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Agreement Between the Stages Cycling and SRM Powermeter Systems during Field-Based Off-Road Climbing

Howard T Hurst[1]✉, Stephen Atkins[1], Jonathan Sinclair[1] and John Metcalfe[1]

Abstract

The aim of this study was to determine the agreement between two portable cycling powermeters for use during field based mountain biking. A single participant performed 15 timed ascents of an off-road climb. The participants' bicycle was instrumented with Stages Cycling and SRM powermeters. Mean and peak power output and cadence were recorded at 1 s intervals by both systems. Significant differences were determined using paired t-tests, whilst agreement was determined by calculating the bias and random error and the associated 95% limits of agreement (LoA). Significant differences were found between the two systems for mean power output (p<0.001), with the Stages powermeter under reporting power by 8 ± 1 % compared to the SRM. Bias and random error for mean power output were -18 ± 7 W (95 % LoA = 12 - 25 W above and below the mean). CV was 5.5 % and 5.2 %, for the Stages and SRM respectively. Peak power output was significantly lower with the Stages powermeter (p=0.02) by 6 ± 1 % when compared to the SRM powermeter. Bias and random error for peak power output were -25 ± 74 W (95 % LoA = 49 – 99 W above and below the mean), whilst CV was 13.7 % and 13.1 %, for Stages and SRM respectively. No significant differences were found for mean or peak cadence, whilst CV were <3 % for mean cadence for both systems and <6 % for peak cadence for both systems. This study found that both powermeters provided a reliable means of recording mean power output and cadence, though peak power values were less reliable. However, the Stages system significantly underestimated mean and peak power output when compared with the SRM system. This may in part be due to differences in strain gauges configuration and the subsequent algorithms used for the calculation of power output and the potential bilateral influences on power output production.

Keywords: cycling, power output, cross-country

✉ **Contact email:** *hthurst@uclan.ac.uk* (HT. Hurst)

[1] *Division of Sport, Exercise and Nutritional Science, University of Central Lancashire, UK. United Kingdom.*

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Introduction

Mobile cycling powermeters have been used for nearly 20 years to determine the power output responses and adaptations to training and competition. However, their use has largely been limited to that of elite racers, coaches and sports scientists due to the expense of these systems, often in excess of £1000. In addition, several systems have been developed such as the PowerTap rear hub based system (PowerTap, Madison, USA), Polar S710, which comprised of a chainstay mounted vibration sensor and a speed sensor fitted to the lower guide wheel of the rear derailleur (Polar Electro, Kempele, Finland), Ergomo Pro, a bottom bracket based system (Ergomo, Oppenheim, Germany) and the Look Keo pedal system (Look, Nevers, France). However, these systems have been shown to be invalid though reliable (Millet et al. 2003; Hurst and Atkins 2006; Duc et al. 2007; Kirkland et al. 2008; Sparks et al. 2014). Weight is also a factor when choosing a powermeter, with systems often adding between 240-650 g to the mass of a bicycle. Therefore, a lighter cheaper powermeter is desirable.

Currently, the most popular powermeter is the SRM powermeter crankset (SRM, Jüllich, Germany). This has been validated previously and is seen as the 'gold standard' measurement for cycling power output under road cycling conditions (Jones and Passfield 1998; Martin et al. 1998; Lawton et al. 1999; Balmer et al. 2004), though few studies have determined the reliability of the SRM for MTB use. However, the system is also one of the most expensive on the market at over £2000. The SRM powermeter is a modified crankset that incorporates a number of strain gauges (4-20 depending upon model used) bonded to the inner chainring bolt circle of the crankset. Angular displacement of the crank arm is recorded by the strain gauges and converted into a power value proportional to the pedal force. This signal is then transmitted to a handlebar mounted powercontrol unit or compatible GPS cycling computer. From the head unit data such as power, cadence, speed and heart rate can be viewed and downloaded to a personal computer.

Over the past 5 years there has been a rapid increase in the development of more affordable, sub £1000 powermeters. One such device is the Stages Cycling powermeter. Unlike the SRM system, the Stages powermeter uses the left hand crank arm where strain gauges are housed in a small plastic case bonded to the rear side of the crank arm. As the crank measures power at the left side only, the algorithm for power calculation simply doubles this values to get a complete reading for both left and right sides. The system also differs from the SRM in how it determines cadence. The Stages system uses accelerometers within the same casing, whilst the SRM system uses an electromagnetic switch within the bolt circle, consisting of two thin metal elements that contact each other each revolution of the crankset when passing a magnet attached to the bottom bracket of the bicycle frame. Stages Cycling also claim their system improves the speed of cadence data collection, and subsequently accuracy, by removing the need for additional magnets and moving parts, such as those required in the SRM's electromagnetic cadence method. However, this claim has not been validated. Therefore, the purpose of this study was to determine the level of agreement between the mountain bike variants of the Stages and SRM powermeter systems during a field based off-road ascent.

Materials and methods

Participants

One male participant (age 32 yrs; stature 173.2 cm; body mass 72.6 kg) took part in the study. A single participant was deemed appropriate as this ensured consistency between trials. Additionally, the participant was fully familiarised with the test route and had trained there on average twice per week for more than 4 years. Thus the use of a sole participant reduced the level of variability between trials. The participant was a well-trained cyclist with over 10 year's National level racing experience. The study was granted ethical approval by the University of Central Lancashire Ethics Committee and in accordance with the Declaration of Helsinki and the international standards required by the Journal of Science and Cycling (Harriss and Atkinson 2011). The participant was informed both verbally and in writing of the test procedures and written informed consent was obtained.

Equipment

The participant rode a 29" wheel full suspension cross-country mountain bike with 100 mm of rear suspension travel and fitted with a Rock Shox Recon 120 mm front suspension fork (Superlight 29, Santa Cruz Bicycles, USA). The suspension systems were set up in accordance to the manufacturers' recommendations for a 72-74 kg rider, resulting in a rear shock air pressure of 150 PSI and a front shock pressure of 125 PSI. Both front and rear shocks were operated in open mode throughout all trials. Tyre pressure was 35 PSI front and rear.

The bicycle was fitted with an SRM Shimano XT 2 x 10 MTB powermeter crankset (SRM, Jüllich, Germany). This system consists of eight strain gauges housed within the inner bolt circle of the crankset and has been validated previous and was therefore used as the criterion measure of power output and cadence (Jones and Passfield 1998; Martin et al. 1998; Lawton et al. 1999). Additionally, a Stages Cycling Shimano XT powermeter was fitted to replace the stock left hand crank arm (Stages Cycling, Saddleback Ltd., UK) to enable simultaneous recording of data during each run. The number of strain gauges used in the Stages crank is currently undisclosed. However, public statements by Stages that complexity (i.e. more strain gauges) is not always more accurate, may suggest a fewer number of strain gauges than that used by the SRM system. Crank length for both systems were 175 mm. The SRM system was paired to a Garmin Edge 510 GPS bicycle computer, whilst the Stages powermeter was paired to a Garmin Edge 810 computer. The use of different computers was due to pairing issues when trying to connect the powermeters to the same model of computer. Prior to each run a static calibration was performed for both powermeters. This involved rotating the powermeters several times to wake the systems and then following the calibrate process on the Garmin computers. Whilst the position of the crank arm was irrelevant in the calibration of the SRM, the Stages powermeter had to be in the 6 o'clock position. Total bicycle weight was 13.91 kg.

Protocols

Testing was performed over 3 consecutive days on an off-road climb consisting of primarily gravel. Distance and vertical ascent were recorded with both Garmin computers with the Edge 810 reporting a mean distance of 1.59 ± 0.02 km and the Edge 510 reporting a significantly lower mean distance of 1.56 ± 0.26 km ($t_{(14)}$=6.29; p<.001). However, coefficient of variance (CV) was 1.25 % and 1.67 % for the 810 and 510 respectively, and therefore within acceptable limits. Both GPS units reported a vertical ascent of 100 m and also showed good reliability with CVs of 0.12 % and 0.16 % for the 810 and 510 respectively. The mean gradient of the climb was 6.1 % with a maximum gradient of 12.7 %. A GPS profile of the route can be seen in figure 1. Though differences were found between the two GPS units, it was not the purpose of this paper to investigate agreement between GPS systems. In addition, the distance recorded by the units was independent of power output and therefore, had no influence upon the data collected from the powermeters.

Prior to each test session, the participant performed a 15 min self-paced warm up consisting of low intensity cycling and dynamic stretches. Following this the participant was instructed to complete 5 consistently timed climbs on each of the three test session (15 runs in total) at the participant's perceived race pace. Each trial was separated by 15 min to ensure full recovery and each session was separated by 24 hours. All testing was performed between 18:00 – 20:00 pm in dry conditions with a mean temperature of 12.3 ± 3.1 °C. Variables recorded were mean power output, peak power output, mean cadence and peak cadence determined for both systems and analysed for statistical differences.

Statistical analysis

Normality of data was confirmed using a Kolmogorov-Smirnov test. Prior to analyses data were downloaded to the Garmin Connect online software, where mean and peak data for each trial were determined. These data were then analysed for statistical difference using SPSS 20 (SPSS Inc., Chicago, IL, USA).

Pair t-tests were used to determine any significant differences between means. Data were checked for heteroscedasticity by correlating the absolute differences between Stages and SRM power and cadence against the mean power and cadence, as described by Atkinson and Nevill (1998). This analysis revealed no heteroscedasticity, therefore data were not logarithmically transformed, and absolute limits of agreement were determined. The 95 % limits of agreement were determined using the Bland-Altman method (Bland and Altman 1986). The differences in power output and cadence were derived relative to the mean values (Stages + SRM)/2, and 95 % of the differences were expected to lie between the two limits of agreement, defined as the mean difference ± 1.96*sd, expressed as bias ± random error. These methods have previously been used by Hurst and Atkins (2006) and Duc et al. (2007) for similar comparisons of cycling powermeters.

The reliability of the two powermeters were determined using the mean coefficient of variation (CV) of all 15 trials for each variable, calculated as SD divided by the mean multiplied by 100, and reported separately for each powermeter. Statistical significance was set at the alpha level of p≤.05.

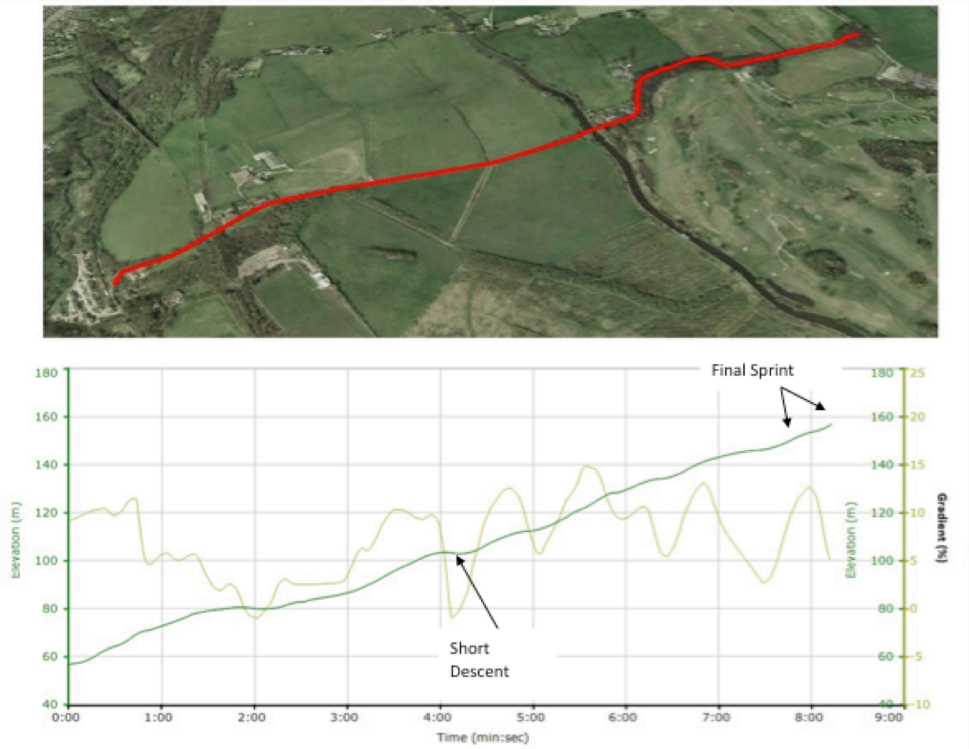

Figure 1. GPS trace of course profile and percent gradient.

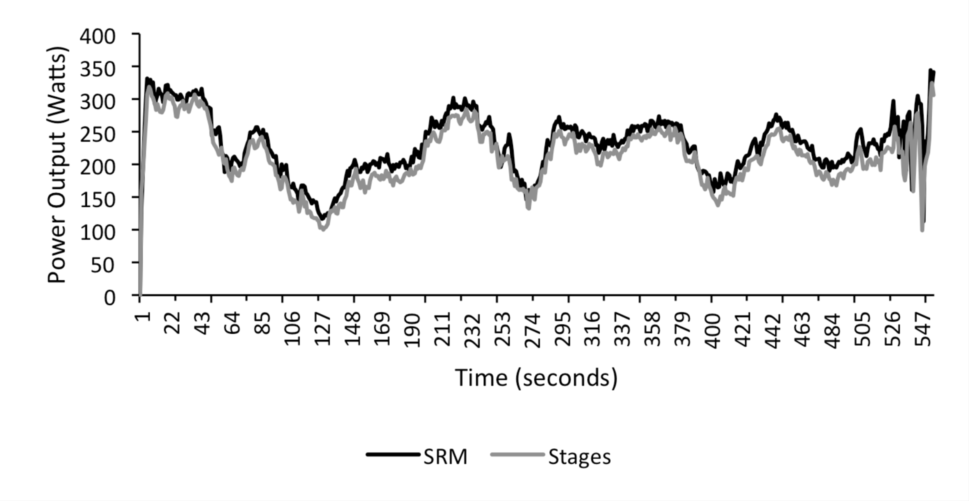

Figure 2. Power output averaged at 1 second intervals for SRM and Stages Powermeters.

Results

When data were averaged for the 15 climbs significant differences were revealed for mean power output between the Stages and SRM systems ($t_{(14)}$=-21.05; p<.001), with the Stages powermeter underestimating mean power by 8 ± 1 % compared to the SRM. Mean power output were 210 ± 12 W and 228 ± 12 W for the Stages and SRM, respectively. Figure 2 shows the temporal changes in power output for each system when averaged at 1 second intervals.

Bias and random error for mean power output between the two systems were -18 ± 7, with 95 % limits of agreement of 12 W above the mean to 25 W below the mean. The Bland-Altman plot in figure 3 shows all of the differences between the two measures fell within ±

1.96*sd of the mean of the differences. CV for recording of mean power output was 5.5 % and 5.1 %, for the Stages and SRM respectively.

Significant differences were also reported for peak power output between the two systems ($t_{(14)}$=-2.55; p=.02). The Stages powermeter reported peak values 6 ± 1 % lower than the SRM, with the average peak power being 432 ± 59 W and 456 ± 59 W for the Stages and SRM respectively. Bias and random error for peak power output between the two systems were -25 ± 74, with 95 % limits of agreement of 49 W above the mean to 99 W below the mean. The Bland-Altman plot in figure 4 again shows all of the differences between the two measures fell within ± 1.96*sd of the mean of the differences. CV for peak power we 13.7 % and 13.1 %, for Stages and SRM respectively.

Data averaged over the 15 ascents revealed significant differences in mean cadence between the Stages and SRM ($t_{(14)}$=-3.06; p=.009), despite mean values of 75 ± 2 revs.min^{-1} and 76 ± 2 revs.min^{-1} for the Stages and SRM, respectively. However, standard error of the mean (SEM) was only 0.13 for mean cadence, and may explain this apparent anomaly. Figure 5 shows the temporal changes in cadence for each system when averaged at 1 second intervals.

Bias and random error for mean cadence between the two systems were -0.4 ± 1, with 95 % limits of agreement of 0.6 revs.min^{-1} above the mean to 1 revs.min^{-1} below the mean. All of the differences between the two measures fell within ± 1.96*sd of the mean of the differences. CV for mean cadence were 3.0 % and 2.7 % for the Stages and SRM powermeters respectively.

No significant difference was found for peak cadence between the two systems ($t_{(14)}$=.36; p>.05). Average peak cadence were 102 ± 6 revs.min^{-1} and 102 ± 5 revs.min^{-1} for the Stages and

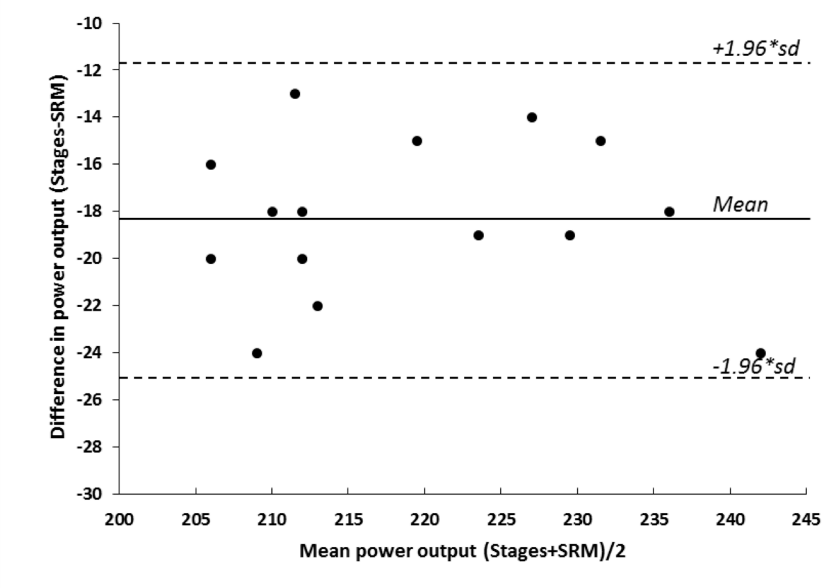

Figure 3. Bland-Altman plot of the differences between mean power output of the Stages and SRM systems plotted against the mean power output of the two systems.

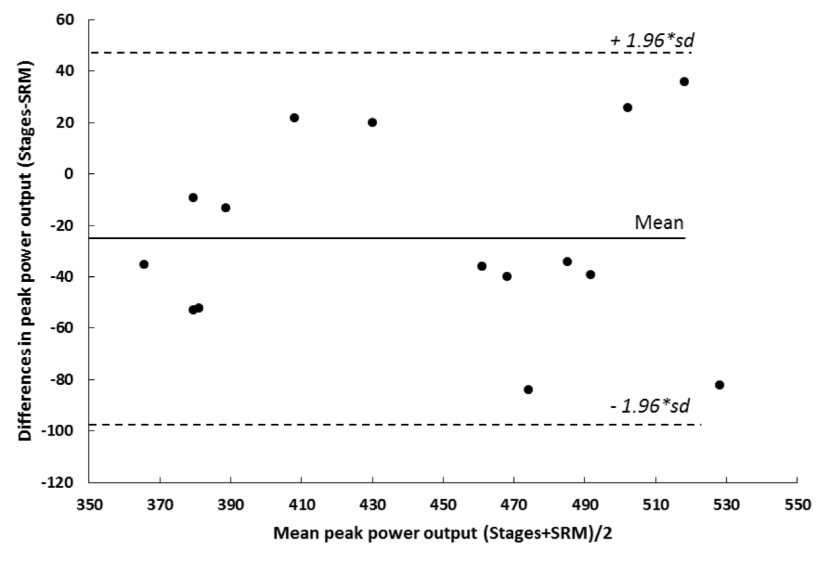

Figure 4. Bland-Altman plot of the differences between peak power output of the Stages and SRM systems plotted against the mean peak power of the two systems.

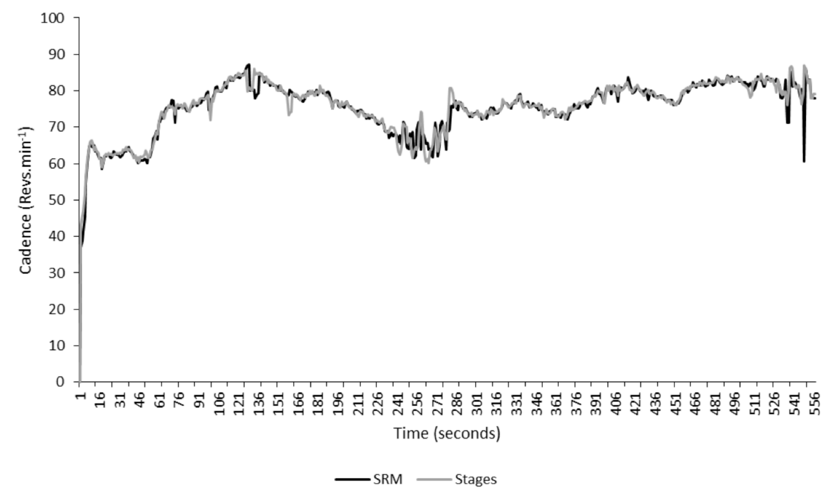

Figure 5. Mean cadence averaged at 1 second intervals for SRM and Stages Powermeters.

SRM, respectively. Bias and random error for peak cadence were 0.3 ± 6, with 95 % limits of agreement of 6 revs.min^{-1} above the mean to 5 revs.min^{-1} below the mean. All

except one of the differences in peak cadence between the two systems fell within ± 1.96*sd of the mean differences. The CV for peak cadence were 5.7 % and 4.7 %, for the Stages and SRM respectively.

Discussion

In all cycling disciplines, the accurate determination and expression of power output is an important corollary of enhanced training quality and subsequent performance optimisation. In the present study, we compared the agreement between two commonly available portable powermeters, both tailored towards use in mountain biking disciplines.

The SRM powermeter system has been agreed to represent a valid and reliable measure of power output and cadence during cycling, and is often referred to as the ‘gold standard’ in portable systems, particularly for road cycling conditions (Jones and Passfield 1998; Martin et al. 1998; Lawton et al. 1999). It is clear that the emergent Stages Cycling system does not show agreement with the SRM powermeter, and underestimates power output by an average of 8 %, when undertaking off-road climbing tasks. Similar disagreement is evident when looking at peak power outputs during the same climb. Van Praagh et al. (1992) proposed that in order for powermeters to be deemed accurate and reliable, data should be within a 5 percent margin of error. However, with the exception of mean cadence and peak cadence for the SRM, both systems revealed coefficients of variation above this proposed 5 percent threshold. When comparing the result of the present study to previous research into agreement between cycling powermeters, CV was greater than that previously reported for the PowerTap hub system (CV = 2.1 %), Polar S710 (CV = 2.2 %) and Ergomo Pro (CV = 4.1 %) (Bertucci et al. 2005; Millet et al. 2003; Duc et al. 2007). In addition, Bertucci, Crequy and Chiementin (2013) looked at the G-Cog powermeter for use in BMX. Like MTB, BMX is characterised as high intensity, intermittent cycling activity. However, Bertucci et al. (2013) reported higher CV’s for the G-Cog BMX powermeter than those reported in the present study. The G-Cog showed a CV of 27 % for field based sprints and between 50 and 65 % for laboratory based trials, showing the system is neither valid nor reproducible.

Direct comparison with the aforementioned studies may however, not be warranted. As these studies have used laboratory based trials, though Bertucci et al. (2013) did include field based trials, conditions would have been far more consistent and controllable than those in the present field based study. However, such laboratory based testing is limited in its’ ecological validity, as field based conditions would never be so repeatable and thus laboratory testing is limited in its ability to truly determine the validity and reliability of powermeters in real world settings. Though some variability is inevitable when field testing, the present study aimed to reduce this as much as possible by using one trained cyclist who was very familiar with the test course.

One possible reason for the reduced reliability reported in the present study, is the influence of trail vibrations. Previous studies have focused on either laboratory based trials or road riding condition, were surface vibrations are likely to be more stable than those observed during off-road MTB activity. This supposition is further supported by the fact that power output was most variable during the last 30 s of the ascent, which coincided with a relatively steep 9 % gradient that was also the rockiest section of the course. Therefore, the increased trail shock during this section may have reduced wheel contact with the ground and lead to reduced reliability of power transfer through the powermeters due to an increase in chain vibration and therefore a reduction in the chain tension on the crankset. Jones and Passfield (1998) also reported that vibration within a chain driven system could lead to reductions in power output due to frictional losses. Such losses would likely be increased during MTB activity.

Whilst the rocky nature of the top section of the course may have influenced the power output reading to some extent, pacing may also have been influential. Although the participant was instructed to perform self-determined race pace runs, and the use of one participant would have potentially reduced any variations in results, it is highly unlikely that power output was exactly the same during each section of the climb. As such these small variation in pacing may also have contributed to some of the differences observed in power output.

Data also revealed a drop in power output by both systems over three periods of approximately 20-30 s at around 80 s, 220 s and 380 s into the ascent. These drops in power may again be indicative of a pacing strategy being employed by the participant, as the drops in power coincided with short flatter sections of the course, and in the case of data around the 220 s point as short descent, immediately prior to harder, steeper sections.

Overall, peak power was underestimated by the Stages powermeter. However, at times the bias was in a positive direction, i.e. the Stages system overestimated peak power. Reasons for this are unclear, though it may be a result of differences in strain gauge arrangement, as the Stages powermeter houses them in a small localised area of the left cranks arm, unlike the SRM whose strain gauges are located around the inner bolt circle of the crankset. Such an arrangement as used in the Stages powermeter may affect power measurements more during sprint efforts, as the positive bias appears to occur more during the final sprint to the finish. Additionally, cadence was also higher for the Stages during this period of the run. As a result some of the negative bias may be cancelled out by the positive bias, therefore caution should be taken when interpreting the peak power data.

Significant differences were reported in mean cadence between systems, though not peak cadence. However, this difference should be taken in context, as despite this, both systems showed a high degree of agreement and reliability. However, the standard error of the mean (SEM) was only 0.13, and may explain this apparent anomaly. Therefore, claims that the use of accelerometry to determine cadence within the Stages system improves accuracy of determination could not be supported from our findings.

A key issue relates to the location of the strain gauge cluster. The technologies involved in the SRM and Stages Cycling systems may have an impact upon such disagreement between systems. To determine pedal forces, and predict actual power output, deformation based sensors have been commonly used. These strain gauges are normally positioned within the bottom bracket or bolt circle (proximal location) or at the crank arm (distal location). The SRM system integrates eight strain gauges into the inner chainring bolt circle of the crankset, located on the right side of the bottom bracket. In contrast, the Stages system has an unknown number of strain gauges located in the crank arm of the left side of the bottom bracket.

Whilst Jones and Passfield (1998) showed that a higher number of strain gauges reduced the variability in powermeter data acquisition, the location of the strain gauges may also be influential. To date, there is no information published with regard to differences in power output associated with varying placement of strain gauges within the drivetrain. Deformation of embedded strain gauges may potentially be biased due to a proximal or distal location, allied to the relative stiffness of the crank arm itself. The Stages system will resolve forces on the crank arm surface into tangential and radial forces at the proximal spider. With respect to crank stiffness, this is one of the proposed reasons Stages state their powermeter only works with metal crank arms, as carbon variants don't possess the same, consistent deformation properties of metal and therefore result in greater variability in data.

Another factor that may have influenced the results of the present study is right versus left side leg bias. The algorithm used to determine power, for the Stages system, simply doubles the value determined at the left crank, and then creates an average. This may create problems in situations where a contralateral force production imbalance is present.

Normal cycling actions, especially climbing, requires a cooperative effort between both legs. To date, there is a dearth of contemporary information assessing absolute and relative power output between right and left sides, in field based settings. A key reason for this relates to the lack of a truly integrated portable powermeter that can assess symmetry in power output. Instead, most portable powermeters, that utilise assessment within the forward drivetrain (crank arms/spider), aggregate results determined from a single side. This creates evident issues when considering potential contralateral imbalances in power output. Though the Garmin Vector system and InfoCrank have the ability to report left/right power balance, these systems have yet to be scientifically validated. In addition, there use is limited to road based cycling activity and not mountain biking.

Bilateral asymmetries have been proposed in cyclists (Smak et al. 1999), though such asymmetries may reduce with elevations in workload (Carpes et al. 2010, 2011; Liu and Jensen, 2012). In the current study, workload was self-determined, though the participant was asked to ensure effort intensity close to race pace. By using a single, experienced, mountain bike rider as the participant, potential variability between riders, particularly regarding technical aptitude and application, would be reduced. Such an approach has been used previously (Bertucci et al. 2005). Further research is warranted to determine the role of asymmetries in muscle force production during field based trials. However, in the absence of a viable portable meter, to determine asymmetries, lab-based determination of contralateral imbalance may be prudent, prior to field trials.

Conclusions

Our findings revealed that the Stages Cycling powermeter significantly underestimated both average and peak power output, when compared to the SRM powermeter. Both systems were agreeable in the determination of both average and peak cadence. Both values, as measured by the Stages, exceeded the manufacturer claimed accuracy level of ±2 %. To date, there are no published studies assessing the accuracy of the innovative Stages Cycling system, whether in road or off-road conditions. Controlling field based riding conditions, via the use of a single, experienced participant and a reproducible course for each trial, will reduce the potential for subsequent bias in data. Similarly, issues relating to calibration and temperature discrepancies can be accommodated due to both systems requiring a zero offset procedure prior to each trial.

The Stages Cycling powermeter does represent an affordable and practical solution to the field based determination of cycling power output. However, the reliability of the system is relatively low when used for off-road cycling. Further research is needed to identify why such large variation occurred. A key challenge may be the underpinning algorithm to determine power output. The assumption that a simple 'doubling' of the power output determined in the left leg, normally non-dominant in most riders, will not take into account likely bilateral asymmetries. Potential adjustments to this algorithm may be prudent. It is also important to note, that whilst the SRM system has frequently been purported to be the 'gold standard' in power output assessment, and has shown high reliability during laboratory and road cycling trials, this may not be the case for MTB applications. Our results have shown that during off-road ascending on a relatively non-technical climb, the potential influence of trail shocks may still have been sufficiently great to reduce tension within the drive train and therefore decrease the reliability with which force is applied to the SRM powermeter.

Practical applications

The current study demonstrates that variability exists in data recording for both Stages and SRM powermeters when used during off-road cycling As such data recorded with either powermeter should be used with caution when interpreting training loads. Athletes and coaches should also be aware of the potential influence of bilateral muscles imbalances may have on the accuracy of the data recorded.

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