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Research article

REPRODUCIBILITY OF OUTDOOR FLAT AND UPHILL CYCLING TIME TRIALS AND THEIR PERFORMANCE CORRELATES WITH PEAK POWER OUTPUT IN MODERATELY TRAINED CYCLISTS

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ABSTRACT
The aims of the present study were firstly to examine the reproducibility of outdoor flat and uphill cycling time trials (TT), and secondly to assess the relationship between peak power output (W_{peak}) obtained in the laboratory and outdoor cycling performance in moderately trained cyclists. Eight competitive male cyclists first performed a progressive cycle ergometer test in the laboratory to determine W_{peak} (W). Thereafter, they performed three 36 km TT (TT_{36}) on a flat course on separate days and at the same time of the day. On a different day, they also performed three 1.4 km uphill TT ($TT_{1.4}$) in a single day. The coefficient of variation (CV) values across three TT_{36} and $TT_{1.4}$ ranged from 1.1 - 1.4% and 2.6 - 2.9%, for performance time (min) and mean power (W), respectively. The correlation between absolute W_{peak} (W) obtained in the laboratory and mean power during TT_{36} and $TT_{1.4}$ was 0.90 ($p < 0.01$) and 0.98 ($p < 0.01$), respectively. Absolute W_{peak} (W) correlated significantly with performance time in TT_{36} ($r = -0.72$, $p < 0.05$) but not in $TT_{1.4}$ ($r = -0.52$, $p > 0.05$). The correlation between relative W_{peak} ($W \cdot kg^{-1}$) and performance time in TT_{36} and $TT_{1.4}$ was $r = -0.65$ ($p > 0.05$) and $r = -0.91$ ($p < 0.01$), respectively. In conclusion, under stable environmental conditions, performance time and mean power are highly reproducible in moderately trained cyclists during outdoor cycling TT. Laboratory determined absolute W_{peak} (W) may predict cycling performance on a flat course but relative W_{peak} ($W \cdot kg^{-1}$) is a better predictor of performance during uphill cycling.

KEY WORDS: Field-based, reliability, performance time, mean power, heart rate, PowerTap powermeter.

INTRODUCTION

Performance tests are an integral component of assessment for competitive cyclists in practical and research settings (Paton and Hopkins, 2001). In order to evaluate the effectiveness of nutritional strategies, ergogenic aids or training regimens, practitioners have traditionally used criterion tests that include sub-maximal performance rides to exhaustion at a fixed percentage of peak oxygen uptake ($VO_{2\,peak}$) or peak power output (W_{peak}) (e.g. Coggan and Coyle, 1987; Coyle et al., 1991; McLellan et al., 1995). However, Krebs and Powers (1985) and Jeukendrup et al. (1996) have shown that the reproducibility of time to exhaustion protocols are poor and suggested that time trial (TT) protocols may result in better performance evaluation.

The ease of measuring laboratory-based variables during simulated cycling TT has resulted in a comprehensive evaluation of the reproducibility of performance and physiological variables. Several studies have examined and reported high reproducibility of laboratory-based cycling TT performance in well-trained cyclists (Hickey et al., 1992; Jeukendrup et al., 1996; Laursen et al., 2004; Palmer et al., 1996). However, due to changeable environmental factors and non-standardized field conditions, limited research is available on the trial-to-trial variations of such protocols in field conditions and in particular, with moderately trained cyclists. Smith et al. (2001) were reportedly the first to examine the reproducibility of field-based 40 km cycling TT performance using the SRM (Schoberer Rad Messtechnik, Welldorf, Germany) powermeter, but only in well-trained cyclists. Relative to the biological changes that occur during repeated tests, knowledge of the reproducibility of performance and physiological variables may help practitioners interpret ‘real’ or significant changes more appropriately.

Peak power output (W_{peak}) obtained during a progressive cycle ergometer test in the laboratory has been used to predict performance of well-trained cyclists because of its strong relationship with mean power and performance time during cycling TT (Balmer et al., 2000; Bentley et al., 2001; Hawley and Noakes, 1992). However, data on the relationship between outdoor cycling TT performance and W_{peak} in moderately trained cyclists is lacking.

The large discrepancy between the air-conditioned laboratory environment and the hot and humid outdoor environment in the local climate coupled with the non-specificity of laboratory test protocols results in a considerable challenge of making the test results meaningful and specific to the actual cycling environment. Moreover, moderately trained rather than well-trained cyclists are often employed as subjects during interventional studies. Therefore, there is a need to investigate field-based cycling performance in moderately trained cyclists and its correlation with laboratory tests. As a result, the aims of the present study were firstly to examine the reproducibility of outdoor flat and uphill cycling TT, and secondly to assess the relationship between laboratory determined W_{peak} and outdoor cycling performance in moderately trained cyclists.

METHODS

Subjects

Eight moderately trained, competitive male cyclists volunteered to take part in the study. Their mean age, height, body mass, W_{peak} and $VO_{2\ peak}$ were 22.5 ± 3.4 years, 1.73 ± 0.04 m, 64.8 ± 9.8 kg, 343 ± 27 W and 3.81 ± 0.36 $L{\cdot}min^{-1}$, respectively. These subjects had been actively cycling on a regular basis (> $4{\cdot}week^{-1}$) for at least 2 years and their physiological characteristics were lower than those of well-trained cyclists (mean W_{peak} = 439 W; mean $VO_{2\ peak}$ = 5.4 $L{\cdot}min^{-1}$) (Mujika and Padilla, 2001). Written informed consent and pre-participation medical questionnaire were provided prior to the commencement of the study that was approved by the institutional ethics review committee.

Procedures

Subjects first performed a progressive cycle ergometer test to exhaustion in the laboratory to determine peak oxygen uptake ($VO_{2\ peak}$) and peak power output (W_{peak}). Following that, they completed three outdoor 36 km TT (TT_{36}) on a flat course on three separate days and three outdoor 1.4 km uphill TT ($TT_{1.4}$) on another day. Subjects performed all tests within a three-week period, with at least 72 h separating each test day. Subjects were requested to perform the same type of training for the duration of the study and to refrain from heavy physical exercise 24 h before a test day. Subjects completed a food diary on which they recorded their food and fluid intake for the day preceding a TT as well as for the day on which they performed their TT. They were then instructed to repeat this dietary regimen before each subsequent trial. They had trained and participated in local TT races prior to their involvement in the study and were familiar with the field locations in the study.

Progressive exercise test

$VO_{2\ peak}$ and W_{peak} were determined on an electronically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). After a self-selected warm-up of 5 min, the incremental test commenced at an initial workload of 100 W with increment of 15 W every minute thereafter. Throughout the test, minute ventilation (V_E), oxygen uptake (VO_2), carbon dioxide expired (CO_2) and respiratory exchange ratio (RER) were measured breath-by-breath using an open circuit spirometry system (Vmax 29, SensorMedics Corporation, USA). The oxygen and carbon dioxide gas analysers were calibrated prior to the $VO_{2\ peak}$ test with known concentrations of standard gases and the flow meter was calibrated using a three-litre syringe. Heart rate (HR) was monitored continuously using a short-range telemetry monitor (S610, Polar Electro OY, Kempele, Finland). Subjects were considered to have attained $VO_{2\,peak}$ when any two of the following criteria were met: i) volitional exhaustion, ii) maximal RER > 1.05, and/or iii) HR > 95% of age-predicted maximum HR (HR_{max}, based on the formula of 220 – age in years). VO_{2peak} was recorded as the highest value obtained over any 60 s period. The measurement of W_{peak} was based on the calculation of completed work in (W) plus the fraction of time spent in the final non-completed workload multiplied by 15 W (e.g. a subject abandoned the test 30 s after beginning a workload of 305 W, his W_{peak} would be calculated as 290 W + (0.5 x 15 W), which would amount to 297.5 W).

36 km flat TT

Subjects completed three TT_{36} on a flat course on three separate days and at the same time of the day. Warm-up was self-selected and recorded and remained consistent throughout all trials. For each trial, the subjects wore the same clothes and used their own bicycles fitted with a mobile cycling powermeter, PowerTap Pro^{TM} (PT) (Graber Products, Madison, WI, USA) in the hub of the rear wheel. Bertucci et al. (2004) and Gardner et al. (2004) had previously showed that the PT is both reliable and valid. Two sets of PT were used in the study and each subject would use the same set for all his trials. The PT torque was zeroed before each trial according to the manufacturer's instructions. Environmental temperature, humidity and airflow were monitored continuously with a heat stress system fitted with an air probe (QT36, Quest Technologies, USA). Tires were inflated to 110-120 psi and kept consistent throughout all trials. Each trial consisted of three 12 km loops. Subjects were allowed to choose their preferred cadence and gear ratio and were instructed to adopt similar strategies and complete the distance in as fast a time as possible. During each trial, time, power output, and heart rate were continuously monitored and subjects were blinded to this information. Environmental conditions were consistent on all test days (temperature: 30.0 ± 1.3 °C; relative humidity: 56.0 ± 1.4 %; wind speed: 0.8 ± 0.5 $m \cdot s^{-1}$).

1.4 km uphill TT

Subjects completed three $TT_{1.4}$ on an uphill course in one day. A rest interval of 40 minutes separated each trial in order to eliminate any possible fatigue effects. The trials were performed on a hill with an average gradient of 7.1% calculated as the ratio of the overall elevation (100 m) (GPSports SPI10, Canberra, Australia) by the distance (1400 m). The instructions given to the subjects, warm-up and measurements obtained were similar to those described for TT_{36}. Environmental conditions were consistent on all test days (temperature: 28.6 ± 0.7 °C; relative humidity: 64.5 ± 4.6 %; wind speed: 0.9 ± 0.3 $m \cdot s^{-1}$).

Statistical analysis

The SPSS software (11.5 for Windows) was used for all statistical analyses. Descriptive data (means and standard deviations) of all the subjects and their performance in the trials were computed. Mean values for all trials were compared using one-way analysis of variance (ANOVA). Reproducibility of the performance and physiological variables were examined using the within-subject random variation as represented by the coefficient of variation (CV) and the intraclass correlation coefficient (ICC) (Model: Two-Way Mixed Effects; Type: Consistency). CV values for individual subjects were calculated by dividing each subject's SD by their mean values. The 95% confidence intervals (95% CI) were calculated using the methods of McGraw and Wong (1996). Pearson product moment correlation was used to examine the relationships between W_{peak} (W and $W \cdot kg^{-1}$) and mean power and performance time in TT. For all analyses, the alpha level of statistical significance was established at $p < 0.05$.

RESULTS

Individual subject data for mean power and performance time are presented in Tables 1 and 2, respectively. There were no significant differences between trials ($p > 0.05$) for all variables measured.

The coefficient of variation (CV), intraclass correlation coefficients (ICC) and 95% confidence intervals (CV [95% CI] and ICC [95% CI]) for each variable across all trials are presented in Table 3.

Table 4 shows the correlation matrix between absolute and relative W_{peak} (W and $W \cdot kg^{-1}$) obtained in the laboratory and mean power and performance time during TT_{36} (W_{36}, T_{36}) and $TT_{1.4}$ ($W_{1.4}$, $T_{1.4}$).

DISCUSSION

The main finding of the present study was that outdoor flat and uphill cycling TT performance was highly reproducible in moderately trained cyclists. It is known that the reproducibility of laboratory-based cycling performance is high for well-trained cyclists when the exercise durations were familiar to them (Hickey et al., 1992; Jeukendrup et al., 1996; Laursen et al., 2004; Palmer et al., 1996).

Smith et al. (2001) were reportedly the first to demonstrate that field-based 40 km cycling TT performance using the SRM powermeter was highly reproducible in well-trained cyclists. The authors in the cited study reported a CV of 1.7% for

Table 1. Mean power (W) across three TT_{36} (W_{36}) and three $TT_{1.4}$ ($W_{1.4}$).

	Subject	1	2	3	4	5	6	7	8	*Mean*	*SD*
TT36	**Trial 1**	231	172	256	246	225	230	202	251	227	27.9
	Trial 2	236	183	248	264	241	218	210	254	232	26.6
	Trial 3	236	192	255	259	247	228	202	255	234	25.4
	Mean	*234*	*182*	*253*	*256*	*238*	*225*	*205*	*253*	*231*	*26.1*
	SD	*2.9*	*10.0*	*4.4*	*9.3*	*11.4*	*6.4*	*4.6*	*2.08*		
	CV (%)	*1.2*	*5.5*	*1.7*	*3.6*	*4.8*	*2.9*	*2.3*	*.8*	*2.9*	*1.7*
TT1.4	**Trial 1**	318	297	377	376	381	317	299	361	*340.8*	*36.5*
	Trial 2	316	292	381	384	358	307	295	369	*337.8*	*39.2*
	Trial 3	305	275	359	379	356	303	285	359	*327.6*	*39.9*
	Mean	*313*	*288*	*372*	*380*	*365*	*309*	*293*	*363*	*335*	*38.2*
	SD	*7.0*	*11.5*	*11.7*	*4.0*	*13.9*	*7.2*	*7.2*	*5.3*		
	CV (%)	*2.2*	*4.0*	*3.2*	*1.1*	*3.8*	*2.3*	*2.5*	*1.5*	*2.6*	*1.0*

performance time across three outdoor 40 km TT. Comparatively, low CV values of 1.4% and 1.1% for performance time in TT_{36} and $TT_{1.4}$, respectively, showed that even in moderately trained cyclists, performance was highly reproducible in the present study. Possible factors that might have contributed to the high reproducibility were that subjects rode their own bikes and were accustomed to the distances of the test protocols. In addition to these factors, we also attribute the high reproducibility of performance time to stable environmental conditions. These postulations were supported by Palmer et al. (1996) who showed that the CV values for performance time during laboratory simulated cycling, when subjects rode their own bikes, were 1.1% and 1.0% for 20 km TT and 40 km TT, respectively, in well-trained cyclists.

In the present study, the CV values for mean power were 2.9% and 2.6% for TT_{36} and $TT_{1.4}$, respectively. Similarly, Smith et al. (2001) reported a CV of 2.6% for outdoor 40 km TT. Analyses by Hopkins (2000) estimated that the CV values for mean power in Palmer et al's (1996) laboratory-based study were 2.4% and 3.3% for 20 km TT and 40 km TT, respectively. Based on these data, we observe that the variations of mean power produced by moderately trained cyclists during outdoor TT are comparable with those of well-trained cyclists in both indoor and outdoor conditions. Additionally, there seemed to be a trend indicating higher CV values for mean power when compared to performance time. It is noteworthy that mean power is not less reproducible than performance time but rather an artifact of the non-linear time-power relationship (Seiler et al., 1998; Schabort et al., 1998). The relationship between a change in muscular power output and the corresponding change in movement velocity of an object moving through air or water is not linear because of the exponential relationship between movement velocity and the resulting drag force acting on the object (Sanderson and Martindale, 1986; Secher, 1983). Power is a third-order polynomial function of velocity. The impact of wind drag is highly significant in cycling TT as cyclists are riding at high speeds and wind velocity is the primary resistance to movement.

It has been proposed that heart rate may not be a good indicator of exercise intensity as it can be

Table 2. Performance time (min) across three TT_{36} (T_{36}) and three $TT_{1.4}$ ($T_{1.4}$)

	Subject	1	2	3	4	5	6	7	8	*Mean*	*SD*
TT36	**Trial 1**	54.38	58.85	53.03	54.25	56.55	57.13	59.20	52.50	55.74	2.57
	Trial 2	53.97	59.00	53.68	52.97	57.57	57.90	57.53	50.47	55.39	3.02
	Trial 3	55.02	59.30	54.05	53.17	55.27	59.50	58.57	51.63	55.81	2.97
	Mean	*54.46*	*59.05*	*53.59*	*53.46*	*56.46*	*58.18*	*58.43*	*51.54*	*55.65*	*2.77*
	SD	*.53*	*.23*	*.52*	*.69*	*1.15*	*1.21*	*.84*	*1.01*		
	CV (%)	*1.00*	*.40*	*1.00*	*1.3*	*2.0*	*2.1*	*1.4*	*2.0*	*1.4*	*.6*
TT1.4	**Trial 1**	3.55	3.60	3.27	3.17	3.80	3.87	3.88	3.22	*3.55*	*.29*
	Trial 2	3.62	3.63	3.28	3.13	3.92	4.00	3.98	3.20	*3.60*	*.36*
	Trial 3	3.63	3.68	3.27	3.15	3.90	4.00	3.97	3.23	*3.60*	*.35*
	Mean	*3.60*	*3.64*	*3.27*	*3.15*	*3.87*	*3.96*	*3.94*	*3.22*	*3.58*	*.33*
	SD	*.04*	*.04*	*.01*	*.02*	*.06*	*.08*	*.06*	*.02*		
	CV (%)	*1.2*	*1.1*	*.2*	*.6*	*1.7*	*1.9*	*1.4*	*.5*	*1.1*	*.6*

Table 3. Coefficient of variation (CV) and intraclass correlation coefficient (ICC) for variables measured during TT_{36} and $TT_{1.4}$. Data are means (±SD) [95% CI].

		CV (%) [CI]	ICC [CI]
TT_{36}	**Mean power (W)**	2.9 (1.7) [2.1 - 4.6]	.94 [.82 - .99]
	Performance time (min)	1.4 (.6) [1.0 - 2.2]	.91 [73 - .98]
	Heart rate ($b \cdot min^{-1}$)	3.0 (2.3) [2.2 - 4.7]	.69 [.30 - .92]
$TT_{1.4}$	**Mean power (W)**	2.6 (1.0) [1.9 - 4.1]	.97 [.91 - .99]
	Performance time (min)	1.1 (.6) [.8 - 1.7]	.99 [.96 - 1.00]
	Heart rate ($b \cdot min^{-1}$)	1.0 (.6) [.7 - 1.6]	.90 [.70 - .98]

affected by environmental changes, hydration status and positional changes on the bike (Jeukendrup and van Diemen, 1998). In the present study, the ICC for mean heart rate was 0.60 for TT_{36} and 0.90 for $TT_{1.4}$. Since the duration for TT_{36} was more than ten times that for $TT_{1.4}$, the factors that may affect heart rate response were likely to have greater influence on the former, thus resulting in a higher variation. Bishop (1997) reported an ICC of 0.91 for mean heart rate during repeated 1 h cycling TT in the laboratory. In the cited study, mean power was reportedly more reliable (ICC = 0.97). Overall, the reproducibility of sub-maximal heart rate response is moderate to high, but practitioners need to be watchful of the factors that may increase the likelihood of variations.

The second finding of the present study was that mean power during TT_{36} (W_{36}) may be predicted with some confidence from absolute W_{peak} (W) obtained in the laboratory ($r = 0.90$, $p < 0.01$). This finding is in agreement with data from previous studies using well-trained cyclists (e.g. Balmer et al., 2000; Bentley et al., 2001; Hawley and Noakes, 1992). Balmer et al. (2000) reported a highly significant correlation ($r = 0.99$, $p < 0.001$) between absolute W_{peak} (W) and mean power during outdoor 16.1 km TT. In the present study, a highly significant relationship was also found between mean power during $TT_{1.4}$ ($W_{1.4}$) and absolute W_{peak} (W) ($r = 0.98$, $p < 0.01$). The higher correlation for the latter can be attributed to the greater emphasis of muscular power during an uphill climb.

In contrast, absolute W_{peak} (W) was only modestly correlated with performance time in TT_{36} (T_{36}) ($r = -0.72$, $p < 0.05$), and differences in T_{36} may be attributed primarily to variations in individual aerodynamics since environmental conditions were consistent on all test days. This is not surprising as Balmer et al. (2000) also reported a low correlation ($r = -0.46$, $p > 0.05$) between absolute W_{peak} (W) and performance time in 16.1 km TT. In the cited study, the correlation was even lower than that of the present study because the environmental conditions were not standardized as subjects competed in separate TT races. Therefore, factors such as wind speed, direction, temperature and humidity might have additional influences over and above individual aerodynamics on performance time. With well-trained cyclists, Hawley and Noakes (1992) showed that absolute W_{peak} (W) correlated strongly with 20 km cycle time ($r = -0.91$, $p < 0.001$) under standardized environmental conditions when all subjects completed their TT in the same event held on the same day. In the cited study, the course of the TT was mainly flat and consisted of four laps of 5 km oval circuit.

The non-significant relationship between absolute W_{peak} (W) and performance time in $TT_{1.4}$ ($T_{1.4}$) ($r = -0.52$, $p > 0.05$) in the present study reiterated the importance of power-to-weight ratio during uphill cycling in comparison with riding on a flat course. Some of the riders who attained higher absolute W_{peak} (W) also had larger body masses and thus were at a disadvantage during climbing. However, when riding on a flat course, a larger rider has an advantage (in terms of absolute oxygen consumption and power output) due to a lower frontal surface area to body weight ratio than a smaller rider (Swain et al., 1987). This advantage is lost when cycling uphill. This argument is supported by a strong relationship ($r = -0.91$, $p < 0.01$) found between relative W_{peak} ($W \cdot kg^{-1}$) and $T_{1.4}$ and a non-significant relationship ($r = -0.65$, $p > 0.05$) between relative W_{peak} ($W \cdot kg^{-1}$) and T_{36}. Hawley and Noakes (1992) also reported that the correlation between W_{peak} (W) and outdoor 20 km cycling time was decreased when W_{peak} was expressed relative to body mass ($W \cdot kg^{-1}$) ($r = -0.68$, $p < 0.01$).

CONCLUSIONS

In conclusion, under stable environmental conditions, performance time and mean power are

Table 4. Correlation coefficient matrix of laboratory determined absolute and relative W_{peak} (W and $W \cdot kg^{-1}$) with mean power and performance time in TT_{36} (W_{36}, T_{36}) and $TT_{1.4}$ ($W_{1.4}$, $T_{1.4}$). *$p < 0.05$; ** $p < 0.01$.

	W_{36} (W)	T_{36} (min)	$W_{1.4}$ (W)	$T_{1.4}$ (min)
Absolute W_{peak} (W)	.90**	-.72*	.98**	-.52
Relative W_{peak} ($W \cdot kg^{-1}$)	--	-.65	--	-.91**

highly reproducible during outdoor cycling TT in moderately trained cyclists provided they are familiar with the test protocol and duration. Laboratory determined absolute W_{peak} (W) may predict cycling performance on a flat course but relative W_{peak} ($W \cdot kg^{-1}$) is a better predictor of performance during uphill cycling.

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KEY POINTS

- Under stable environmental conditions, performance time and mean power are highly reproducible in moderately trained cyclists during outdoor flat and uphill cycling time trials.
- Laboratory determined peak power output (W_{peak}) (W) may predict cycling performance on a flat course.
- Laboratory determined relative W_{peak} ($W \cdot kg^{-1}$) is a better predictor of performance during uphill cycling

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