 0.97–1.0, SEE of 2.5%). Figure 2 shows the relationship between PPO and 16.1-km TT_{TIME},

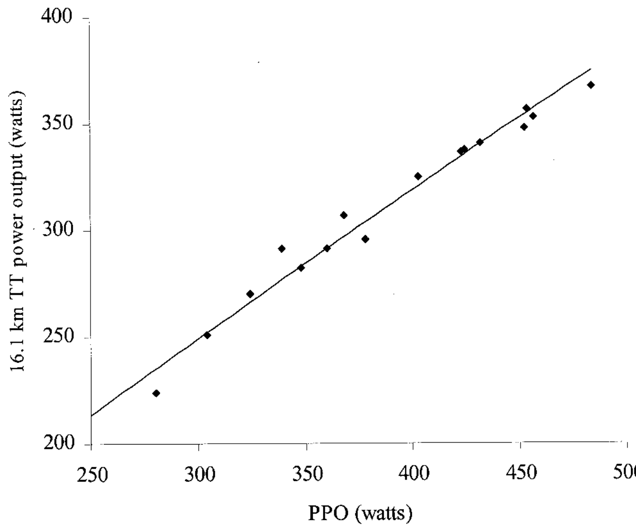

Figure 1—The relationship between time trial performance (W, mean power output for 16.1-km) and peak power output (W) in 16 subjects. Data fitted with a line of best fit calculated from the log-linear regression of time trial performance power on peak power (r = 0.99, $P <$ 0.001). Power (W) measured during the time trial was related to PPO (W) by the following linear and power function equations: 16.1-km TT_{PO} = 0.67·(PPO) + 50 and 1.92·($PPO^{0.85}$), respectively.

a weak correlation was found between PPO and 16.1-km TT_{TIME} using linear (r = 0.46, $P = 0.07$; 95%CI = −0.05–0.78, SEE of 1:09 min:s) and log-linear models (r = 0.48, $P = 0.06$; 95%CI = −0.02–0.79, SEE of 5.1%). Similarly, a weak correlation was found between 16.1-km TT_{PO} and 16.1-km TT_{TIME} using linear and log-linear models (r = 0.46 and 0.48, respectively). However, correlation coefficients were significantly improved when the ratio of PPO: body mass ($W \cdot kg^{-1}$) and 16.1-km TT_{PO}:body mass ($W \cdot kg^{-1}$) were regressed on 16.1-km TT_{TIME} using a linear model (r = 0.64; $P < 0.01$, 95%CI = 0.21–0.86, SEE of

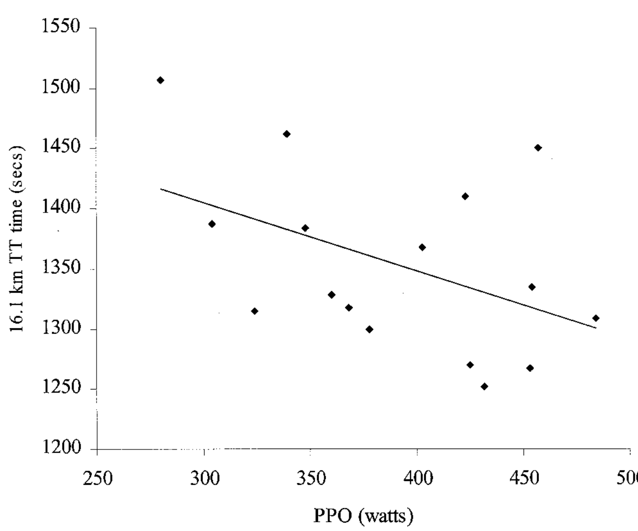

Figure 2—The linear relationship between time trial performance time (s, 16.1-km) and peak power output (W) in 16 subjects. Data fitted with a line of best fit calculated from the linear regression of time trial performance time on peak power (r = 0.46, $P >$ 0.05). Performance time (s) recorded for the time trial was related to PPO (W) by the following linear and power function equations: 16.1-km TT_{TIME} = 1575 - 0.57·(PPO); and 3585·($PPO^{-0.16}$), respectively.

1:00 min:s and r = 0.66; $P < 0.01$, 95%CI = 0.24–0.87, SEE of 0:58 min:s) respectively.

When the relationship between PPO and 16.1-km TT_{PO} was assessed in seven riders who achieved the highest values for PPO (range 423 to 484 W) and 16.1-km TT_{PO} (range 337 to 368 W), analysis of the data revealed a strong relationship between PPO and 16.1-km TT_{PO} using linear (r = 0.99; $P < 0.001$, 95%CI = 0.91–0.99; SEE of 3 W) and log-linear models (r = 0.98; $P < 0.001$, 95%CI = 0.97–1.0, SEE of 0.8%). However, for this group, no relationship was found between PPO and 16.1-km TT_{TIME} (r = 0.06 and 0.07, $P = 0.89$ and 0.87 for linear and log-linear models, respectively). Power measured during the time trial was related to PPO by the following linear and power function equations: 16.1-km $TT_{PO} = 0.51 \cdot (PPO) + 121$ and $6.53 \cdot (PPO\ 0.65)$, respectively.

DISCUSSION

To evaluate the performance ability of endurance athletes, it is necessary to use laboratory based tests that are reliable, valid, and sensitive to small changes in an athlete's fitness level (7). This is particularly important when performing repeated measurements over a period of time and when laboratory data is applied to the field to predict actual performance. The findings of the present study show that peak power output recorded across three MAP trials was highly reproducible and that PPO could be used to predict average power output maintained during a field based 16.1-km time trial.

The mean coefficient of variation (1.32%) for PPO in the present study was in agreement with the CV value for maximal aerobic power (W_{peak}) reported by Lindsay et al. (12) of 1.30% (unbiased estimate). Unfortunately, the reproducibility of power output recorded during a field-based 16.1-km time trial has not been assessed. However, the reproducibility of laboratory based time trial performance was investigated by Palmer et al. (17), who reported CV values of 1.1 and 1.0% for time to complete 20- and 40-km rides. To our knowledge, we are the first authors to present data for power output recorded during an outdoor 16.1-km time trial race.

Data from the present study show that individual performance power during a 16.1-km TT can be accurately predicted from PPO (r = 0.99). Therefore, instead of using heart rate response and/or average speed, a cyclist using an SRM power meter could ride to a predetermined power output based on PPO recorded during a MAP test. It is worth noting that Jeukendrup and van Diemen (8) found that the relationship between heart rate and power can be uncoupled during prolonged exercise and can be affected by the rider's position and environmental conditions. The authors concluded that power output measured during training and racing could be used to provide a more reliable assessment of exercise intensity.

The strong relationship between PPO and time trial performance power reported in this study suggests that a change in PPO could have a direct affect on 16.1-km TT power. Notably in the study by Lindsay et al. (12), maximal aerobic power (W_{peak}) increased in highly trained cyclists who completed a 4-wk high-intensity interval training program. However, even though the relationship between W_{peak} and time trial performance was high (r = 0.84), increases in W_{peak} (~5%) were not significantly related to an improvement in Kingcycle 40-km time. Similarly, Westgarth-Taylor et al. (23) found that high intensity training increased W_{peak}, but there was no significant relationship between the change in W_{peak} and a decrease in 40 km time. It was postulated that cycling performance was a combination of the cyclists' absolute W_{peak} and their ability to sustain a high percentage of W_{peak} and that W_{peak} could account for 70–90% (5,12) of the variation in time trial performance time. Data from the present study suggest that PPO can account for 98% of the variation in 16.1-km TT performance power and 21% of the variation in time trial time.

It is worth noting that the assessment of W_{peak} by Lindsay et al. (12) and Westgarth-Taylor et al. (23) involved a continuous 25-W incremental test (the duration of each increment was 150 s) performed on a Lode ergometer. In the present study, PPO was assessed using a continuous Kingcycle (~20 $W \cdot min^{-1}$) ramp test. Although both of these tests assess maximal power, the measurement of W_{peak} was based on the calculation of completed work rate in W plus the fraction of time spent in the final noncompleted work rate multiplied by 25 W, and PPO was calculated as the highest average power output recorded during any 60-s period of the ramp protocol. Several studies (2,4,26) have found that the assessment of maximal power can be affected by the method of testing; however, further investigation is required to establish whether a change in PPO due to the effects of training/detraining would be matched by a change in time trial performance power.

Peak power output was a strong predictor of 16.1-km TT performance power across a wide range of ability (time trial power 224 to 368 W). Therefore the heterogeneity of the subjects may have influenced the relationship between PPO and 16.1-km TT power. However, Figure 1 shows that the relationship between PPO and time trial power was also high in the best performers (time trial power 337–368 W), and therefore peak power could be used to predict the performance power of cyclists who maintain both high and low power outputs. Although a weak correlation was found between peak power and time trial time, it is important to note that no correlation was found between peak power and performance time in the best performers. This finding needs to be considered when studies investigate the effects of a treatment/intervention on cycling performance and use performance time to indirectly assess the power output of competitive cyclists.

The finding that peak power was not strongly related to time trial time is not surprising when the effects of individual aerodynamics and variable environmental conditions are considered. The relationship between power output and speed is dependent on factors such as wind speed and direction, ambient temperature, and atmospheric pressure as well as body size, racing position, and bicycle design. In the present study, cyclists competed in separate time trial races, and therefore environmental conditions were not standardized. Furthermore, each rider's performance power and time trial time was assessed during a single event and cyclists used their own self-selected racing position and bicycle equipment. Studies that have reported strong relationships between field based performance time and a laboratory based measure of power output have typically recorded the time trial time of a group of riders during the same event completed on the same day (5) used the personal best performance time of each rider (1) or the mean individual performance time achieved during a series of races (17). Data reported in the present study showed that average power output provided a more valid assessment of endurance performance than time trial time.

Coyle et al. (1) found that laboratory based 1 h performance power was highly related to personal best time to complete a 40-km time trial ($r = -0.88$); however, the SEE for the prediction of performance time was ± 1:48 (min:s). Similarly, Hawley and Noakes (5) found a strong relationship between 20-km cycle time and W_{peak} ($r = -0.91$) with a SEE of ± 1:36 (min:s). In the present study, a weak relationship was found between power output recorded during 16.1-km TT and time trial time in the group of 16 riders (SEE of ± 1:09 (min:s). This finding suggests that peak power and time trial performance power could not be used to provide an accurate predictor of time trial time. It is worth noting that the SEE for time trial performance power calculated from the regression of PPO on 16.1-km TT power was ± 3%. Further research is required to determine the effect of ± 3% performance power on 16.1-km time trial time.

Hawley and Noakes (5) reported that the correlation between W_{peak} and outdoor 20-km cycling time was decreased when W_{peak} was expressed relative to body mass, it was suggested that for a relatively low ratio between W_{peak} and body mass, performance time was less for riders with a large body mass. It was explained that when riding on a flat course the larger rider experiences less wind resistance due to a relatively smaller body surface area. It is reasonable to assume that the topography of the course used in this study may have influenced the finding that the relationship between peak power output and performance time was improved when PPO was expressed relative to body mass.

In summary, PPO achieved during a maximal aerobic power test is highly reproducible and can be used effectively to predict power output but not performance time during a field based 16.1-km time trial. Further investigation is warranted concerning the reproducibility of performance power during field-based time trials and the relationship between PPO and endurance cycling performance.

Address for correspondence: James Balmer, Department of Sport Science, Canterbury Christ Church University College, Canterbury, CT1 1QU, United Kingdom; E-mail: j.balmer@cant.ac.uk.

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