RESEARCH ARTICLE

The reliability of a 30-minute performance test on a Lode cycle ergometer

Matthew W Driller✉[1, 2]

Abstract

High retest reliability is desirable in tests used to monitor athletic performance. The purpose of the present study was to determine the reliability of a 30-minute cycle test on a cycle ergometer (Lode, Groningen, Netherlands). Following an incremental VO_{2max} test, 10 highly-trained cyclists (mean ± SD; age = 30 ± 6 years; VO_{2max} = 67.7 ± 2.5 mL.kg^{-1}.min^{-1}) completed three 30-minute cycling tests on a Lode cycle ergometer each separated by more than 48 hours. The cycle test implemented a fixed workload for 15-minutes (set at 70% VO_{2max} power output), followed by a 15-minute time-trial. Variables determined during the test were mean power (W_{mean}), blood lactate concentration at 15-minutes (BL_{15}), peak blood lactate concentration (BL_{peak}) and mean heart rate (HR_{mean}). W_{mean} in trial 1 (312 ± 23 W) increased by 0.8% (95% confidence interval: -0.7 to 2.3%) in trial 2 and by a further 0.4% (-0.3 to 1.1%) in trial 3. The typical error of measurement expressed as a coefficient of variation (CV%) for W_{mean} was 1.3% (1.0 to 1.8%). The CV for BL_{15} was 10.9% (8.3 to 15.9%), BL_{peak}; 8.4% (6.5 to 13.0%) and HR_{mean}; 2.4% (1.8 to 3.4%). The average intraclass correlations between trials were W_{mean}: 0.98 (0.96 to 1.00), BL_{15}: 0.94 (0.85 to 0.98), BL_{peak}: 0.88 (0.71- 0.97) and HR_{mean}: 0.88 (0.71 to 0.97). A strong correlation existed between VO_{2max} and PPO in the incremental test and W_{mean} in the 30-minute TT (r = 0.86, 0.93, respectively). The testing protocol performed on a Lode cycle ergometer in the current study is reproducible in highly-trained cyclists, making it a reliable method for monitoring cycling performance.

Keywords: reliability, cycling, reproducibility, performance test

✉ **Contact email:** matthew.driller@gmail.com (MW. Driller)

[1] Australian Institute of Sport, Australia.

[2] Sport Performance Optimisation Research Team, University of Tasmania, Australia.

_____

Introduction

Monitoring changes in athletic performance and evaluating the effects of different interventions on exercise performance in highly-trained cyclists have been studied extensively (Lamberts et al. 2011), with little focus on the reproducibility of performance tests used. In professional cycle races, small differences in performance can determine the difference between finishing on the podium or in the minor placings, indicating that performance changes as small as 1% in highly-trained cyclists can be meaningful (Currell and Jeukendrup 2008; Paton and Hopkins 2006). Therefore, in highly-trained cyclists, any within-subject tests of cycling performance should have sufficient precision to detect changes of this magnitude and any lack of precision makes it very difficult to interpret meaningful differences in performance when studying highly-trained athletes.

The reliability of a performance test refers to its reproducibility when the test is administered over several occasions on the same individual. Reliability has become a focus in the field of sport science as it determines how well a test can track athletic performance or determine the effect certain interventions may have on performance (*e.g.* ergogenic aids, nutritional supplements, or training programs). A common method of evaluating the reliability of a test is referred to as the typical error of measurement (TEM). The TEM in performance consists of both systematic and random errors (Lamberts et al. 2009). In cycling, the systematic error may relate to the inability of an ergometer to accurately measure power output (Paton and Hopkins 2001). The random error includes the test-retest variation in cyclists who do not always perform each test in an identical fashion. The more highly-trained or experienced the cyclist, the lower the chance of random error or test-retest variation (Lamberts et al. 2009; Zavorsky et al. 2007). Random error can be minimised by using an appropriate type of test. Research has shown that time to exhaustion protocols may have a TEM (as expressed by coefficient of variation % - CV) of >10%, whereas time trials are more reliable as they have been shown to have a CV of <5% (Currell and Jeukendrup 2008).

Jeukendrup et al. (1996) studied the reproducibility of three different cycling tests in well-trained cyclists. Cyclists were split into three groups and performed one of three tests, six times. The tests, and their respective CV's were: a) cycling at 75% of VO_{2max} power until exhaustion = 26.6% CV; b) a 45 min pre-load at 70% VO2max power followed by a 15 min maximal time-trial = 3.49% CV; or c) a one hour time trial = 3.35% CV. The researchers concluded that reproducibility of time to exhaustion tests are poor and unreliable but tests that include a preload followed by a time-trial may result in better performance evaluation (Jeukendrup et al. 1996). Krebs and Powers (1989) also reported high

within-individual variation (CV: 27%) and low retest correlation (0.51) when cyclists exercised at a constant power to exhaustion. In contrast to time to exhaustion tests, Lamberts et al. (2009) reported a low variation in 40km performance time (CV: 0.7%) and 40 km mean power (CV: 1.7%) in cyclists who rode their own racing bikes on an electronically-braked cycle ergometer, suggesting the importance of familiarity and replicating a cyclists own bike setup if using a stationary ergometer. An ergometer that closely reflects the feel of cycling with good adjustability may provide a superior means of assessing cycling performance. With the development of highly adjustable and accurate ergometers, the systematic error in performance tests may be reduced (Paton and Hopkins 2001).

There are many different types of cycle ergometers used in sports science and university laboratories worldwide. When it comes to stationary ergometers, the load is an integral part of determining power output (watts) and is generated by sliding friction, electromagnetic braking or air resistance. A popular electromagnetically braked ergometer is the Lode cycle ergometer (Lode, Groningen, Netherlands). Lode cycle ergometers have even been labeled as being the "gold standard" for cycle ergometry (Earnest et al. 2005). While there are many studies that have used Lode cycle ergometers to measure cycling performance (Hawley and Noakes 1992; Hoogeveen et al. 1999; Jeukendrup et al. 1996) and many exercise laboratories that possess Lode ergometers, no studies have examined the reliability of these ergometers to evaluate time-trial cycling performance (~30 minutes) in highly-trained cyclists. Tests of cycling performance lasting ~30 minutes are highly applicable to the sport, as many cycling tours include time-trial stages of distances ranging from 10-30 km's which typically take between 15-45 minutes (Lucia et al. 2001). Furthermore, including a period of fixed power output to a time-trial test may be an effective and reliable way to examine and monitor differences in physiological variables over repeated trials, as has previously been examined (Jeukendrup et al. 1996; Lamberts et al. 2009).

Given the number of studies that use cycle tests to evaluate the effect of interventions or monitor the performance of athletes in the literature, coupled with the relatively low number of studies that report the reliability of these tests, further research is warranted to determine if the tests used are sensitive enough to interpret meaningful changes in performance. More specifically, the research into the reliability of endurance cycling tests (lasting ~30 minutes) on a commonly used cycle ergometer (Lode) is scarce. Therefore, the aim of the present study was to determine the test-retest reliability of a 30-minute cycling test (15-minute fixed power output, 15-minute time-trial) on a Lode cycle ergometer in trained, competitive cyclists. A further aim of the study was to evaluate the relationship between results from an incremental exercise test (VO2max, peak power output) and performance in the 30-minute cycling test.

Materials and methods
Subjects
Ten highly-trained cyclists (mean ± SD; age = 30 ± 6 years; mass = 75.4 ± 6.4 kg; height = 181 ± 5 cm; VO_{2max} = 67.7 ± 2.5 mL.kg^{-1}.min^{-1}, PPO = 452 ± 37 W; relative PPO = 6.0 ± 0.5 W/kg) volunteered to take part in the current study. All testing took place during the competition phase of the cycling season in Australia where all subjects were regularly competing at either State or National level cycling events. Subjects provided informed consent prior to any testing taking place. The study was approved by the Australian Institute of Sport Research Ethics Committee and was conducted in accordance with the international standards required by the Journal of Science and Cycling (Harriss and Atkinson 2009).

Designs
The current study involved subjects attending four separate testing sessions at our laboratory over a three-week period. Initially, subjects completed an incremental cycling test on an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands) to establish each individual's peak power output (PPO) and VO_{2peak}. Following the incremental cycling test, three cycle tests were performed separated by > 48 hours within a maximum of 10 days. In order to control any dietary variables, subjects completed a 24-hour food diary prior to their first trial and were instructed to replicate their diet as closely as possible before the subsequent trials. Training was also controlled for, with subjects completing identical training in the 48 hours before testing on all occasions. Subjects were asked to refrain from strenuous exercise (< 24 h) and caffeine (< 12 h) and to arrive at each session in a fully rested, hydrated state. All testing was performed at the same time of day (± 1 h) to minimize diurnal variation, and tests were always performed on the same cycle ergometer.

Procedures
Cycle ergometer
All cycle tests were performed on an electromagnetically braked Lode cycle ergometer. Lode cycling ergometers are able to switch from a pedaling rate independent mode (hyperbolic mode) to a pedaling rate dependent mode (linear mode). In the hyperbolic mode a certain work rate is imposed to a subject and this load is constant, independent of the subjects' pedaling rates. In the linear mode the ergometer acts like a mechanically braked ergometer: with increasing pedaling rate, the work rate increases according to the following formula:

$$W = L \cdot (RPM)^2.$$

Where RPM is the pedaling rate and L is a (constant) linear factor.

Prior to the start of the study, the Lode cycle ergometer was calibrated on a dynamic calibration rig using a first principles approach by specialists at the Australian Institute of Sport (Gardner et al. 2004).

Incremental exercise test

The incremental cycling test started at 150 watts and increased in power output by 25 watts every minute until volitionary exhaustion was reached or until the subject could no longer maintain a pedal cadence of >70 rev•min^{-1}. Cardiorespiratory-metabolic variables were measured throughout the progressive exercise test using a fully automated indirect calorimetry system, set at a 30-second sample rate (AIS, Belconnen, ACT, Australia). The analyzer was calibrated before each test using alpha gases of known concentration, according to the manufacturer's instructions. VO_{2peak} was taken as the highest VO_2 value recorded over one minute during the incremental test. PPO for the incremental test was determined using the following formula:

$$PPO = Wcom + (t/60 \times 25)$$

Where W_{com} is the power output for the last full workload completed, it is the time in seconds that the final uncompleted workload was sustained, 60 is the target number of seconds in each workload and 25 is the workload increment in watts.

30-minute cycling test (TT)

To determine the test-retest reliability of the 30-minute cycling test (TT), subjects performed the test three times in 10 days. The TT consisted of a 10 minute warm-up period (two minutes at each of the following intensities: 125W, 150W, 175W, 200W, 70% PPO), 15 minutes at a workload equal to 70% PPO, followed immediately by a 15-minute time trial (Table 1). During the first 15-minutes the ergometer was in hyperbolic mode, so that the work rate (70% PPO) was independent of pedalling rate. During the 15-minute time trial the ergometer was set to linear mode so that with increasing pedalling rate the work rate increased. This meant that subjects could pace their effort and attempt to maintain a high pedalling rate over 15-minutes to maximize power output. The linear factor setting used on the ergometer was chosen in a way which would cause a pedalling rate of 90-100 RPM at 70% PPO. The exercise protocol used in the current study has been used previously (Driller & Halson, 2012, Vaile et al. 2008), however, the test-retest reliability of this protocol on a Lode cycle ergometer is not known. During the final 15-minutes of the TT, subjects could view the elapsed time and were required to produce as much work as possible in the timeframe, but no other information was provided. Immediately following the TT, a standardized cool down was completed (five minutes at 40% PPO), making the total duration of the test 46 minutes (*see* Table 1).

Physiological variables

Blood lactate concentration was measured via a capillary finger-tip sample and was

Table 1. Protocol for the warm-up, exercise test and cool down

Warm-up
2 min @ 125 W
2 min @ 150 W
2 min @ 175 W
2 min @ 200 W
2 min @ 70% PPO
60 s passive rest (setup for cycle test)
30-minute cycle test (TT)
15 min @ 70% PPO
15 min time-trial
Warm-down
5 min @ 40% PPO

analyzed with a Lactate-Pro analyzer (Shiga, Japan). The test-retest reliability of the Lactate Pro has been previously reported, with typical error of measurement results ranging from 0.1-0.4 mmol.L^{-1} at blood lactate concentrations of 1-18 mmol.L^{-1} (Tanner et al. 2010). Blood lactate was measured following the 15-minute fixed-workload section of the TT (BL_{15}) and immediately after the TT (BL_{peak}). During all tests, heart rate was recorded continuously using a RS800 heart rate monitor (Polar Electro Oy, Kempele, Finland). The average heart rate over the entire TT was used for analysis (HR_{mean}).

Statistical analyses

All data were log-transformed and analysed using an Excel spreadsheet for reliability (Hopkins 1997). Typical error of measurement was expressed in both absolute terms and as a CV% along with upper and lower 95% confidence limits (CL). An individual's CV was calculated as the SD of an individual's repeated measurement expressed as a percent of their individual mean test score (Hopkins 2000). The intraclass correlation between trials was determined in combination with the 95% CL. Pearson's r was used to determine the correlation between incremental test

Table 3. Mean performance and physiological variables from 10 highly-trained cyclists during and following a 30-minute performance test on a Lode cycle ergometer over three separate testing sessions. Data are presented as mean ± SD.

	Test 1	Test 2	Test 3
W_{mean} (W)	312 ± 23	315 ± 29	316 ± 28
BL_{15} (mmol·L^{-1})	7.8 ± 2.8	7.7 ± 2.4	7.6 ± 2.6
BL_{peak} (mmol·L^{-1})	9.9 ± 2.3	10.8 ± 2.5	10.7 ± 2.0
HR_{mean} (bpm)	161 ± 9	159 ± 10	162 ± 9

W_{mean} = mean power output for the 30-min test; BL_{15} = blood lactate concentration following the 15-min fixed workload; BL_{peak} = blood lactate concentration immediately post the 30-min test; HR_{mean} = average heart rate for the entire test.

Table 2. Correlations (pearson's r) between incremental exercise test variables and the 30-minute performance test.

	VO_{2max} (ml.kg^{-1}.min^{-1})	VO_{2max} (L.min^{-1})	PPO	PPO$_{W/kg}$
W_{mean}	0.72*	0.86*	0.93[†]	0.44[^]
$W_{mean/kg}$	0.87*	0.19	0.67[#]	0.52[#]

[†] Nearly perfect correlation. * Very large correlation. [#] Large correlation. [^] Moderate correlation.
W_{mean} = mean power output for the 30-min exercise task (TT); $W_{mean/kg}$ = mean power output relative to body mass for the TT; PPO = peak power output in the incremental test; PPO$_{watts/kg}$ = peak power output relative to body mass.

variables and mean power during the TT. Thresholds for assigning qualitative terms to the strength of correlations were as follows: <0.1, trivial/very small; <0.3, small/low; <0.5, moderate/medium; <0.7, large/high; <0.9, very large/very high; and <1.0, nearly perfect (Hopkins 1997).

Results

Linear factor settings on the Lode cycle ergometer varied within the range of 0.030-0.040 depending on the subjects' cadence preference and target power (70% PPO). A *very large* and *nearly perfect* correlation existed between performance in the incremental test (VO_{2max}, $ml.kg^{-1}.min^{-1}$; and PPO, W) and W_{mean} (averaged over the three trials for all individuals) in the 30-minute TT ($r = 0.86$ and 0.93, respectively; $P < 0.05$ – Table 2). W_{mean} in trial one (312 ± 23 W) increased by 0.8% (95% CL: -0.7 to 2.3%) in trial two and by a further 0.4% (-0.3 to 1.1%) in trial three (Table 3). The highest correlation and lowest typical error (expressed as a CV%) for W_{mean} was between tests two and three ($r = 1.00$, 0.7% - Table 4), with the mean CV across all trials equaling 1.3% (1.0 to 1.8). The highest typical error for W_{mean} was found between tests one and two (4.9 W, 1.5%), possibly suggesting the need for one familiarization trial. BL_{15} had the highest correlation and lowest typical error between tests one and two, while these values for BL_{peak} and HR_{mean} occurred between tests two and three (Table 4). The difference from the mean for W_{mean}, BL_{15}, BL_{peak} and HR_{mean} in all trials for each individual is shown in Figure 1.

Discussion

The primary findings from this investigation suggest that using a protocol consisting of 15-minutes at a set workload followed by a 15-minute time trial on a Lode cycle ergometer, results in highly reproducible performance in highly-trained cyclists. The reliability of this test, on the Lode cycle ergometer, in highly-trained cyclists was associated with a low typical error of measurement (as expressed by CV%) and a high within-subject intraclass correlation (1.3% and 0.98, respectively – Table 4). This typical error of measurement translates to just 4.1 watts (95%CL: 3.2-5.9) in mean power output over the duration of the self-paced 15 min TT test. The low TEM found within the current protocol suggest that this test can assist scientists and coaches to better understand factors that may influence cycling performance.

To determine the absolute reliability between tests (within-subject variation), the mean coefficient of variation for all comparisons (2v1, 3v2, 3v1) was evaluated (Table 4). Based on other studies (Laursen et al. 2003; Zavorsky et al. 2007), it was hypothesized that the variation would decrease from the second to the third time trial compared to the variation from the first to the second and from the first to the third time trials. Our study supported this hypothesis, with the highest CV resulting from the first two trials (1.5%) and the lowest CV occurring between trials two and three (0.7%). While there was no significant difference in performance between trials, there was a larger increase in mean power output from trial one to two (Table 3). This suggests that when evaluating endurance performance using this protocol, a familiarization trial should be performed before the baseline test in order to improve the reliability of the measure, as supported by previous research (Micklewright et al. 2010). An additional familiarization session might therefore lower the TEM even further and improve the current testing protocol.

Table 4. Mean within-subject intraclass correlation (ICC), absolute typical error of measurement (TEM) and typical error as a coefficient of variation (%) between tests. Data are presented as mean (95%CL).

	W_{mean} (W)	BL_{15} ($mmol \cdot L^{-1}$)	BL_{peak} ($mmol \cdot L^{-1}$)	HR_{mean} (bpm)
ICC(2to1)	0.98 (0.91-0.99)	0.96 (0.85-0.99)	0.86 (0.47-0.97)	0.84 (0.47-0.96)
ICC(3 to 2)	1.00 (0.98-1.00)	0.90 (0.66-0.98)	0.88 (0.52-0.98)	0.96 (0.83-0.99)
ICC(3 to 1)	0.96 (0.85- 0.99)	0.90 (0.66-0.98)	0.80 (0.38-0.95)	0.71 (0.19-0.92)
Mean	**0.98 (0.96-1.00)**	**0.94 (0.85-0.98)**	**0.88 (0.71-0.97)**	**0.88 (0.71-0.97)**
TEM (2 to 1)	4.9 (3.3-8.9)	0.8 (0.5-1.4)	0.9 (0.6-1.9)	4.4 (3.0-8.0)
TEM (3 to 2)	2.1 (1.4-3.8)	1.1 (0.7-1.9)	0.9 (0.6-1.7)	2.3 (1.6-4.3)
TEM (3 to 1)	4.7 (3.3-8.6)	0.7 (0.5-1.3)	0.5 (0.4-0.9)	4.2 (2.9-7.7)
Mean	**4.1 (3.2-5.9)**	**0.9 (0.7-1.2)**	**0.8 (0.6-1.2)**	**3.8 (2.9-5.4)**
CV(2 to 1)	1.5 (1.0-2.8)	8.8 (6.0-16.6)	10.3 (6.7-22.1)	2.8 (1.9-5.1)
CV(3 to 2)	0.7 (0.5- 1.3)	13.6 (9.1-26.6)	8.5 (5.6-18.1)	1.5 (1.0-2.7)
CV(3 to 1)	1.4 (1.0- 2.6)	9.8 (6.7-18.7)	6.5 (4.4-12.1)	2.6 (1.8-4.8)
Mean	**1.3 (1.0-1.8)**	**10.9 (8.3-15.9)**	**8.4 (6.5-13.0)**	**2.4 (1.8-3.4)**

W_{mean} = mean power output for the 30-min test; BL_{15} = blood lactate concentration following the 15-min fixed workload; BL_{peak} = blood lactate concentration immediately post the 30-min test; HR_{mean} = average heart rate for the entire test.

Figure 1. Difference (%) of each individual trial from the mean of three trials for each individual. W_{mean} = mean power output for the 30-min test; HR_{mean} = average heart rate for the fixed workload section of the test; BL_{15} = blood lactate concentration following the 15-min fixed workload; BL_{peak} = blood lactate concentration immediately post the 30-min test.
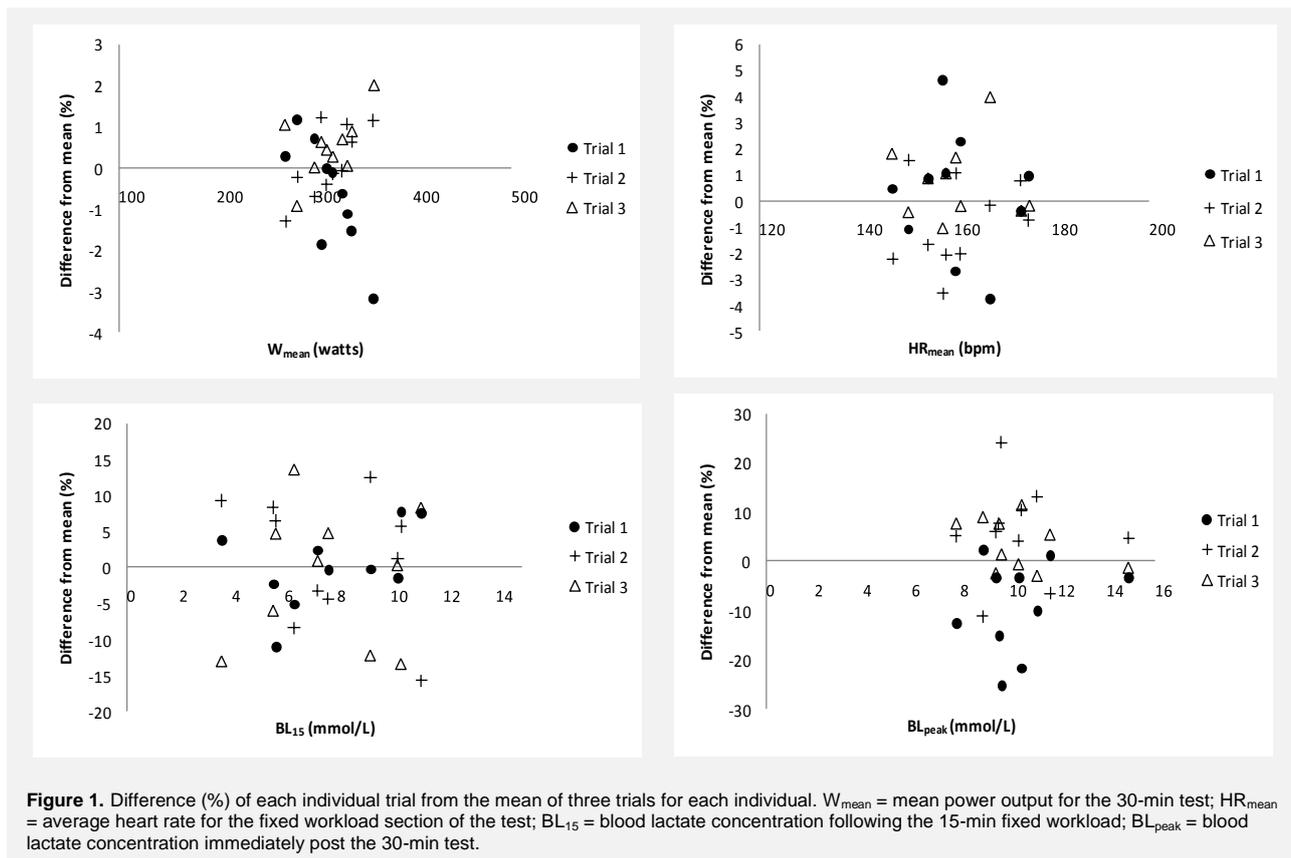
The average typical error observed in the current study (1.3%) is much lower than that of other studies in the literature that have implemented protocols of similar durations (~30 min) using stand-alone cycle ergometers (Sporer and McKenzie 2007; Zavorsky et al. 2007). Instead, the reliability findings in the current study seem to be in line with the work by Lamberts et. al (2009) who found a CV of 1.7% in a 40 km time trial performed on subjects' own bicycles attached to an electronically-braked ergometer (Computrainer, Seattle, USA). Indeed, ergometers that allow attachment of an individual's own bicycle, have been shown to produce more reliable results than stand-alone ergometers (Lamberts et al. 2011). Earnest et al. (2005) reported a CV of 8% over two time to exhaustion tests on a Lode cycle ergometer lasting ~20 min in well-trained cyclists. Also using a Lode ergometer, Jeukendrup et al. (1996) examined the reliability of a similar protocol used in the current study, with a longer test (45 min at a fixed workload followed by a 15 min time-trial) and reported a CV of 3.5% over five experimental trials in moderate to well-trained cyclists and triathletes. Similarly, Zavorsky et al. (2007) reported a CV of 3.6% over three repeated 20km time-trials performed on a Veletron cycle ergometer in 16 recreational to trained cyclists. In this study, the researchers divided their results into the top eight and bottom ten performers (based on power output), and reported CV's of 2.5% and 4.5%, respectively. These results would suggest, that the more highly-trained, the lower the chance of random error or test-retest variation.

In addition to the training status of subjects used in these studies, other factors that may attribute to higher variability in performance than shown in the current study includes the type of ergometer used and the type of test used (Paton and Hopkins 2001). As evidenced in the Earnest et al. (2005) study, tests using an "open end" point (e.g. time to fatigue tests) tend not to be as reproducible. In tests with an undefined end point, psychological factors (such as motivation and boredom) may be more likely to influence performance. Alternatively, in tests that have a known end point, like the test used in the current study, this is not as likely to have the same effect.

A novel aspect of the testing protocol used in the current study was the sub-maximal fixed workload section of the test. This may be a useful component for measuring physiological changes over time in individual athletes (e.g. blood lactate concentrations and heart rate). The CV's in the current study were 10.9% and 2.4% for blood lactate concentration and heart rate, respectively. This CV for mean heart rate was relatively low, and similar to that reported in previous cycling reliability studies (Lamberts et al. 2009; Sporer and McKenzie 2007; Zavorsky et al. 2007). While a 10.9% CV for blood lactate might seem high, it translates to a raw value of just 0.9 mmol.L-1 (95%CL: 0.7 to 1.2), which is not much outside the typical error of measurement for the lactate pro analyzer (Tanner et al. 2010). A further aspect of interest in the current test protocol used was the strong relationship between time-trial performance and VO2max variables from the test performed at the start of the study (Table 2). This is evidenced by a strong

correlation between mean power output in the 30-minute test and both VO2max (L.min-1) and peak power output (watts) in the incremental test (r = 0.86 and 0.93, respectively).

If the current test is used for monitoring changes in athletic performance, 70% of PPO would need to be regularly established by performing an incremental exercise test, which may not always be practical. For this reason, tests used for monitoring where the workload is fixed using other variables (e.g. heart rate), may be more appropriate (Lamberts et al. 2011). A further limitation of the current protocol is that the Lode cycle ergometer cannot be set up exactly the same as the subjects own bicycle, (e.g. same components, gearing, angles and dimensions) which has been suggested as a critical factor for producing reliable results (Paton and Hopkins 2001). However, the reliability of the Lode ergometer in the current study is highly comparable with studies performed on a subjects own bicycle attached to an ergometer (Lamberts et al. 2009; Palmer et al. 1996).

Smak et al. 1999 have studied the influence of the different cadences (60 to 120 rpm at the work rate of 250 W) on the pedaling symmetry. They have shown that the group of cyclists (n=11) tested has not a significant pedaling asymmetry according to the pedaling cadence. However, they indicate a high variability between the cyclists. For two cyclists the AI decreases according to the pedaling cadence and for two other cyclists the AI increases according to the pedaling cadence. In the present study the pedaling cadence has been similar during the test and thus cannot affect the AI.

Smak et al. 1999 have shown that the positive average power of the dominant leg was significantly lower than that of the non-dominant leg. They also indicated that the non-dominant leg could have a negative action (negative crank torque production) during the pedaling recovery phase. It is obvious that the pedaling asymmetry can alter the cycling performance. The cause of this asymmetry can have several explanations: 1) a coordination deficit or 2) a significant muscle atrophy on one of the limbs. The analyse of the pedaling asymmetry can be used to quantify an strength training program with the goal to increase the force of the non-dominant lower limbs if there is an muscular atrophy. This program could be performed on the bicycle using a low pedaling cadence with high power output level in the goal to generate high values of crank torque. The use of a special crank arm like the Powercranks (Powercranks, Walnut Creek, CA) could also be used. The training with this crank arm to allow independent pedal work by each leg during cycling can increase the pedalling efficiency (Luttrell and Potteiger 2003).

The traditional strength training could have also a great importance. Hansen et al. 2012 have shown that twelve weeks of heavy strength training in addition to their usual endurance training could improve the pedaling efficacy. The pedaling pattern could be improved, for example by performing exercises with feedback on the torque (Henke 1998). In this way the rider can adjust itself the asymmetry.

To help coaches and researchers to analyze and prevent the causes of the pedaling asymmetry it should be interesting to use the infrared thermography as a non-intrusive tool of investigation. This technology is useful to measure the skin temperature and may help to understand the link between an asymmetry in the pedalling process and the resulting temperature maps. Hildebrandt et al. 2010 indicated that any significant asymmetry of more than 0.7 °C can be defined as abnormal and may indicate a physiologic or anatomical variant in the loco-motor system. Reduced skin temperature has also been implicated in musculoskeletal disorder. This muscular disorder could be explained in part the cyclist asymmetry. The link between the pedaling biomechanics and the IR thermography will be tested in a further study.

Conclusion

In summary, this study is the first to show that by using a well-controlled, practical testing protocol which includes 15-minutes at 70% of PPO and a 15-minute time-trial on a Lode cycle ergometer, it is possible to detect small meaningful changes in performance in highly-trained cyclists. Although performing the test on the subjects own bicycle might further improve the reliability and lower the TEM, the Lode cycle ergometer appears to be highly reliable when it comes to stand-alone cycle ergometers, and may provide an appropriate and a more readily available alternative.

References

1. Currell K, Jeukendrup AE (2008) Validity, reliability and sensitivity of measures of sporting performance. Sports Medicine 38: 297-316
2. Driller MW, Halson SL (2012) The effects of wearing lower-body compression garments during a cycling performance test. International Journal of Sports Physiology and Performance. Published ahead of Print.
3. Earnest CP, Wharton RP, Church TS, Lucia A (2005) Reliability of the Lode Excalibur Sport Ergometer and applicability to CompuTrainer electromagnetically braked cycling training device. Journal of Strength & Conditioning Research 19: 344-348
4. Gardner AS, Stephens S, Martin DT, Lawton E, Lee H, Jenkins D (2004) Accuracy of SRM and Power Tap Power monitoring systems for bicycling. Medicine and Science in Sports and Exercise 36: 1252-1258
5. Harriss DJ, Atkinson G (2011) Update - ethical standards in sport and exercise science research. International Journal of Sports Medicine 32: 819
6. Hawley JA, Noakes TD (1992) Peak power output predicts maximal oxygen uptake and performance. European Journal of Applied Physiology 65: 79-83
7. Hoogeveen AR, Schep G, Hoogsteen J (1999) The ventilatory threshold, heart rate, and endurance performance: relationships in elite cyclists. International Journal of Sports Medicine 20: 114-117

8. Hopkins WG (1997) A new view of statistics. Will G. Hopkins
9. Hopkins WG (2000) Measures of reliability in sports medicine and science. Sports Medicine 30: 1-15
10. Jeukendrup A, Saris W, Brouns F, Kester A (1996) A new validated endurance performance test. Medicine & Science in Sports & Exercise 28: 266
11. Krebs PS, Powers SK (1989) Reliability of laboratory endurance tests. Medicine & Science in Sports & Exercise 21: S10
12. Lamberts RP, Swart J, Noakes TD, Lambert MI (2011) A novel submaximal cycle test to monitor fatigue and predict cycling performance. British Journal of Sports Medicine 45: 797-804
13. Lamberts RP, Swart J, Woolrich RW, Noakes TD, Lambert MI (2009) Measurement error associated with performance testing in well-trained cyclists; application to the precision of monitoring changes in training status. International Journal of Sports Medicine 10: 33-44
14. Laursen PB, Shing CM, Jenkins DG (2003) Reproducibility of a laboratory-based 40-km cycle time-trial on a stationary wind-trainer in highly trained cyclists. International Journal of Sports Medicine 24: 481-485
15. Lucia A, Hoyos J, Chicharro JL (2001) Physiology of professional road cycling. Sports Medicine 31: 325-337
16. Micklewright D, Papadopoulou E, Swart J, Noakes T (2010) Previous experience influences pacing during 20 km time trial cycling. British Journal of Sports Medicine 44: 952-960
17. Palmer GS, Dennis SC, Noakes TD, Hawley JA (1996) Assessment of the reproducibility of performance testing on an air-braked cycle ergometer. International Journal of Sports Medicine 17: 293-298
18. Paton CD, Hopkins WG (2001) Tests of cycling performance. Sports Medicine 31: 489-496
19. Paton CD, Hopkins WG (2006) Ergometer error and biological variation in power output in a performance test with three cycle ergometers. International Journal of Sports Medicine 27: 444-447
20. Sporer BC, McKenzie DC (2007) Reproducibility of a laboratory based 20-km time trial evaluation in competitive cyclists using the Velotron Pro ergometer. International Journal of Sports Medicine 28: 940
21. Tanner RK, Fuller KL, Ross MLR (2010) Evaluation of three portable blood lactate analysers: lactate pro, lactate scout and lactate plus. European Journal of Applied Physiology 109: 551-559
22. Vaile J, Halson S, Gill N, Dawson B (2008) Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. Journal of Sports Sciences 26: 431-440
23. Zavorsky GS, Murias JM, Gow J, Kim DJ, Poulin-Harnois C, Kubow S, Lands LC (2007) Laboratory 20-km cycle time trial reproducibility. International Journal of Sports Medicine 28: 743-748