Validity and Reliability of the PowerTap Mobile Cycling Powermeter when Compared with the SRM Device

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Abstract

The SRM power measuring crank system is nowadays a popular device for cycling power output (PO) measurements in the field and in laboratories. The PowerTap (CycleOps, Madison, USA) is a more recent and less well-known device that allows mobile PO measurements of cycling via the rear wheel hub. The aim of this study is to test the validity and reliability of the PowerTap by comparing it with the most accurate (i.e. the scientific model) of the SRM system. The validity of the PowerTap is tested during i) sub-maximal incremental intensities (ranging from 100 to 420 W) on a treadmill with different pedalling cadences (45 to 120 rpm) and cycling positions (standing and seated) on different grades, ii) a continuous sub-maximal intensity lasting 30 min, iii) a maximal intensity (8-s sprint), and iiii) real road cycling. The reliability is assessed by repeating ten times the sub-maximal incremental and continuous tests. The results show a good validity of the PowerTap during sub-maximal intensities between 100 and 450 W (mean PO difference −1.2 ± 1.3 %) when it is compared to the scientific SRM model, but less validity for the maximal PO during sprint exercise, where the validity appears to depend on the gear ratio. The reliability of the PowerTap during the sub-maximal intensities is similar to the scientific SRM model (the coefficient of variation is respectively 0.9 to 2.9 % and 0.7 to 2.1 % for PowerTap and SRM). The PowerTap must be considered as a suitable device for PO measurements during sub-maximal real road cycling and in sub-maximal laboratory tests.

Key words
Cycling · mobile powermeter · SRM system · power output · comparison

Introduction

In the last decade several mobile cycling powermeters (e.g. SRM, Max One, Polar S710, PowerTap, Ergomo) have become available for use by cyclists, trainers, and coaches. Mobile cycling powermeters have two important advantages compared to the traditional stationary bicycle ergometers used in laboratories. At first, they can be used for real (off-)road and track cycling power output (PO) measurements during training and competitions, as well as for PO measurements during laboratory testing. Secondly, the cyclist is able to ride his own bicycle during laboratory testing. This avoids positional adjustment problems that often happen when stationary ergometers (e.g. the Monark or Lode ergometers) are being used.

Like stationary ergometers, mobile powermeters have to provide a valid and reliable PO. Some mobile cycling powermeters have been studied for their validity and reliability (e.g. SRM [10,12,13], Max One [6], and Polar S710 [15]), whereas others have, until now, not yet been studied (e.g. PowerTap and Ergomo). Both the Max One (Look, Nevers, France) and Polar S710 (Polar Electro, Kempele, Finland) devices appear invalid, how-

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Bibliography
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ever both appear to be reliable. The SRM system (SRM, Jülich, Welldorf, Germany) obtain the best validation results, because its PO measurement appear valid and reliable. The SRM system is a crankset that continuously measures PO from torque and angular velocity. The torque is calculated by strain gauges (4, 8, and 20 strain gauges for respectively the "amateur", "professional", and "scientific" model) which are located between the crank axle and the chain-ring. Their deformation is proportional to the torque generated by each pedal revolution. Paton and Hopkins [18] declared in their review on stationary ergometers and mobile cycle powermeters that the SRM system appeared to be the best device for monitoring changes in the performance of a cyclist, due to its negligible error in its PO measurements. Since successful professional cyclists started to use the SRM system some years ago, it has become a well-known training-tool for elite cyclists. The SRM system has also recently been used as a reference system to validate other ergometers like the Polar S710 [15] and the Axiom PowerTrain ergometer [2].

The PowerTap (CycleOps, Madisson, USA) is a less known mobile cycling powermeter that measures the PO with strain gauges localised in the hub of the rear wheel. As far as we know, the validity and reliability of the PowerTap have not been studied yet.

Thus the aim of this study is to assess the validity and reliability of the PowerTap power output (PO_{PT}) by comparing it with the SRM power output (PO_{SRM}) of the high accurate scientific model (20 strain gauges). The validation procedure is performed by cycling at a great range of exercise intensities (100 to 1000 W) with different pedalling cadences (45 to 120 rpm), cycling conditions (level ground cycling, uphill cycling, and sprinting), and cycling positions (seated and standing uphill cycling) in the laboratory (on a large treadmill and on an Axiom ergometer) and in the field.

Materials and Methods

Subjects

A national level male competitive cyclist (age: 25 years old, height: 1.80 m, body mass: 74 kg) volunteered as subject for this study. Prior to testing and after having received full explanation concerning the nature and purpose of the study, the subject gave written informed consent. The study was approved by the ethics committee of the institute. Before participating, the subject underwent several habituation sessions in order to familiarise with the testing procedure.

Instrumentation

All testing sessions were performed with the same road racing bicycle that was equipped with clipless pedals. The bicycle tyre pressure was inflated to 700 kPa and the chain was well lubricated. The bicycle was fitted with a SRM crankset comprising 20 strain gauges (the scientific model) and the rear wheel was equipped with the PowerTap hub (the professional model).

The PowerTap system uses similar strain gauge technology (8 gauges) as the SRM to measure the produced torque, whereas the PowerTap measures torque at the hub. Since PowerTap measures torque at the rear hub, it needs to measure the angular velocity at the same point. Angular velocity is measured with a sensor in the hub that marks each revolution of the hub relative to a receiver mounted on the seat stay. Unlike the SRM that uses magnetic induction to transmit the data from the measuring crank to the hard-wired powercontrol (screen display), the PowerTap uses a radio frequency signal to transmit the torque and angular velocity data from the hub to this seat stay receiver, which is hard-wired to the powercontrol.

Protocols

The validity and reliability of the PowerTap were investigated in the laboratory at sub-maximal and maximal intensities during three experimental protocols, which included i) a sub-maximal incremental test, ii) a sub-maximal 30-min continuous test, and iii) a sprint test. The incremental and continuous sub-maximal tests were performed on a large treadmill (S 1830, HEF Tecmachine, Andrézieux-Bouthéon, France) of 1.8 m wide and 3.8 m length, whereas the sprint tests were performed on an Axiom PowerTrain ergometer (Elite, Fontaniva, Italy), which has recently been described by Bertucci et al. [3]. The subject performed the three protocols on the same day and repeated all protocols 10 times on 10 different days during a 12-d period. At least 1 h separated each protocol for the instrumentation to cool and the temperature in the laboratory was maintained at a constant 20 °C during all tests. One extra test was performed in the field to study the overall validity of the PowerTap.

Before each test, the SRM and the PowerTap were "calibrated" according to the manufacturer's recommendations, i.e. the zero power offset was reset, although the setting of the zero offset does not substitute for a standardized calibration. However, the standardized calibration rig (i.e. the resetting of the SRM "frequency versus torque" slope) was performed just a few days before our first testday by the SRM manufacturer in Germany and resulted in an accuracy of ± 0.5 % (the manufacturer's proclamation). The PO_{PT}, the PO_{SRM}, the velocity, and the pedalling cadence were stored every 1 s in the laboratory and every 5 s in the field.

Sub-maximal incremental test

A sub-maximal incremental test was performed that consisted of trials on a large treadmill with 0, 2, 4, and 6 % slopes. On each slope, the pedalling cadence effect on PO was tested with three different gear ratios (39/15, 39/19, and 39/23) and two velocities (15 and 25 km/h). The combinations of these velocities and gear ratios resulted in six different pedalling cadences (45, 60, 75, 80, 100, and 123 rpm). All the trials were performed in seated position, and the three trials with a 6 % slope and a speed of 15 km/h were also performed in standing position. This enabled the comparison between the seated and standing position and the testing of the position and pedalling cadence effects on PO. Thus, the cyclist rode successively (without stopping to pedal) these 27 different trials (4 slopes + 3 cadences + 2 velocities + standing position at 6 % and 15 km/h), each trial lasting 1 minute. The 27 trials were randomized during each of the 10 sub-maximal incremental tests performed.

Sub-maximal continuous test

To test the PowerTap validity across time, a 30-min continuous exercise test was performed at 25 km/h on a 2 % slope with a gear ration of 39/15 (80 rpm).

Every day, before the first test, the subject's body mass was measured to avoid its influence on the PO during the sub-maximal incremental and continuous tests that were performed on an inclined treadmill. A slight change in subject mass would have changed the PO required to maintain the cyclist stationary on the treadmill. Changes in body mass were corrected by adding or removing water from two bottles in the bottlecages of the racing bicycle.

Sprint test

The sprint test consisted of three different 8-s sprint trials in seated position to determine maximal PO (PO_{max}). The three sprint trials were performed with three different gear ratios (low, middle, and high gear ratios of 39/23, 39/17, and 39/14, respectively) to test the validity of the PowerTap PO_{max} with different pedalling cadences. The method of the experimental sprint test has recently been reported by Bertucci et al. [3]. During these sprint tests the race bicycle was mounted on a computerized Axiom ergometer. The rear wheel of the bicycle was fixed to the rear wheel quick release skewer in the stand of the ergometer. This stand restrains a lot the lateral motion of the rear wheel. After each sprint test there was a 5-min active recovery period at low intensity (~ 150 W). The PO_{max} was defined as the maximal PO value obtained in each sprint.

Field test

The field test consisted of a 3-h real road cycling session on hilly ground in cold weather (5 °C) and included the different laboratorial experimental conditions (seated and standing positions, different pedalling cadences, different slopes).

Statistics

The PO_{PT}, PO_{SRM}, and pedalling cadence of the sub-maximal incremental test were averaged every 1 min to obtain the mean PO_{PT}, PO_{SRM}, and pedalling cadence for each condition. However, PO_{PT} and PO_{SRM} showed large variability (high SD values) at 0% treadmill grades (PO < 100 W) caused by the subject freewheeling in the trials in order to stop them from riding off the front of the treadmill. Thus the data of the trials at 0% gradient were not included in the statistical analysis. PO data of the sub-maximal continuous test and the field test were averaged over the whole test duration to obtain the mean PO_{PT} and PO_{SRM}. Moreover, the PO data of the sub-maximal continuous test were averaged every 5 minutes to examine the PO drift. Spearman's correlation coefficient (r) was used to determine the degree of association between PO_{PT} and PO_{SRM} during the ten sub-maximal incremental tests. The data of the submaximal incremental tests were checked on heteroscedasticity by calculating the heteroscedasticity correlation between 1) the absolute differences between PO_{PT} and PO_{SRM} and 2) the mean PO as described by Atkinson and Nevill [1]. Although this analysis showed that heterscedasticity was not present, the data were logarithmically transformed according to the recommendations of Nevill [16] and Nevill and Atkinson [17]. The 95% levels of agreement of the PO differences between the SRM and the PowerTap of the sub-maximal incremental test (only seated conditions) were defined using the method of Bland and Altman [2]. The PO differences were drawn in relation to the mean values and 95% of the differences were expected to lie between the two "limits of agreement" which were mean difference ± 2 standard deviation (SD) of the differences, expressed as bias ± random error according to Atkinson and Nevill [1]. 95% confidence interval (95%CI) for the bias were also calculated.

The data of the four protocols were tested for normality and homogeneity of variance and turned out to be not normally distributed. Thus, the analysis of differences between i) the mean PO_{PT} and the mean PO_{SRM} of the sub-maximal incremental test, ii) the mean PO_{PT} and the mean PO_{SRM} of the 30-min sub-maximal continuous test, and iii) the PowerTap and SRM PO_{max} during the sprint tests were assessed with paired (non parametric) Wilcoxon tests. Pedalling cadence and cycling position effects on PO_{PT} and PO_{SRM} during the sub-maximal incremental exercise test were evaluated with a non parametric two-way (pedalling cadence and cycling position) repeated measures test (Friedman). Time effects during the 30-min test for PO_{PT} and PO_{SRM} were evaluated with a non parametric one-way (time) repeated measures test (Friedman). A pairwise multiple comparison procedure using Tukey test was conducted to determine the significant differences between PO_{PT} and PO_{SRM} according to the time intervals.

To assess the reliability of the PowerTap, the mean coefficient of variation (CV) of the sub-maximal incremental (for every condition) and continuous tests were calculated according to the mean PO_{PT} and PO_{SRM} determined from the 10 experimental protocols. CV were calculated as the standard to mean deviation ratio, multiplied by 100. A significant difference were set at $p < 0.05$. Data were presented as mean values ± SD.

Results

Validity

There was a strong correlation ($PO_{PT} = 0.9888 \cdot PO_{SRM}$, $r = 0.99$, $p < 0.001$) between the PO_{PT} and the PO_{SRM} measured during the sub-maximal incremental exercise test (100 to 420 W). Fig. **1** shows plot of the predicted PO_{PT} values against their residuals. The ratio limits of agreement of the PO differences between the two systems were $1.013 \times\div 1.026$ (95%CI = 0.987 – 1.053). The mean bias between PO_{SRM} and PO_{PT} was 2.9 ± 3.3 W. Averaging the PO from 2 to 6% grades (100 to 420 W) determined a 1.2 ± 1.3% lower PO_{PT} compared with the PO_{SRM} (241.3 ± 101.2 vs. 238.4 ± 100.6 W, respectively). The Friedman test showed that pedalling cadence and cycling position had no effect on the PO_{PT} and PO_{SRM} (p = 0.146 and p = 0.102, respectively). For the three pedalling cadences (47.7, 60.4, and 73.2 rpm), PO_{PT} during stand-

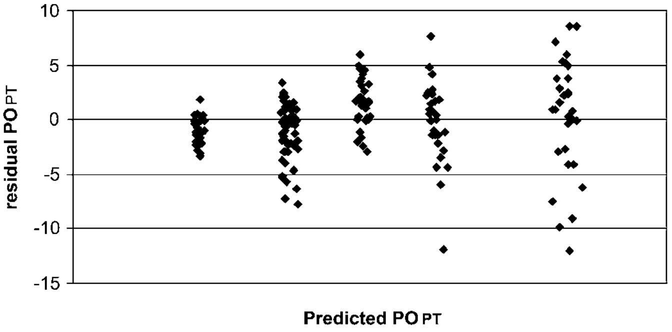

Fig. **1** Plot of predicted PO_{PT} values against their residuals during the sub-maximal incremental exercise test.

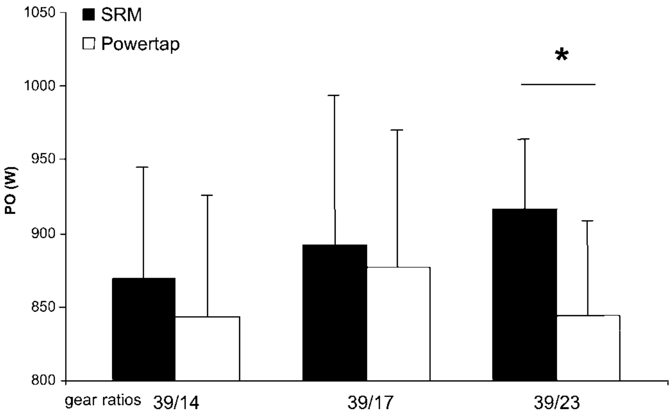

Fig. 2 SRM and PowerTap PO_{max} during maximal exercise tests with high, middle, and low gear ratios.

ing position were not significantly different when compared with PO_{SRM} during seated position ($p = 0.447$, $p = 0.403$, and $p = 0.157$, for each pedalling cadence, respectively).

There was no significant difference ($p = 0.170$) between the mean PO_{SRM} and PO_{PT} during the 30-min continuous tests (187.3 ± 4.4 vs. 184.0 ± 4.6 W, respectively). The Friedman test revealed that time had no effect on the PO_{PT} and PO_{SRM} ($p = 0.735$).

The PowerTap PO_{max} during the sprint test with low gear ratio (39/23) was significantly ($p = 0.016$) lower (8%) compared with the SRM PO_{max} (Fig. **2**). However, there were no significant differences in PO_{max} when cycling with high (39/14) and middle gear ratios (39/17) ($p = 0.173$ and $p = 0.153$, respectively). The pedalling cadences at PO_{max} with the low, middle, and high gear ratios were 149.2 ± 5.3 rpm, 113.5 ± 5.4 rpm, and 93.6 ± 4.6 rpm, respectively.

The field test gave similar mean PO of the two devices ($PO_{PT} = 140.2 \pm 85.3$ W, CV = 61% vs. $PO_{SRM} = 144.6 \pm 83.8$ W, CV = 58%). The PO_{PT} underestimated the PO_{SRM} by 2.7%, but this difference was not significant ($p = 0.116$).

Reliability

The resulting mean CVs for the sub-maximal incremental tests are given in Table **1**. For all 10 incremental tests the mean CV at 2% (100 to 190 W), 4% (180 to 310 W), and 6% grade (245 to 420 W) were 2.7% vs. 2.0%, 1.2% vs. 1.2%, and 1.7% vs. 1.4% for PO_{PT} and PO_{SRM}, respectively. The overall mean CV between 2 to 6% grade was 1.8 vs. 1.5% for PO_{PT} and PO_{SRM}, respectively. For all the 10 trials of the 30-min sub-maximal continuous test, the mean CV was 1.5% and 1.7% for PO_{PT} and PO_{SRM}, respectively.

Table **1** Mean PO_{SRM} and PO_{PT} and CV at different grades, velocities, and pedalling cadences during the sub-maximal incremental exercise test on a treadmill

Grade (%)		*Velocities (km/h)*	*Pedalling cadence (rpm)*	*Mean PO_{SRM} (W)*	*Mean PO_{PT} (W)*	*SRM CV (%)*	*PowerTap CV (%)*
Seated	2	15	47.5 ± 0.3	106.6 ± 2.3	104.8 ± 2.7	2.1	2.6
			60.1 ± 0.1	107.0 ± 2.4	104.8 ± 2.9	2.3	2.8
			73.0 ± 0.1	108.0 ± 2.0	105.0 ± 2.2	1.8	2.1
	2	25	80.1 ± 0.1	184.8 ± 3.6	181.6 ± 5.3	1.9	2.9
			101.7 ± 0.3	186.1 ± 3.6	182.6 ± 4.8	1.9	2.7
			123.1 ± 0.3	188.1 ± 3.9	183.5 ± 5.4	2.1	2.9
	4	15	47.7 ± 0.2	179.0 ± 1.7	177.5 ± 2.3	1	1.3
			60.3 ± 0.3	180.0 ± 1.2	177.8 ± 1.9	0.7	1.1
			73.2 ± 0.3	180.3 ± 1.4	177.3 ± 2.5	0.8	1.4
	4	25	80.3 ± 0.3	306.5 ± 4.6	303.9 ± 2.8	1.5	0.9
			101.9 ± 0.3	307.7 ± 4.2	304.5 ± 3.2	1.4	1.1
			123.4 ± 0.3	310.3 ± 5.2	305.4 ± 3.9	1.7	1.3
	6	15	47.8 ± 0.1	245.6 ± 2.7	245.8 ± 3.2	1.1	1.3
			60.4 ± 0.2	247.1 ± 3.3	246.3 ± 3.9	1.4	1.5
			73.3 ± 0.3	247.6 ± 3.5	244.6 ± 3.9	1.4	1.6
	6	25	80.3 ± 0.3	417.5 ± 6.7	415.3 ± 9.8	1.6	2.4
			102.0 ± 0.1	419.1 ± 5.1	416.1 ± 8.0	1.3	1.9
			123.5 ± 0.3	421.9 ± 6.8	413.8 ± 6.2	1.6	1.5
Standing	6	15	47.7 ± 0.2	246.7 ± 3.5	245.5 ± 3.3	1.4	1.3
			60.4 ± 0.2	248.6 ± 3.0	247.2 ± 3.7	1.2	1.5
			73.2 ± 0.2	251.1 ± 4.1	248.3 ± 4.0	1.6	1.6
Mean						1.5 ± 0.4	1.8 ± 0.6
Confident Interval ($p < 0.05$):						1.7 – 1.3	2.1 – 1.5

No significant difference was observed betwean Mean PO_{SRM} and Mean PO_{PT} ($p < 0.05$)

Discussion

The purpose of this study was to test the validity and the reliability of a new device, the PowerTap that measures PO during real (off-)road and track cycling. The most important finding of this study is that the PO_{PT} appears to provide a valid and reliable PO measurement at sub-maximal intensities when comparing it with the SRM device (the scientific model).

Validity

Sub-maximal exercise

First of all, although the validity results make it tempting to presume that the PowerTap provides a valid PO, one has to consider that the SRM cranks were recently calibrated (by the SRM manufacturer) using a first principle device as has been recommended by Lawton et al. [12] and Paton and Hopkins [18]. Supposing that the claimed accuracy (± 0.5 %) of the SRM scientific model is correct, our results indicate that the PowerTap has an accuracy of ± 2 – 3 % for PO between 100 and 420 W. It slightly exceeds the manufacturer's claimed accuracy of ± 1.5 %. However, pedalling cadence and cycling position (seated vs. standing) turned out to have no effects on the PO_{PT} and there was no PO_{PT} drift during a 30-min ride. Those findings were obtained in the laboratory, but even in the field the PowerTap showed comparable results. The mean PO measurement in the field under cold temperature (5 °C) resulted in only a light and insignificant underestimation (– 2.7 %) of the PO_{PT} compared with the PO_{SRM}. We cannot claim that there is a device (SRM vs. PowerTap) wronger than the other. Temperature could have had a small effect on the mechanical properties of the PowerTap or the SRM. Only the use of the first principle calibration rig at 5 °C could have given a definite answer.

Assuming that the claimed accuracy of the SRM scientific model is correct, the PO_{PT} underestimations in the range of PO studied (– 1.5 % in the laboratory and – 2.7 % in the field under cold temperature for 100 – 420 W) can be explained by the fact that the two devices measure the PO at different parts of the bicycle. The SRM measures PO at the crank, whereas the PowerTap measures PO at the rear wheel hub and does not take into account the mechanical loss in the chain drive system. The dissipations due to chain friction are close to 2 – 4 % [11,13] and could theoretically induce a similar PO_{PT} underestimation compared with the PO_{SRM}. So the PO_{PT} underestimation reported in this study is in accordance with the theoretical chain friction loss.

However, our results differ from an unpublished study [18] which reported that the PO_{PT} were ~ 8 % higher than the PO_{SRM}. Apart from the fact that they used a less accurate professional SRM model with only 4 strain gauges and an older PowerTap model, it was the SRM crank that was incorrect in this case (from personal communications with the author of this article). The dynamic calibration of the SRM crank used in their study showed it to be reading low by ~ 9 %. Therefore, if this were taken into account, the results would be similar to ours.

Sprint test

During the sprint trials with the lower gear ratio the PO_{PT} was 8 % (significantly) underestimated compared with the PO_{SRM}. The upper gear ratios showed no significant differences in PO_{max} between the two devices. During a maximal sprint, the PO_{max} is reached at an optimal pedalling cadence [8,14,19,20]. The PO_{max} of the sprint trials with the three different gear ratios were reached with three different optimal pedalling cadences. The sprint with the lowest gear ratio resulted in the maximal optimal pedalling cadence. A high amount of torque data per s, a less fluid pedalling pattern (low crank inertial load) [5] at high pedalling cadences, and limitations in frequency of torque data measurement, storage, and transfer (from the hub to the receiver) could be possible explanations for the deterioration in the PT validity.

To sum up, assuming that the claimed SRM accuracy is correct, the results of the sprint trials indicate that during a maximal sprint exercise the PowerTap PO_{max} validity deteriorates when the pedalling cadence increases above ~ 115 rpm. However, PowerTap PO_{max} in sprint exercise appeared valid for pedalling cadences below ~ 115 rpm.

Reliability

The importance of reliable powermeters in order to detect small changes in performance has been emphasised in a recent review [9], as in elite athletes the detectable change in performance due to training or ergogenic aids is usually of a magnitude less than 2 %. The mean CV of PO ranging from 100 to 420 W were 1.5 % and 1.8 % for the SRM and the PowerTap, respectively. These low CV values indicate that both the PowerTap and the scientific SRM model provide reliable PO measurements and that they can be used to detect the performance improvements of elite athletes.

The PowerTap compared to other investigated mobile cycling powermeters

Supposing that the manufacturer's claimed accuracy of the SRM models is correct, our study indicates that for PO from 100 to 420 W the PowerTap validity is similar to the professional SRM model (i.e. ± 2.5 %), while the PowerTap reliability is nearly similar to the scientific SRM model (i.e. CV < 2 %).

When we compare the validity and the reliability of the PowerTap with other investigated mobile cycling powermeters like the Max One and the Polar S710, the PowerTap appears to be the best one. The Max One is an older mobile cycling powermeter that also measures the PO at the rear wheel hub, similar to the PowerTap device. However, the Max One does not provide valid PO measurements (over- and underestimations between 50 and 600 W), but appeared reasonably reliable (3.2 % average measurement error) [6]. The invalid PO measurement of the Max One seemed to be due to a progressive loss of strain gauge linearity as the PO increases [6]. More recently, Millet et al. [15] have tested the validity of the mobile Polar S710 cycling powermeter when comparing it with the SRM system (the professional model). The PO measurement of the Polar S710 is performed with a mathematical model taking into account the bicycle chain speed and tension. Millet et al. [15] showed that the PO measurements of the Polar S710 overestimated the PO_{SRM} by 7.4 ± 5.1 %, but that the Polar S710 PO measurements were reliable.

Conclusion

Our study shows that the PowerTap device is a valid and reliable mobile powermeter during sub-maximal intensities between 100 and 450 W, when compared with a scientific SRM model. However, for higher intensities (sprint exercises) with small gear ratios, the device seems to underestimate the PO_{SRM}. The PowerTap must be considered as a suitable device for PO measurements during real road cycling and in sub-maximal laboratory tests. Future investigation should compare the PO of the SRM and PowerTap devices with the PO of other mobile powermeters like the Ergomo and Polar devices.

References

[1] Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med 1998; 26: 217 – 238

[2] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; 1: 307 – 310

[3] Bertucci W, Duc S, Villerius V, Grappe F. Validity and reliability of the Axiom Powertrain cycle ergometer when compared with an SRM ergometer. Int J Sports Med 2005; 26: 59 – 65

[4] Bertucci W, Taiar R, Grappe F. Differences between sprint tests under laboratory and actual cycling conditions. J Sports Med Phys Fitness (in press)

[5] Fregly BJ, Zajac FE, Dairaghi CA. Crank inertial load has little effect on steady-state pedalling coordination. J Biomech 1996; 29: 1559 – 1567

[6] Grappe F, Candau R, Belli A, Rouillon JD. Aerodynamic drag in field cycling with special references to the Obree's position. Ergonomics 1997; 40: 1299 – 1311

[7] Grappe F, Candau R, Barbier B, Hoffman M, Belli A, Rouillon JD. Influence of tyre pressure and vertical load on coefficient of rolling resistance and simulated cycling performance. Ergonomics 1999; 10: 1361 – 1371

[8] Hintzy F, Belli A, Grappe F Rouillon JD. Optimal pedalling velocity characteristics during maximal and submaximal cycling in humans. Eur J Appl Physiol 1999; 79: 426 – 432

[9] Hopkins WG, Schabort EJ, Hawley JA. Reliability of power in physical performance tests. Sports Med 2001; 31: 211 – 234

[10] Jones SM, Passfield L. Dynamic calibration of bicycle power measuring cranks. In: Haake SJ (ed). The Engineering of Sport. Oxford: Blackwell Science, 1998: 265 – 274

[11] Kyle C, Caiozzo V. Experiments in human ergometry as applied to human powered vehicles. Int J Sports Biomech 1986; 2: 6 – 19

[12] Lawton EW, Martin DT, Lee H. Validation of SRM Power Cranks Using Dynamic Calibration. Fifth IOC World Congress, Oct 31 – Nov 5, 1999. Sydney: International Olympic Committee, 1999

[13] Martin JC, Milliken DL, Cobb JE, McFadden KL, Coggan AR. Validation of a mathematical model for road cycling power. J Appl Biomech 1998; 14: 276 – 291

[14] Martin JC, Spirduso W. Determinants of maximal cycling power: crank length, pedalling rate, and pedal speed. Eur J Appl Physiol 2001; 84: 413 – 418

[15] Millet GP, Tronche C, Fuster N, Bentley DJ, Candau R. Validity and reliability of the Polar®S710 mobile cycling powermeter. Int J Sports Med 2003; 24: 156 – 161

[16] Nevill A. Why the analysis of performance variables recorded on a ratio scale will invariably benefit from a log transformation. J Sports Sci 1997; 15: 457 – 458

[17] Nevill AM, Atkinson G. Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. Br J Sports Med 1997; 31: 314 – 318

[18] Paton CD, Hopkins WG. Tests of cycling performance. Sports Med 2001; 31: 489 – 496

[19] Vandewalle H, Peres G, Heller J, Panel J, Monod H. Force-velocity relationship and maximal power on a cycle ergometer. Eur J Appl Physiol 1987; 56: 650 – 656

[20] Van Soest A, Casius R. Which factors determine the optimal pedalling rate in sprint cycling? Med Sci Sports Exerc 2000; 32: 1927 – 1934