

# Evaluation of the Cyclus ergometer and the Stages power meter against the SRM crankset for measurement of power output in cycling

Shem M Rodger<sup>1,2,3</sup>✉, Daniel J Plews<sup>1,2,4</sup>, Joe McQuillan<sup>1</sup> & Matthew W Driller<sup>1</sup>

## Abstract

The purpose of the present study was to evaluate two commercially available power meters: the Cyclus ergometer (CYC) and the Stages power meter (STA) in comparison to a highly-validated power meter (SRM). Ten trained cyclists (mean  $\pm$  SD; age  $24 \pm 8$  y, body mass  $69.7 \pm 7.3$  kg,  $VO_{2peak}$   $64.7$  ml.kg<sup>-1</sup>.min<sup>-1</sup>) performed an incremental exercise test to exhaustion (GXT), two 10-second sprints (10ST) and a 1-min all-out performance test (1minPT) on a bicycle attached to a Cyclus (CYC) cycle ergometer. The bicycle was also fitted with the SRM cranks and the STA power meter. Power output (W) for the CYC and STA for each test was compared to the SRM to determine the validity of the devices. The coefficient of variation (CV) for the STA vs SRM during the GXT was  $2.4 \pm 1.1\%$  ( $\pm 90\%$  CL) and  $2.3 \pm 0.9\%$  for the CYC vs SRM. For the 1minPT, the STA vs SRM had a CV of  $3.4 \pm 1.6\%$  and  $3.0\% \pm 1.6\%$  for CYC vs SRM. Comparison between power meters during the 10ST showed a CV of  $18.2 \pm 1.6\%$  for STA vs SRM and  $13.7 \pm 1.6\%$  for CYC vs SRM. In summary, both the CYC and STA are practical, easy to use devices and exhibit an acceptable level of agreement during low ( $< \sim 500$ W), but not high ( $> \sim 650$ W) power outputs.

**Keywords:** cycling, performance, monitoring, mobile power meter, SRM

✉ Contact email: [shemrodger@gmail.com](mailto:shemrodger@gmail.com) (SM. Rodger)

<sup>1</sup>Health, Sport and Human Performance. The University of Waikato, Hamilton, New Zealand.

<sup>2</sup>High Performance Sport New Zealand, Auckland, New Zealand

<sup>3</sup>Cycling New Zealand, Cambridge, New Zealand.

<sup>4</sup>Sports Performance Research Institute New Zealand (SPRINZ), Auckland University of Technology, Auckland, New Zealand

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## Introduction

Measures of cycling performance by sport scientists as well as coaches, in both laboratory and field settings, have led to the development of a plethora of devices aimed to monitor performance and physiology. More specifically, the measurement of power output has become a critical factor in monitoring cycling performance. Many new tools for monitoring power output in cycling both in the lab and field have entered the market, without any assessment on the reliability of these new tools. For professional cyclists, small differences in performance can determine the difference between finishing on the podium or in the minor placing's, indicating that performance changes as small as 1% in highly-trained cyclists can be meaningful (Currell and Jeukendrup 2008). Therefore the accuracy and reliability of devices to measure power is of great importance.

In the laboratory, a number of cycle ergometers have been developed and assessed, including the Velotron

(Abbiss et al. 2009), Kingcycle (Balmer et al. 2000b), Lode (Driller 2012) and Wattbike (Driller et al. 2012) ergometers. However, the limitation of many of these ergometers, is the ecological validity, given the cyclist is not using their own bike. A new product that is yet to be validated is the Cyclus ergometer (Model II, Leipzig, Germany). The design of the Cyclus ergometer allows numerous types of bicycles (road, track, mountain, time-trial) to be attached to the ergometer allowing for tests and training to be performed on an individual's own bicycle.

In the field, mobile power meters provide the ability for sport scientists and coaches to measure power and subsequently interpret the competitive characteristics of the various cycling disciplines. There are a number of commercially available mobile power meters that have also been studied extensively, employing a variety of methods of measuring power including through the crank arms, the rear hub, the pedal, the bottom bracket and through chain tension. The SRM monitoring system (Schoberer Rad Messtechnik, Jülich, Germany) is considered to be the 'gold standard' for mobile power meters, with the manufacturer claiming to have an accuracy of  $\pm 0.5\%$ . Indeed, numerous research studies have confirmed the claims that the SRM device is valid and reliable (Balmer et al. 2000b; Bertucci et al. 2005b; Gardner et al. 2004; Lawton et al. 1999). Given the accuracy of the SRM system, it has also been used as the criterion measurement to validate other ergometers and power meters (Balmer et al. 2000a;



Duc et al. 2007; Gardner et al. 2004; Kirkland et al. 2008). Some of the limitations of the SRM system are the cost and the mechanical expertise required to easily change between bikes. A relatively new product in the mobile power meter market, the Stages power meter (Stages Cycling, Boulder, USA), has aimed to alleviate limitations identified with SRM cranks, by offering a similar product at a lower price and claiming to be easier to switch between bikes. One recent study (Hurst et al. 2015) compared the STA to the SRM power meter during mountain bike field conditions. Hurst et al. (2015) found the STA to be a reliable measure of mean power, however the STA was a less reliable measure of peak values and significantly underestimated mean as well as peak power output compared to the SRM. Manufacturers of the Stages power meter claim  $\pm 2\%$  accuracy; however, they are yet to be evaluated for their accuracy in a laboratory setting.

Therefore, the aim of the current study is to compare the Cyclus ergometer and the Stages crank for monitoring power output in cyclists, with an SRM power meter in a controlled laboratory setting.

## Materials and methods

### Participants

Ten trained cyclists (mean  $\pm$  SD; age  $24 \pm 8$  y, body mass  $69.7 \pm 7.3$  kg,  $VO_{2peak}$   $64.7$  ml.kg<sup>-1</sup>.min<sup>-1</sup>) volunteered to participate in the current study. Both male (9 participants) and female (1 participant) cyclists of varying abilities were recruited in order to test the power monitoring devices through a range of different pedalling techniques and cadences. Participants provided informed consent prior to any testing taking place. The study was approved by the Institutions' Human Research Ethics committee.

### Experimental Design

The validity of the Stages power meter (STA; track model, Stages Cycling, Boulder, USA) and Cyclus ergometer (CYC; Model II, Leipzig, Germany) were compared to the SRM (SRM; wireless track, Schoberer Rad Messtechnik, Jülich, Germany) power meter in the controlled setting of a sport science laboratory ( $21 \pm 1$  °C). The protocol for testing the power measuring devices included: an incremental step test (GXT); two x 10 sec sprint tests (10ST); and a 1-min isokinetic cycle test (1minPT). Prior to the session participants were asked to refrain from strenuous exercise (<12 h prior to session) and to arrive at each session in a fully rested, hydrated state. The order of tests is shown in Figure 1. The testing battery used in the current study aimed to investigate each power meters accuracy over a range of power outputs from  $\sim 140$ -1000 W.

### Materials

The cycling frame (Avanti Pista Pro, Auckland, New Zealand) to be mounted to the CYC ergometer was initially fitted with a SRM (to derive power from the drive side) and a STA crank (to derive power from the non-drive side) for purposes of comparison. The slope of the SRM power meter was assessed prior to and following the study by static calibration (Woolles et al. 2005) and found to be identical at both time points in agreement with previous research evaluating SRM reliability (Gardner et al. 2004). The laboratory bike was adjusted to fit the individual by altering the stem length and seat height to replicate the cyclist's own bike as closely as possible. The gear ratio used for all testing was a 53 x 13; and was programmed into the ergometers settings. The CYC ergometer applies resistance according to the user input protocol through

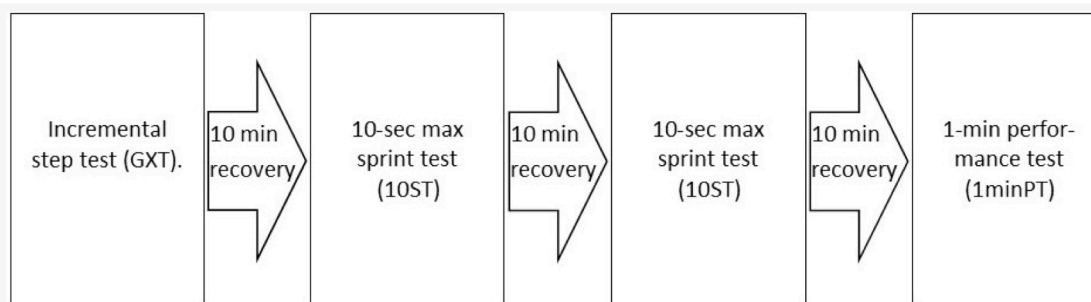


Figure 1. Order of tests performed during testing session.

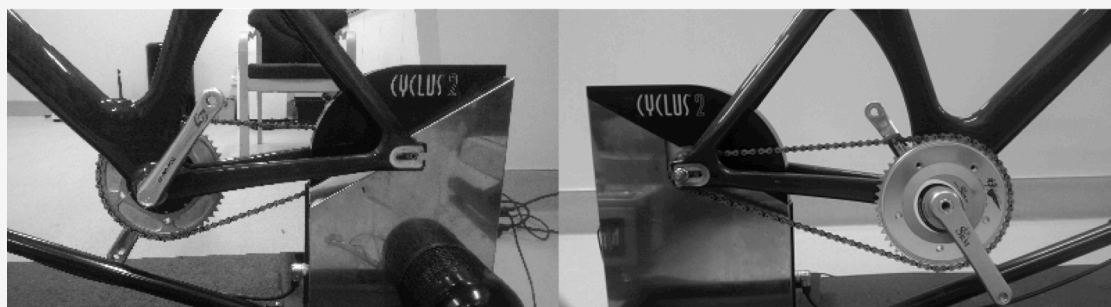


Figure 2. Experimental set-up from the non-drive side (a) and the drive side (b), for the evaluation of the Stages and Cyclus ergometers when compared with the SRM cycle ergometer.

a regenerative braking resistance mechanism (up to 3000 W), powered by a direct current motor. The STA, placed on the non-drive side, measures power from strain gauges on the crank arm; assuming a balanced bi-lateral power profile. SRM-derived power was calculated by 18 strain gauges that were located between the crank axle and the chain-ring. Before each test, calibration (“zero offset” procedure) of the SRM, and the STA were performed according to the manufacturer’s instructions. Both mobile power meter devices were paired with Garmin watches (Forerunner 910XT, Garmin, USA) for data capture at a one-sec storage interval

### Incremental GXT

Participants performed an incremental step test until volitional exhaustion (starting at 140 W and increasing by 40 W every 3 min). During the incremental test, participants were able to ride at a self-selected cadence above 70 rpm. The test was stopped when participants felt they could no longer continue, or if cadence fell below 70 rpm. Following the incremental step test, a 10-min recovery period was employed to allow the athletes to recover before performing the remaining tests.

### Max Sprint test (10ST)

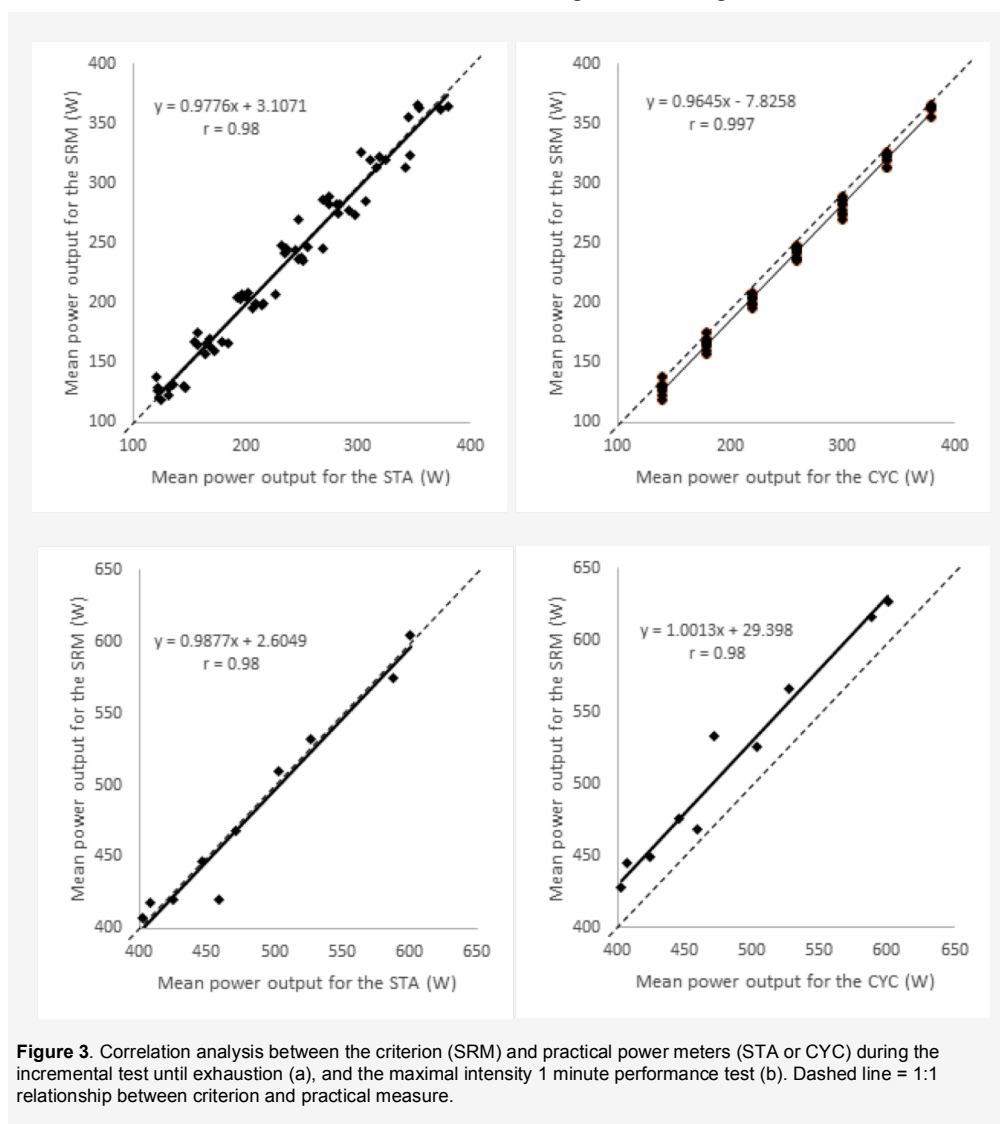
Following the 10-min recovery period, participants were required to complete 2 x 10 sec seated maximal effort sprints from a rolling start, however cadence was not controlled. We utilised the Wingate anaerobic test program on the Cyclus ergometer with the initial load applied set to 0.075 W.kg<sup>-1</sup> of participant’s body mass. To reduce the technological limitations of the devices sensor response latency, the 10ST began when participants increased their cadence above 70 rpm as determined by the CYC ergometer. A three-min recovery period was used between the two sprints. Upon completion of the second sprint, participants recovered for a period of 5-min prior to the next assessment.

### 1-minute Performance Test (1minPT)

The 1minPT was performed using the isokinetic maximum strength test protocol on the Cyclus ergometer where the cadence was set at 100 rpm for the duration of the test. Participants were instructed to ride the 1minPT at a maximal intensity and the Cyclus ergometer either increased or decreased resistance to ensure cadence remained ~100 rpm.

### Statistical analysis

Data is presented as mean ± SD unless stated otherwise. Comparison of the SRM with the CYC and STA was achieved through calculating the typical error of estimate (TE) ±90% confidence limits. Due to the heteroscedastic nature of power output, the data were log-transformed and the agreement between the power monitors under investigation was determined using an excel spreadsheet for validity (Hopkins 2015), and is expressed both in raw units (W) and as a coefficient of variation (CV) %. The SRM was set as the criterion measure, with the STA and CYC as the practical measures in the spreadsheet. While correlation analysis indicates the degree to which two variables are associated, it does not necessarily indicate the extent to which values agree or disagree. To overcome this



**Figure 3.** Correlation analysis between the criterion (SRM) and practical power meters (STA or CYC) during the incremental test until exhaustion (a), and the maximal intensity 1 minute performance test (b). Dashed line = 1:1 relationship between criterion and practical measure.

limitation, the approach of quantifying the level of agreement between the different power monitors measuring the same parameter (in this case power output) was employed (Altman and Bland 1983; Atkinson and Nevill 1998). The mean bias between methods  $\pm$  random error ( $\pm 2$  standard deviations or 95% of a normally distributed population) was determined (Bertucci 2012).

## Results

On average, the STA measured  $2.2 \pm 13.9$  W higher than the SRM over the duration of the GXT, whereas the CYC measured  $16.9 \pm 4.9$  W (mean  $\pm$  SD) higher than the SRM. When compared to SRM during the GXT, the CV for the STA was  $2.4 \pm 1.1\%$  ( $\pm 90\%$  CL) and the CYC was  $2.3 \pm 0.9\%$  (Table 1, Figure 3). Mean cadence over the entire GXT was  $93 \pm 7$  rpm for the SRM,  $93 \pm 7$  rpm for the STA and  $93 \pm 8$  for CYC. The TE for cadence was  $1.9 \pm 1.2\%$  (rpm  $\pm 90\%$  CL) and CV,  $2.2 \pm 1.6\%$  (%  $\pm 90\%$  CL) for the STA compared to the SRM. Similarly, the cadence for the CYC compared to the SRM, demonstrated a TE of  $0.1 \pm 1.2$  (rpm  $\pm 90\%$  CL) and CV of  $0.7 \pm 1.6$  (%  $\pm 90\%$  CL).

Mean power across the 10ST sprints was  $703 \pm 132$  W for the SRM,  $725 \pm 94$  W for the STA and  $656 \pm 90$  W

for the CYC. Analysis of the average power for the 10ST (Table 2) identified a CV of  $21.9 \pm 1.4\%$  for the STA and  $16.0 \pm 1.4\%$  for the CYC, compared to the SRM.

Average power was considerably higher for the CYC ( $513 \pm 72$  W) compared to both the STA ( $480 \pm 71$  W) and SRM ( $483 \pm 71$  W) for the 1minPT (Table 2). When compared to SRM for average power during the 1minPT, STA had a CV of  $3.4 \pm 1.6\%$  and CYC had a CV of  $3.0 \pm 1.6\%$ .

## Discussion

The results from the current study highlight that both the Stages power meter and the Cyclus ergometer are more accurate during longer, less intense cycling efforts than short sprint efforts, when compared to the SRM power meter. At lower intensities ( $<500$ W) the reproducibility of bias that exists between the STA and CYC in comparison to the SRM is acceptable, therefore these power meters could be used to make relative comparisons with cyclists. This is evident through relatively accurate average power output during both the incremental step test ( $<5\%$  CV) and 1 min maximal performance test ( $<4\%$  CV), as opposed to the 10 sec sprint test which show higher variations in power

**Table 1.** Analysis between power meters during an incremental test until exhaustion (GXT). Mean differences ( $\pm$  SD), range of mean differences ( $\pm$  2SD), typical error of estimate (TE  $\pm 90\%$ CL) and coefficient of variation (CV%  $\pm 90\%$  CL) are shown for all comparisons between SRM power meter and both Stages power meter (STA) and Cyclus cycle ergometer (CYC).

	SRM power output (Watts)	Mean difference $\pm$ SD		Range of mean difference ( $\pm$ 2SD)		TE (W $\pm 90\%$ CL)		CV (% $\pm 90\%$ CL)	
		SRM vs STA	SRM vs CYC	SRM vs STA	SRM vs CYC	SRM vs STA	SRM vs CYC	SRM vs STA	SRM vs CYC
		Step 1	$129 \pm 5$	$2.2 \pm 10.6$	$11.2 \pm 5.2$	-19.0 to 23.5	0.8 to 21.6	$5.6 \pm 1.5$	$4.7 \pm 1.5$
Step 2	$170 \pm 5$	$1.1 \pm 11.5$	$14.2 \pm 5.0$	-22.0 to 24.2	4.2 to 24.2	$5.3 \pm 1.5$	$5.3 \pm 1.5$	$3.2 \pm 1.6$	$3.2 \pm 1.6$
Step 3	$203 \pm 4$	$3.3 \pm 12.2$	$17.2 \pm 4.3$	-21.0 to 27.6	8.6 to 25.8	$4.4 \pm 1.5$	$3.8 \pm 1.5$	$2.2 \pm 1.6$	$1.9 \pm 1.6$
Step 4	$242 \pm 5$	$3.5 \pm 12.8$	$17.7 \pm 4.5$	-22.1 to 29.1	8.7 to 26.7	$4.8 \pm 1.5$	$4.2 \pm 1.5$	$2.0 \pm 1.6$	$1.8 \pm 1.6$
Step 5	$280 \pm 6$	$0.7 \pm 16.2$	$19.7 \pm 6.2$	-31.7 to 33.1	7.3 to 32.1	$6.4 \pm 1.5$	$6.2 \pm 1.5$	$2.3 \pm 1.6$	$2.3 \pm 1.6$
Step 6*	$314 \pm 18$	$4.9 \pm 16.8$	$19.9 \pm 4.9$	-28.8 to 38.5	10.2 to 29.7	$5.2 \pm 1.3$	$4.5 \pm 1.8$	$1.6 \pm 1.8$	$1.6 \pm 1.8$
Step 7**	$362 \pm 4$	$-0.6 \pm 13.6$	$18.1 \pm 3.9$	-27.9 to 26.7	10.3 to 25.9	$4.0 \pm 2.2$	$4.5 \pm 2.2$	$1.1 \pm 2.2$	$1.3 \pm 2.2$
Mean	-	$2.2 \pm 13.9$	$16.9 \pm 4.9$	-	-	$5.1 \pm 0.8$	$4.7 \pm 0.8$	$2.4 \pm 1.1$	$2.3 \pm 0.9$

\* Step 6 data from 8 participants. \*\* Step 7 data from 5 participants. 'Steps', as determined by the Cyclus.

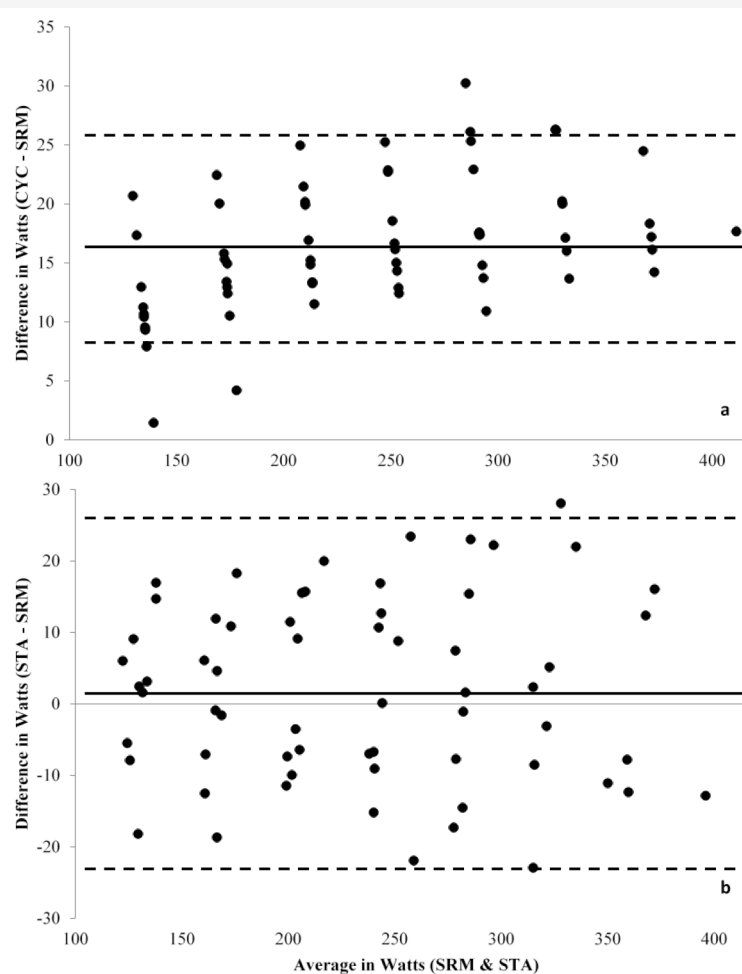
**Table 2:** Analysis between power meters during a 1 min maximal performance test (1minPT) and a 10 sec maximal sprint test (10ST). Mean differences ( $\pm$  SD), range of mean differences ( $\pm 2$  SD), typical error of estimate (TE  $\pm 90\%$  CL) and coefficient of variation (CV%  $\pm 90\%$  CL) are shown for all comparisons between SRM power meter and both Stages power meter (STA) and Cyclus cycle ergometer (CYC).

	SRM power output (Watts)	Mean difference $\pm$ SD		Range of mean difference ( $\pm$ 2SD)		TE ( $\pm 90\%$ CL)		CV (% $\pm 90\%$ CL)	
		SRM vs STA	SRM vs CYC	SRM vs STA	SRM vs CYC	SRM vs STA	SRM vs CYC	SRM vs STA	SRM vs CYC
10ST, mean power (W)	$703 \pm 132$	$-46.9 \pm 142.3$	$22.1 \pm 91.3$	-331.5 to 237.7	-160.5 to 204.8	$132.4 \pm 1.3$	$94.0 \pm 1.3$	$21.9 \pm 1.4\%$	$16.0 \pm 1.4\%$
10ST, peak power (W)	$864 \pm 160$	$-26.2 \pm 65.9$	$-34.7 \pm 205.9$	-158.0 to 105.6	-446 to 377.1	$67.6 \pm 1.3$	$164.5 \pm 1.3$	$9.1 \pm 1.4\%$	$22.2 \pm 1.4\%$
10ST, mean cadence (W)	$138 \pm 13$	$-23.5 \pm 28.8$	$0.8 \pm 6.3$	-81.0 to 34.1	-11.8 to 13.5	$10.5 \pm 1.3$	$6.1 \pm 1.3$	$9.2 \pm 1.3\%$	$5.3 \pm 1.3\%$
1minPT (W)	$483 \pm 71$	$-3.3 \pm 14.2$	$30.0 \pm 13.7$	-31.7 to 25.1	2.7 to 57.4	$14.9 \pm 1.5$	$14.2 \pm 1.5$	$3.4 \pm 1.6\%$	$3.0 \pm 1.6\%$
1minPT, Cadence (RPM)	$100 \pm 5$	$0.4 \pm 2.7$	$1.2 \pm 2.2$	-5.0 to 5.7	-3.3 to 5.7	$2.7 \pm 1.5$	$2.2 \pm 1.5$	$2.9 \pm 1.6\%$	$2.4 \pm 1.6\%$

comparisons to the SRM (>15% CV).

The performance time of top cyclists from race to race can typically vary by 0.4 to 2.6%, depending on the type of event (Paton and Hopkins 2006). Therefore, a power meter must possess enough precision to monitor small variations in performance in order to enhance athlete monitoring. Both the STA and CYC manufacturers claim that the accuracy of their products falls within  $\pm 2\%$  accuracy. Our study resulted in CV's of  $2.4 \pm 1.1\%$  and  $2.3 \pm 0.9\%$  for STA and CYC, respectively, during the GXT. While this falls slightly outside the manufacturers claims, Lawton et al. (1999) reported that SRM power meters (4-strain gauge models) had errors of up to 2.5% at certain power outputs when compared to a dynamic calibration rig. Indeed, it has been suggested that a CV of <5% is acceptable for power meters (Van Praagh et al. 1992). The agreement between the STA and the CYC when compared to the SRM, decreased as the duration of the test shortened, and the intensity increased (Table 2). Our results suggest that the use of both power meters for testing performance during maximal intensity sprint tests (such as the 10ST) may need to be reconsidered due to the large typical error when compared to the SRM. However, to the author's knowledge, the SRM itself is yet to be validated over a 10-second sprint and therefore, the use of the SRM as the gold standard measure for this test may not be entirely accurate. Interestingly, the STA reported inaccurate cadence measures during the maximal sprint test that were far lower than the SRM. Similarly, recent research using a mountain bike equipped with both a STA and SRM power meter found a CV of 5.5% for the STA compared to the SRM during an off-road climb of ~1.5 km (Hurst et al. 2015). However in similar findings to ours the CV increased to 13.7% when the intensity increased as measured from the difference in peak power between the STA and SRM over twelve trials. The authors concluded that the STA system significantly underestimated mean and peak power output when compared with the SRM system. It was postulated that the discrepancies may in part be due to differences in strain gauge configuration and the subsequent algorithms used for the calculation of power output and the potential bilateral influences on power output production. A known limitation of the STA power meter is that inaccurate power values will be displayed when a left-right force production imbalance is present as the STA power meter multiplies cadence and torque together to determine the power of a single pedal

stroke. Indeed, the closer agreement in peak power ( $9.1 \pm 1.4\%$ ) compared to average power ( $19.7 \pm 1.4\%$ ) agrees with the findings by Hurst et al. (2015) in regards to the inaccuracies faced by the STA to measure peak powers. These inaccuracies may also be due to technological limitations of the devices and their sensor response latency. The authors attempted to minimise the possibility of such confounding factors through a rolling start (70rpm), however, it is possible that the power monitoring devices may not have been able to respond quick enough during the 10ST. Similarly, the smoothing algorithm may not have been able to respond fast enough to provide accurate results. Previous research performed on other cycling power meters allows the comparison of the STA power meter and CYC ergometer relative to other power monitoring devices. Due to the mobility of the STA, the power meter has a different target market to that of the CYC. Therefore the STA is compared with similar power meters that can be attached to a bicycle and ridden in the field during both training and racing. Reliability studies by Bertucci et al. (2005b) as well as research by Duc et al. (2007) demonstrated the PowerTap hub system to have a CV of 1.8% and 2.1%, respectively. These CV values were attained in a similar incremental



**Figure 4.** The level of agreement plots (Bland-Altman) showing 95% limits of agreement (represented as dashed lines) between a) SRM vs CYC and; b) SRM vs STA. Solid black line represents the mean bias between methods.



step test protocol (100 to 420 W) to that seen in our study and are lower (and therefore suggest greater reliability) than those recorded by the STA. Similarly, Millet et al. (2003) found the Polar S710 to have a CV of 2.2% using an in-field test, where subjects were asked to ride at 75% peak power output (as determined from an incremental test until exhaustion) for 6 min uphill. However issues have been identified with the Polar S710 with regards to accuracy during intense intermittent exercise (Hurst and Atkins 2006) and performance quantification during downhill cycling potentially related to chain vibration, chain tension, and time interval sampling rates (Gordon et al. 2007). Similarly, the Ergomo Pro revealed a CV of 4.1% and indicates a less reliable measure of power when assessed using an incremental step test (from 100 to 420 W) (Duc et al. 2007).

Due to the ever increasing competition and accuracy of in-field power meters, there is a need for stationary ergometers to be extremely accurate to suffice their cost and inflexibility in regards to riding environments. In comparison to other fixed ergometers, the CYC compared to the Wattbike ergometer demonstrated a CV of 2.6% when assessed against the SRM in a submaximal incremental test between 150 and 300W (Hopker et al. 2010). Research by Balmer et al. (2000b) demonstrated the CV of the Kingcycle for peak power to be 2.0% (where peak power output was around 430 W and calculated as the highest average power during any 60-s period of the test). The CV value alluded to for the Kingcycle was attained with the addition of a stabilization kit that aims to minimize the changes in resistance between the tire of the bicycle rear wheel and the roller of the air-braked flywheel. Without the stabilization kit, the CV of the Kingcycle for peak power was 4.7%. The Axiom PowerTrain cycling ergometer has also been assessed for reliability against an SRM during an incremental test between around 130 and 400W (Bertucci et al. 2005a). It was found that the mean CV in power output for all of the increments was 2.2% indicating that the Axiom provides a more reliable measure of power than the Cyclus. From the analysis between power monitoring devices, it is evident that mobile power meters with the ability to be used in the field can be reliable, therefore the need for fixed ergometers has become negligible to assess a cyclist's performance.

In conclusion the current study is the first to evaluate the accuracy of the Stages power meter and the Cyclus ergometer in a laboratory setting. Both methods of measuring power output are accurate during longer, less intense (<500 W) cycling efforts. At these intensities the accuracy is acceptable, therefore these power meters could be used to make relative comparisons both within and between cyclists. What is limited in both devices is their accuracy during short sprints (< around 10 sec). Therefore care should be taken when using these power monitoring tools to test short, high-intensity efforts. Future studies should evaluate the validity of both the STA power meter and CYC ergometer by comparing it with a dynamic

calibration rig in order to confirm the findings from the current study. Further focus on the influence of pedalling cadence with no change in power output and the potential drift of power during longer durations (>21 min) should also be considered.

### Practical application

The CYC and STA are reliable measures of power output for durations longer or ~1 min and at intensities less than ~500 W. Both power monitoring devices are less accurate during cycling efforts less than ~10 sec. Future research should determine whether the inaccurate power measures witnessed by both devices during the 10 sec maximal sprint stem from short maximal accelerations or higher powers.

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### Conflict of interest

The authors declare that they have no conflict of interest.

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