Reliability of Mean Power Recorded During Indoor and Outdoor Self-Paced 40 km Cycling Time-Trials

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The purpose of this study was to assess reliability of both indoor and outdoor 40 km time-trial cycling performance. Eight trained cyclists completed three indoor 40 km time-trials on an air-braked ergometer (Kingcycle™) and three outdoor 40 km time-trials on a local course. Power output was measured for all trials using the SRM™ powermeter. Mean performance time across three indoor trials was 54.21 ± 2.59 (min:sec) and was significantly different ($P < 0.05$) to mean time across three outdoor trials (57.29 ± 3.22 min:sec). However, there was no significant difference ($P = 0.34$) for mean power across three indoor trials (303 ± 35 W) when compared to outdoor performances (312 ± 23 W). Within-subject variation for mean power output expressed as a coefficient of variation (CV) improved in both indoors and outdoors for trials 2 and 3 (CV = 1.9%, 95% CI 1.0–3.4 and CV = 2.1%, 95% CI 1.1–3.8) when compared to trials 1 and 2 (CV = 2.1%, 95% CI 1.2–3.8 and CV = 2.4%, 95% CI 1.3–4.3). These findings indicate that power output measured using the SRM powermeter is highly reproducible for both laboratory-based and actual 40 km time-trial cycling performance.

Key words: Cycling performance, reproducibility, SRM powermeter, fixed-distance.

Introduction

Although numerous studies have examined self-paced indoor cycling time-trial performance in order to evaluate reliability of time [10,16,17] and power output [3] or both [6,20], limited research is available on the reliability of outdoor competitive cycling performance (8). For researchers to investigate the effects of treatments on performance, within-subject variation (random variation of a subject's repeated measurement) must be evaluated. A low within-subject variation provides a greater accuracy for single measurements and improves tracking of changes in measurements in practical settings. Reliability of measured variables also permits the researcher to determine suitable sample sizes and establish acceptable confidence limits in experiments [9].

Performance time has been a popular method to assess reliability of laboratory cycling tests due to the ease of measurement. Reported within-subject variation expressed as coefficient of variation (CV) for distances ranging from 20 to 100 km [17,20] has been low (1.1–1.7%). However, the use of time as an accurate indicator of performance when investigating the effects of treatments in actual competition has limitations [2]. Analyses of data collected by Palmer et al. [17] and recent research by Schabort et al. [21] revealed that CV's for mean power calculated over three repeated 20, 40 and 100 km cycle tests using a Kingcycle air-braked ergometer ranged between 2.4 and 3.7% [9]. Furthermore, with the exclusion of respiratory and lactate sampling during the majority of these studies, limited data on the repeatability of other key physiological responses during self-paced time-trials are available.

The Kingcycle ergometer allows cyclists to ride their own bicycles within a laboratory environment and therefore has been used to replicate actual outdoor cycling. Although several studies have used Kingcycle tests to assess performance, recent work by Balmer et al. [1] found that the Kingcycle air-braked ergometer did not provide a valid measure of power output when compared with the Schoberer Rad Messtechnik (SRM) powermeter. With the development of the SRM powermeter, performance can be assessed during indoor and outdoor cycling [11] with measurement of power output being both valid [12,13] and reliable [12]. Due to the inherent difficulties associated with the Kingcycle air-braked ergometer [1], it is now necessary to evaluate the reproducibility of mean power for indoor and establish reliability of mean power for outdoor time-trial cycling performance with more accurate and versatile equipment. The aim of this study was to establish the reliability of mean power output in 40 km laboratory time-trial cycling performance using the SRM powermeter, respiratory and lactate measurements, and secondly determine the reliability of competitive 40 km outdoor time-trial cycling performance.

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Methods

The study consisted of two parts, which involved the completion of 1) three indoor laboratory-based 40 km time-trials and 2) three outdoor field-based 40 km time-trials. All subjects performed both parts, which were separated by a four-week period. In addition each subject completed a progressive maximal aerobic power test (MAP) [2] prior to each part to assess maximal power output (W_{max}), maximal oxygen uptake ($\dot{V}O_2$peak) and maximal heart rate (HR_{max}). All laboratory tests were performed on an air-braked ergometer (Kingcycle™, EDS Portaprompt Ltd, High Wycombe, UK). On arrival at the laboratory the subject's own bicycle was first fitted with the SRM powermeter (Julich, Welldorf, Germany) and tyre pressure was standardised at 100 p.s.i. The bicycle was then attached to the Kingcycle ergometer and an additional stabilising strap was fitted. This consisted of a strap fed through the rails of the subject's saddle and secured firmly to the frame of the ergometer (this was used to minimise changes in resistance between the tyre of the bicycle and the roller of the air-braked flywheel).

Before each test calibration of the SRM powermeter and Kingcycle ergometer was performed using previously described procedures [12,17], respectively. In addition a further calibration was performed to match power output recorded by the SRM powermeter and Kingcycle ergometer. Subjects rode at ~300 W, as indicated by the Kingcycle computer software. During this time the Kingcycle was adjusted to either increase or reduce the resistance of the rear wheel on the air-braked flywheel, once power recorded using both systems had been matched, no further adjustments were made throughout the test. Throughout all indoor time-trials power output (W) was averaged per 1 min using the Kingcycle ergometer software and averaged every one-second using the SRM powermeters with distance being calculated *via* the Kingcycle ergometer. Subjects were assigned either a 2, 4 or 20-strain gauge SRM powermeter, which was kept constant across all testing protocols.

Subjects

Eight non-elite, endurance-trained, competitive male cyclists volunteered to take part in this study. Physical characteristics are presented in Table **1**. Each rider had previous experience of laboratory-based testing and regularly competed in 40 km competitive time-trials. Prior to testing, in accordance with the institutional ethical regulations, written informed consent was obtained. Throughout the study subjects served as their own control maintaining their normal diet and daily activity patterns and were instructed not to train within the 24 hours prior to testing.

Table 1 Physical characteristics of eight subjects (mean ± SD)

Age (yrs)	31 ± 5
Height (m)	1.79 ± 0.06
Body mass (kg)	72.6 ± 4.5
W_{max} (W)	412 ± 42
$\dot{V}O_2$peak ($l \cdot min^{-1}$)	5.11 ± 0.70
$\dot{V}E_{max}$ ($l \cdot min^{-1}$)	151 ± 28
HR_{max} ($b \cdot min^{-1}$)	190 ± 6

Part I

Indoor time-trial performance

Subjects completed three 40 km time-trials at the same time of day in a three-week period. A minimum of three and a maximum of ten days separated each trial. Prior to each trial subjects completed a self-selected warm-up, which was standardised across trials. After a short rest the subject was asked to cover a distance of 40 km in the shortest time possible achieving the highest average power output. Feedback in the form of heart rate response ($b \cdot min^{-1}$), elapsed time (min : sec), and percentage distance covered were the only visual cues given during the trials. For the completed 40 km time-trial total time (min : sec), mean heart rate ($b \cdot min^{-1}$), and mean power output (W) were calculated. Subjects were not informed of their mean power output and actual performance time until all trials had been completed.

Lactate measurement

At 4 km intervals during each time-trial capillarised blood samples were taken from the finger using previously described procedures [5]. Blood was analysed following the exercise test using a Biosen 5030 lactate analyser (EKF, Germany), which previous research has shown provides a valid and reliable assessment of blood lactate [5].

Respiratory gas analysis

During each time-trial expired gases was assessed *via* a Hans Rudolph breathing facemask with 2730 series large Y shaped valves (Hans Rudolph, Kansas City, USA) with low resistance ducting, and $\dot{V}O_2$ and $\dot{V}E$ were measured using an on-line Covox Cardiopulmonary analyser (Fitness Research Systems, Exeter, United Kingdom). Preceding each exercise trial, the analyser was calibrated using gases of known concentrations (Cryoservices, Worcester, United Kingdom) with volume being calibrated using a 3-L gas syringe (Hans Rudolph, Kansas City, USA).

At the 20 km point during the trial subjects were instructed to remove the Hans Rudolph facemask but maintain their effort. Within a time window of two minutes subjects consumed a 5% glucose polymer solution (TechoFuel, Rainham, UK). A concentration between 5 – 10% has been suggested as being optimal for gastric emptying [14], however, several subjects claimed to have previously experienced stomach discomfort after consuming high concentrations of glucose and therefore the lower value was selected. The quantity of fluid consumed during the first trial was recorded and kept constant throughout subsequent trials.

Part II

Outdoor time-trial performance

All outdoor time-trials were performed on a local 40 km course regularly used for regional and national competitions. Trials were completed at the same time of day and separated by at least one week. Each time-trial was completed under Road Time-trials Council regulations [19]. The SRM powermeter was fitted to the subject's bicycle prior to the ride and calibrated. Prior to each separate time-trial subjects were instruc-

ted to perform their normal pre-race preparation and warm-up as if competing in a 40 km time-trial competition.

Starting the race at one-minute intervals, subjects raced individually to complete the distance in the quickest time. During the ride heart rate response ($b \cdot min^{-1}$) and elapsed time (min : sec) were the only forms of feedback given to the cyclists. Fluids were permitted during the time-trials, as fluids would normally be consumed during actual competition [23]. For the completed 40 km time-trial total time (min : sec), mean heart rate ($b \cdot min^{-1}$), and mean power output (W) were calculated.

Statistical analyses

For all indoor and outdoor 40 km time-trial performances mean values were calculated for all measured variables. Within-subject variation expressed as a coefficient of variation (CV) was derived by log-transformed two-way analyses of variance previously described [21]. Confidence intervals (95% CI) for CV's were calculated by the methods of Tate and Klett [24]. CV's for individual subjects were calculated by dividing each cyclist's SD by their mean value. Statistical difference between values ($P < 0.05$) was assessed using ANOVA. All values are expressed as mean and standard deviation (mean ± SD) unless otherwise stated.

Results

Individual subject data for mean performance time and power output (SRM) achieved during three indoor and outdoor cycling time-trials are presented in Tables **2** and **3**, respectively. Mean power output for all three indoor trials was not significantly different to mean power calculated for the three outdoor time-trials ($P = 0.34$). Mean heart rates for indoor trials 1, 2 and 3 were 173 ± 7, 172 ± 5 and 171 ± 6 $b \cdot min^{-1}$, whilst for outdoor trials mean heart rates were 174 ± 6, 173 ± 6 and 171 ± 6 $b \cdot min^{-1}$, respectively. There was no significant difference for mean heart rate across all three indoor and outdoor time-trials (172 ± 6 vs. 173 ± 6 $b \cdot min^{-1}$, $P = 0.77$). Mean oxygen uptake ($\dot{V}O_2$) and ventilation ($\dot{V}E$) across three indoor time-trials were 4.14 ± 0.48 and 111 ± 13 $l \cdot min^{-1}$, respectively, whilst mean blood lactate was 6.96 ± 1.4 $mmol \cdot min^{-1}$. Coefficient of variation (CV) across trials 1 & 2 and 2 & 3 for measured variables during both indoor and outdoor cycling time-trial performance are presented in Table **4**. For all variables repeatability improved for trials 2 & 3 when compared to trials 1 & 2, except mean heart rate measured during outdoor cycling time-trials.

Table 2 Mean performance time (min : sec) achieved by individual subjects in three indoor and three outdoor 40 km time-trials. ANOVA revealed a significant difference between indoor and outdoor mean performance time ($P < 0.05$)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Indoor 40 km TT										
Trial 1	52:16	55:06	57:16	1:00:41	54:52	53:44	50:26	53:47	54:46	3.08
Trial 2	52:56	54:28	56:58	59:42	53:56	53:26	49:23	52:06	54:07	3:07
Trial 3	53:25	54:09	57:23	58:46	54:20	53:13	49:54	52:06	54:10	2:49
Mean	52:52	54:34	57:12	59:43	54:23	53:28	49:54	52:40	54:21	2:59
SD	0:35	0:29	0:13	0:58	0:28	0:16	0:32	0:58		
CV	**1.09**	**0.89**	**0.38**	**1.60**	**0.86**	**0.49**	**1.05**	**1.85**	**1.0%**	
Outdoor 40 km TT										
Trial 1	53:22	53:41	53:23	1:02:36	58:44	59:29	56:08	56:12	56:42	3:21
Trial 2	55:44	54:03	55:45	1:03:42	59:57	58:21	55:34	53:53	57:07	3:22
Trial 3	55:34	55:11	57:30	1:06:00	1:00:03	1:01:23	56:34	57:02	58:37	3:40
Mean	54:53	54:18	55:33	64:06	60:01	59:18	56:05	55:35	57:29	3:22
SD	1:19	0:47	2:04	1:44	1:20	0:52	0:30	1:31		
CV	**2.41**	**1.44**	**3.72**	**2.71**	**2.21**	**1.46**	**0.89**	**2.72**	**1.7%**	

Table 3 Mean power output (W) achieved by individual subjects in three indoor and three outdoor 40 km time-trials. Power recorded using the SRM powermeter. ANOVA revealed no significant difference between indoor and outdoor mean power output ($P = 0.34$)

Subject	1	2	3	4	5	6	7	8	Mean	SD
Indoor 40 km TT										
Trial 1	314	292	277	240	287	309	354	309	298	32.9
Trial 2	314	292	276	242	306	314	372	330	306	38.3
Trial 3	309	301	272	252	299	323	365	326	306	34.5
Mean	312	295	275	245	297	315	364	322	303	35.0
SD	2.9	5.2	2.7	6.4	9.6	7.1	11.2	9.1	35.0	
CV	**0.92**	**0.76**	**0.96**	**2.63**	**3.32**	**2.25**	**3.47**	**2.50**	**2.01%**	
Outdoor 40 km TT										
Trial 1	320	315	310	265	308	322	345	305	311	22.5
Trial 2	308	308	298	269	322	329	346	318	312	22.9
Trial 3	307	320	284	269	308	328	352	320	311	25.8
Mean	312	314	297	268	313	326	348	314	312	22.9
SD	7.2	6.0	13.0	2.3	8.1	3.8	3.8	8.1	22.9	
CV	**2.32**	**1.92**	**4.38**	**0.86**	**2.58**	**1.16**	**1.09**	**2.59**	**2.55%**	

Table 4 Coefficient of variation (CV [95%CI) for variables measured during both indoor and outdoor 40 km time-trials

	Trial 1 and 2	Trial 2 and 3
Indoor 40 km Time-Trial		
Mean power Kingcycle	2.3% (1.3–4.2)	1.5% (0.8–2.7)
Mean power-SRM	2.1% (1.2–3.8)	1.9% (1.0–3.4)
Mean time	0.9% (0.5–1.7)	0.7% (0.4–1.2)
Lactate	16.4% (8.4–31.6)	5.7% (2.9–11.0)
$\dot{V}O_2$	3.0% (1.6–5.4)	2.9% (1.6–5.2)
$\dot{V}E$	5.4% (2.9 – 9.7)	4.6% (2.5–8.3)
Heart rate	3.2% (1.7–5.7)	1.7% (0.9–3.1)
Outdoor 40 km Time-Trial		
Mean power-SRM	2.4% (1.3–4.3)	2.1% (1.1–3.8)
Mean time	2.2% (1.2–3.9)	1.1% (0.6–2.0)
Heart rate	1.4% (0.8–2.5)	1.5% (0.8–2.7)

Discussion

To our knowledge this is the first study to have assessed the reproducibility of mean power recorded during both laboratory- and field-based 40 km time-trial cycling performance. The repeatability of indoor mean power is lower than any previously calculated values despite the disruption of respiratory and lactate sampling. Analyses by Hopkins et al. [9] estimated the coefficient of variation (CV) for mean power, recorded using a Kingcycle air-braked cycle ergometer, over three repeated 20 and 40 km cycle tests [17] to be 2.4 and 3.3%. The present study found the repeatability (CV) of mean power, using SRM, across trials 1 & 2 and 2 & 3 to be 2.1 and 1.9%, respectively, whilst mean power, recorded *via* the Kingcycle, across trials 1 & 2 and 2 & 3 was found to be 2.3 and 1.5%, respectively. With the SRM powermeter averaging power every one-second, rather than averaged every minute via the Kingcycle ergometer, greater fluctuations of power were measured, which may explain a higher CV for SRM compared to Kingcycle across trials 2 & 3.

The Kingcycle air-braked cycle ergometer has been frequently used to evaluate the reliability of cycling performance. However, recent work by Balmer et al. [1] revealed that the Kingcycle did not provide a valid measure of power when compared to the SRM powermeter. The authors suggested that this was due to problems associated with the calibration of the Kingcycle and changes in the resistance between the roller of the flywheel and the tyre of the rear wheel during cycling performance. In the present study it is likely that changes in resistance between the tyre and the roller were minimised within and between trials due to the additional stability strap, a more stringent calibration procedure and the steady state nature of the time-trial. Subsequently discrepancies in power output between the SRM powermeter and Kingcycle ergometer were marginal throughout all trials, resulting in a low CV for mean power output.

Data on the reproducibility of mean heart rate, respiratory and lactate measurements during laboratory-based fixed-distance self-paced time-trial cycle performances is limited [6,16,19]. Over repeated one-hour performance rides CV for mean heart rate has been reported to be 2.0% (biased, mean × SD × 100) [3], whilst over three repeated 100 km cycle tests with intermittent sprints within-subject variation expressed as a standard deviation was calculated as being 3.8% [20]. In the present study, CV for mean heart rate was consistent for both indoor and outdoor 40 km time-trials. However, heart rate as a method of monitoring exercise intensity in a practical setting has been criticised as heart rate response can be affected by positional changes on the bike, dehydration and environmental changes [11].

The within-subject variation for mean $\dot{V}O_2$ over 40 km was similar to biased findings previously reported by Hickey et al. (6). Biased CV's of less than 5% were also calculated for mean $\dot{V}O_2$ and $\dot{V}E$ from multiple 'time to exhaustion' cycling trials [15]. In the present study CV for mean blood lactate was larger across trials 1 & 2 (16.4%), whilst across 2 & 3 it decreased (5.7%). Similarly Neary et al. [16] found that for mean lactate measured during 40 km self-paced time-trials a weaker relationship existed across trials 1 and 2 when compared to trials 2 and 3. The lack of a familiarisation trial and possible differences in pacing may have been responsible for a high CV across trials 1 & 2. Palmer et al. [18] suggested that respiratory and lactate sampling during performance trials would interfere with the athlete's ability to concentrate during high-intensity exercise. Conversely our study found respiratory and lactate sampling had minimal, if any, disruption to power output over repeated cycling time-trials.

The ease of measuring laboratory-based variables during a simulated cycling time-trial performance has resulted in a comprehensive evaluation of reliability for power output, performance time and physiological variables. However, due to the problematic nature of field-based performance, such as environmental factors and characteristics unique to outdoor competition [9], there is limited research available on the reproducibility of actual competitive cycling performance. Consequently investigations into the effects of treatments on performance in actual competition have seldom, if ever, been reported [9]. The use of performance time has been used to evaluate reliability of stage(s) during competitive triathlons and the time or distance recorded by elite track-and-field athletes [7,8]. In the present study CV for performance time for both indoor and outdoor trials was small when compared to mean power output. However, this does not imply that mean power is less reliable than mean time, more an artefact of the non-linear time-power relationship [22].

Although time is dependent on a cyclist's aerodynamic and anthropometric characteristics, the use of time/speed as an indicator of outdoor performance and exercise intensity is fraught with difficulties as influences such as wind speed/direction, course topography, body size, and position [4] can affect the cyclist's speed-intensity relationship [11]. The measurement of power output on the other hand provides a more valid measure of exercise performance and exercise intensity than speed or time and therefore is considered a more direct method of monitoring exercise intensity [11].

To summarise, over repeated 40 km laboratory-based time-trials mean power output was found to be more reliable than previously reported values, despite the disruption of respiratory and lactate sampling, whilst to our knowledge this is the first study to have assessed the reproducibility of mean power recorded during field-based 40 km time-trial cycling performance.

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