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Agreement between LeMond Revolution cycle ergometer and SRM power meter during power profile and ramp protocol assessments

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Abstract

This study aimed to evaluate the agreement in cycling power output measurements between the LeMond Revolution cycle ergometer and SRM power meter. The LeMond Revolution measures power output via removal of the rear bicycle wheel and attaching it using a quick-release system, estimating power output through a head-unit that processes drive-train resistance and atmospheric conditions. Fourteen well-trained cyclists completed incremental protocols and power profile assessments on a bicycle fitted with SRM scientific power meter and attached to a LeMond Revolution cycle ergometer. Power output was measured by both devices at 1 Hz. Data from each device were compared using Pearson's correlations, paired t-tests, assessments of heteroscedasticity, Bland-Altman plots and 95% limits of agreement. During incremental tests, errors in power measurement of the LeMond Revolution progressively increased at greater power outputs when compared with SRM (bias: 2-34 W; CV 1.5-6.7%). During power profile assessments, errors in mean power measurement of the LeMond Revolution were also slightly overestimated for all efforts from a rolling start (+3 ± 8%; CV = 5.1%). Conversely, the LeMond Revolution underestimated peak power output during five second sprint efforts and the greatest error was observed between measurements for mean power output during a five second sprint from a stationary start (-7 ± 24%; CV = 10.6%). Overall, the LeMond Revolution is a practical, cost-effective alternative to more expensive ergometers for detecting large changes in mean power output. However, high level of error during high-intensity sprint efforts from a stationary start is a limitation for well-trained sprint cyclists.

Keywords: training, testing, performance, cycling, validity, power

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Introduction

The assessment of power output is important for cyclists, coaches and sport scientists to quantify the workload completed during training and testing. In a laboratory setting, quantification of power output has previously been achieved with the use of complete bicycle ergometers built specifically for this purpose such as the Monark, Wattbike, Cyclops, Cyclus 2 and SRM Indoortrainer, (Hopker, Myer, Jobson, Bruce and Passfield, 2010; Jones and Passfield, 1998; Maxwell et al., 1998). However, these ergometers are relatively expensive, not easily portable, and while the handlebars and seat height are generally adjustable, the cyclists have been unable to use equipment that completely matches their training and racing apparatus. In particular, even if the handlebars, saddle and pedals were customised to suit an individual athlete using one of the above cycle ergometers, there would still be considerable variation in the crank width (Q-factor) and length between bicycles, which would affect muscle geometry, comfort and potentially power output.

In order to measure power output during both laboratory and field cycling, mobile power meters housed within various parts of the bicycle were developed. The most widely accepted mobile power meter remains the Schoberer Rad Messetechnik (SRM) system. (Gardner et al, 2004; Jones and Passfield, 1998; Smith, Davison, Balmer and Bird, 2001). The SRM system utilises strain gauges and a cadence sensor to calculate the torque and angular velocity of the cranks to determine power output, resulting in relatively accurate measurements when compared with a first principles dynamic calibration rig (±2%) (Gardner et al., 2004). However, these systems can be difficult and time-consuming to fit to a bicycle, as well as suffering compatibility issues with the various bottom bracket standards and individual crank lengths used.

Other mobile power meters are available but experience greater inaccuracies when compared with the SRM system. These systems include the PowerTap which is housed within the rear hub (accuracy: -2.5 ± 0.5% vs. dynamic calibration rig and -1.2 ± 1.3% vs.

SRM crankset; Bertucci, Duc, Villerius, Pernin & Grappe, 2005; Gardner et al., 2004), the Stages power meter housed within the non-drive crank arm (accuracy: -8 ± 1% vs. SRM crankset; Hurst, Atkins, Sinclair & Metcalfe, 2015), the Polar S710 which calculates power output via chain speed and tension (accuracy range: 0.6 ± 3.8% to 7.8 ± 4.4% vs. SRM crankset when cycling at 150 W and 60-110 rpm; Millet, Tronche, Fuster, Bentley & Candau, 2003) as well as the Ergomo Pro bottom bracket power meter (accuracy 6.3 ± 2.5% vs. SRM during incremental cycling; Duc, Villerius, Bertucci & Grappe, 2007). Furthermore, each of these mobile power meters including the SRM system require an additional roller/resistance system in order to be used in laboratory testing, and given these limitations, novel and more universal power meters have been developed.

Such power meters include the Kingcycle ergometer which was developed to allow cyclists to use their own bicycle during laboratory testing, with a roller applied to the rear tyre to provide resistance via a connected fan blade. However, changes in pressure between the tyre-roller interface during testing may lead to inconsistent variance when compared to an SRM system (Balmer, Davison, Coleman and Bird, 2000). Ultimately, the Kingcycle overestimated power output data compared to an SRM system by 10 ± 7%. Similarly, the Velotron was also developed to allow the use of a cyclist's own bicycle, however in this case, the rear wheel of the bicycle is replaced with the wheel of the Velotron, with resistance adjusted via a computer control system. During a human-powered trial, the Velotron showed greater accuracy than the Kingcycle when compared with a SRM system but still overestimated (3.7 ± 1.9%) power output (Abbiss, Quod, Levin, Martin and Laursen, 2009). The accuracy of other similar cycle ergometers include the Axiom Power Train (5-12% accuracy vs. SRM during maximal aerobic power test and 10 min time-trial; Bertucci, Duc, Villerius and Grappe, 2005), and the Tacx Fortius (4.2 ± 3.3% to 4.9 ± 1.7% accuracy vs. PowerTap hub during 6 min and 30 min time-trials; 3.5% (3.2-3.9% CI) typical error of estimate vs. PowerTap hub during 20 km time-trials; Bertucci, 2012; Peiffer & Losco, 2011).

Comparatively, the LeMond Revolution cycle ergometer uses a combination of the above technologies, with the rear wheel being removed from the bicycle and resistance being applied via a weighted fan blade and the bicycle's normal gear system. However, unlike the Kingcycle this system is not influenced by changes in tyre pressure as it is firmly fixed to the ergometer at the rear axle.

The LeMond Revolution ergometer is relatively cheap, compact, easily transportable and may be used with any road bike or mountain bike that utilises the standard 130 mm (road) or 135 mm (mountain bike) rear quick-release system. The LeMond Revolution indirectly calculates power output using an algorithm derived from the speed of the flywheel and atmospheric conditions (ambient temperature, humidity and altitude) rather than a calculation of torque and angular velocity as used by the SRM system. While the LeMond Revolution has many potential applications for training and testing, little is known of the accuracy of its power measurements. Therefore, the purpose of this study was to assess the agreement in power output measurement between the LeMond Revolution cycle ergometer and the SRM power meter crankset across a wide range of power outputs that were typical of common laboratory cycling performance tests and training.

Materials and methods

Participants

Fourteen well-trained male cyclists (20.1 ± 2.2 yr; 181.8 ± 4.2 cm; 80.2 ± 9.5 kg; peak power output: 367 ± 52 W; training hours per week: >10 h) from various disciplines (mountain bikers: n = 3; BMX cyclists: n = 4; road cyclists: n = 7) volunteered to participate in the study. Inclusion criteria stipulated that participants must have been competing at the minimum of state level in the previous 12 months and those eligible were screened for pre-existing health conditions and provided informed consent. Whilst fourteen cyclists participated in the study, only ten cyclists completed the maximal incremental test and nine completed the power profile assessment. Five of the cyclists completed both tests and all cyclists had completed both protocols at least once prior to the study. The variance in participant numbers was due to logistic constraints of competition and as such, within-subject comparisons were not performed between tests. All protocols were approved by the Human Research

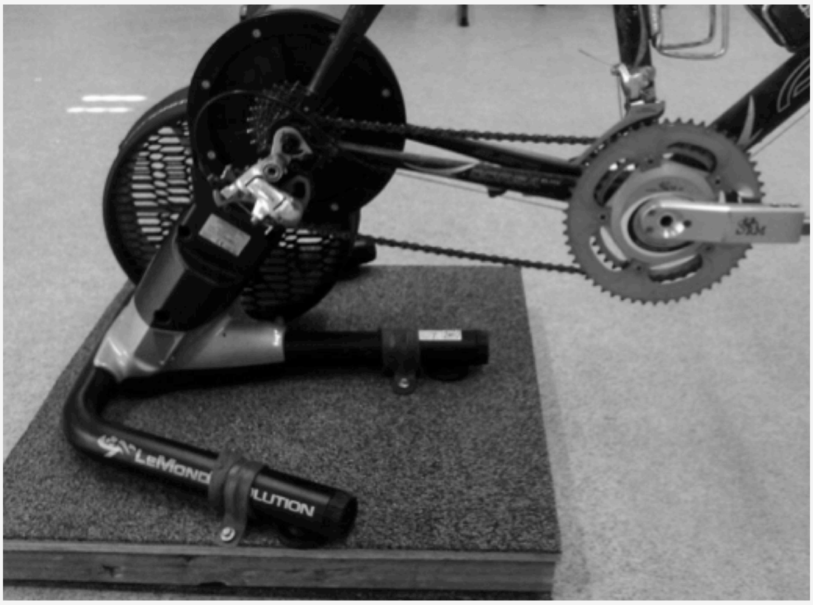

Figure 1. Bicycle attached to LeMond Revolution and SRM crankset

Ethics Committee of the University of Newcastle (H-2011-0350) and the study was completed in accordance with the declaration of Helsinki and the standards required by the Journal of Science and Cycling.

Procedures

Participants were instructed to avoid strenuous exercise, caffeine, alcohol and non-steroidal anti-inflammatory drugs for at least 24 h prior to each testing session. For all testing sessions, a UCI-legal road bicycle (2015 Specialized Allez Comp, Specialized, CA, USA; Aluminium alloy frame with carbon fibre fork) was fitted with a SRM power meter (Scientific model – 20 strain gauges with adjustable crank length; Schoberer Rad Messetechnik, Julich, Germany), which has been shown to produce valid and reliable data (Gardner et al., 2004; Jones and Passfield, 1998). The research team could not access a dynamic calibration rig immediately prior to this study, however the SRM crankset had been calibrated within the previous six months, with SRM systems shown to remain stable for at least 11 months of heavy use (racing) following calibration (Gardner et al., 2004). The rear wheel of the bicycle was removed and attached to a LeMond Revolution with 10 speed (11-25 tooth) rear gear ratio and 39-53 tooth front gear ratio (Figure 1). The testing then allowed the level of agreement to be compared between the two ergometers across a range of power outputs typical of cycling training and performance tests. All tests were performed in an exercise science laboratory under standard laboratory testing conditions (20-23°C; 40-60% humidity).

The bicycle seat height and handlebar position was matched to the cyclist's own training geometry and the cyclist's own pedals were fitted to each crank. Crank length was adjusted to match the cyclist's own bicycle using adjustable SRM cranks. The participants performed a standardised warm-up prior to both tests consisting of cycling between 100-200 W for 10 min as well as one short (5 s) effort at each intensity of 70, 80 and 90% of self-predicted maximal effort. The zero offset of the SRM system was then set as per the manufacturer's specifications. Following this, either a standard maximal incremental test to exhaustion or a power profile assessment (PPA) was performed as previously described (Quod, Martin, Martin and Laursen, 2010).

The maximal incremental test required participants to cycle at 100 W for the first 60 seconds, after which power output increased by 30 $W \cdot min^{-1}$. The test was ceased when the participants could no longer maintain a cadence above 80 rpm at the required power output. Throughout the test, participants viewed the current power output reading on the LeMond Power Pilot head-unit and adjusted the bicycle's normal gear system to achieve the required power output of each stage. Peak power output was determined via the following equation (Kuipers et al., 1985).

$$\text{Peak power output} = P_p + \{T_f \times [(V_f - P_p)/60]\}$$

Where P_p is the power output (W) of the previous complete stage, V_f is the power output (W) at the final stage and T_f is the time at final power.

The PPA consisted of seven maximal efforts (6, 6, 15, 30, 60, 240, 600 s) with active recovery periods (54, 174, 225, 330, 480 and 600 s), as such efforts has been shown to be valid when compared to field-based road cycling efforts (Quod et al., 2010). The first 6 s effort was completed from a standing start to determine acceleration characteristics and the remaining efforts were completed from a rolling start of between 70-80 rpm. Cyclists were instructed to adjust the gear ratio at any time to produce as much power as possible for each effort. The shorter sprints (6-30 s) were typically a maximal sprint while the longer efforts (60-600 s) required a self-selected pacing strategy to produce the maximum sustainable power output throughout the effort. Between efforts, cyclists were instructed to pedal at an easy resistance (<100 W). The participants were consistently verbally encouraged throughout each test.

Power measurements were recorded by the SRM Power Control VII at 1 Hz via calculation of torque and cadence whilst the LeMond Revolution Power Pilot head unit calculated power output at 1 Hz via an algorithm utilising measures of flywheel speed, cadence and atmospheric conditions (temperature and altitude). Due to this low recording frequency of the power meters, only the first 5 s of power data were included in the analysis of the 6 s effort from stationary start, while the highest 5 s of power data were used in the analysis of the 6 s effort from rolling start.

As the data from ramp and PPA tests were not being directly compared within this study, only five of the participants completed both tests, with these being completed on separate occasions separated by at least 48 hr to ensure adequate recovery. The final data resulted in a total of ten ramp tests and nine PPA to be used in the final analysis.

Statistical analysis

The limits of agreement between the power measurements recorded by the LeMond and SRM power meters were compared using Bland-Altman analyses to determine the bias and random error. The two limits of agreement included the mean differences ± 2 standard deviations where 95% of the differences were expected to lie (Bertucci et al., 2005). The data were tested for heteroscedasticity by plotting mean values for the two power meters against the absolute difference in power measurements and by checking the heteroscedasticity correlation. Where heteroscedasticity was present, the data were log transformed to determine the limits of agreement as ratio limits i.e. bias ×/÷ random error as a factor (Atkinson and Nevill, 1998; Bland and Altman, 1986). For both the incremental test and PPA, Pearson's correlations were used to determine the strength of the relationship between the ergometers and were identified as 0.0-0.09 (trivial), 0.10-0.29 (small), 0.30-0.49 (moderate), 0.50–0.69 (large), 0.70–0.89 (very large), 0.90–0.99 (near perfect) and 1.00 (perfect) (Hopkins, 2002). Coefficients of variation (CV) were calculated as a measure of bias between the two power meters for each stage of the incremental test and PPA. Following confirmation of normality via Kolmogorov-Smirnov test, paired t-tests were only used to compare data within the individual stages of the incremental test as fluctuations in power output were minimal and heteroscedasticity was therefore not present. All statistical analyses were completed using PASW (v18.0, SPSS Inc., Chicago, Illinois, USA) and Microsoft Excel (2010, Microsoft Corporation™, Redmond, Washington, USA).

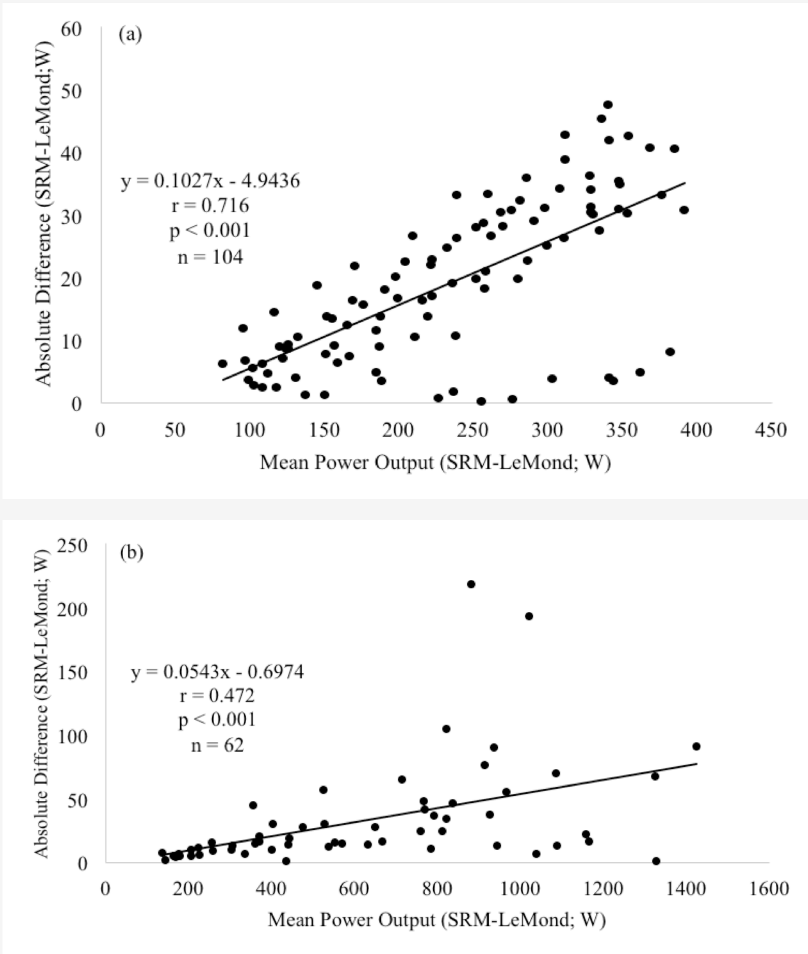

Figure 2. Assessment for heteroscedasticity between SRM and LeMond power meters during the incremental test (a) and the PPA (b).

Results

Incremental test

For the incremental test, Pearson's correlations identified significant, near-perfect relationships between the mean power values of each power meter (r = 0.994, p<0.001), however, a plot of the mean values and absolute differences between the two power meters (Figure 2a) and the heteroscedasticity correlation (r = 0.72, p<0.001) revealed that the data were heteroscedastic. As there was minimal variation in power output (10-30 W) within each individual stage of the test, paired t-tests, coefficient of variation and limits of agreement were calculated individually for each stage (Table 1). Only two participants began the 430 W stage of the incremental test and therefore this data has been excluded. Differences in mean power data between ergometers differed significantly, with the variation increasing progressively for the incremental test stages above 100 W (CV = 3.0-6.7%; p<0.05).

Power profile assessment

A near-perfect correlation was also observed for the PPA data across all efforts (r = 0.989, p<0.001), however the data were again identified as heteroscedastic (Figure 2b; r = 0.47, p<0.001), As there was greater fluctuation of power output within each of the individual all-out efforts (100-1000 W depending on effort duration), the data were log-transformed, resulting in a more acceptable and non-significant heteroscedasticity correlation (r = 0.16, p>0.05). Therefore, limits of agreement are more practically expressed as ratio limits for the PPA and are presented in Table 2, along with coefficient of variation and correlation coefficients. For all PPA efforts of <700 W there was a slight overestimation of power output (1.03 ×/÷ 1.09). The bias and random error for the 5 s stationary effort was large (0.93 ×/÷ 1.24) and the random error in mean power measurement increased with higher power outputs, progressing from ×/÷ 1.09 for efforts <700 W to ×/÷ 1.17 for efforts > 700 W. While this large difference in random error was present, the mean bias between <700 W and >700 W differed by only 4% (1.03 and 0.99, respectively). For measures of peak power during the PPA, the bias and error between the LeMond Revolution and SRM during the 5 s stationary effort were largest (0.93 ×/÷ 1.21).

Discussion

The data demonstrate that errors in mean power measures from the LeMond Revolution progressively increased at higher power outputs when compared with a SRM crank set across various maximal efforts that ranged in duration and intensity. With the exception of the first stage of the incremental test (100 W), the LeMond increasingly overestimated power output compared to the SRM across all other stages (range: 6-31 W; p<0.05). Similarly, during all PPA efforts of <700 W, the CV between LeMond and SRM was an acceptable 4.5%, while this increased to 8.1% for efforts >700 W. In contrast, for 5 s efforts performed from a stationary start, the bias was much greater and instead underestimated the SRM power meter with a high level of error (-7 ± 24%; CV 10.6%).

Table 1. Mean power measures, coefficients of variation, Pearson's correlations and limits of agreement for LeMond and SRM power meters across an incremental test.

Increment (W)	n	LeMond MPO	SRM MPO	CV (%)	r	Bias ± Error (W)
100	10	105 ± 10	102 ± 13	1.5	0.88	2 ± 5
130	10	132 ± 11[a]	126 ± 15	3.0	0.93	6 ± 5
160	10	165 ± 11[a]	155 ± 15	4.3	0.90	6 ± 5
190	10	198 ± 15[a]	185 ± 18	4.9	0.92	13 ± 5
220	10	232 ± 15[a]	214 ± 18	5.7	0.89	18 ± 6
250	10	262 ± 18[a]	241 ± 19	5.9	0.85	21 ± 7
280	10	285 ± 22[a]	263 ± 20	5.7	0.84	22 ± 9
310	9	320 ± 26[a]	291 ± 29	6.5	0.94	28 ± 8
340	8	353 ± 22[a]	321 ± 22	6.7	0.83	32 ± 11
370	8	370 ± 18[a]	337 ± 24	6.7	0.87	34 ± 10
400	6	384 ± 34[a]	353 ± 32	6.0	0.91	31 ± 15

Key: a = significantly higher than SRM ($p<0.05$); CV = coefficient of variation; MPO = mean power output; n = number of efforts; r = Pearson's Correlation.

Table 2. Mean and peak power measures, coefficients of variation, Pearson's correlations and ratio limits of agreement for LeMond and SRM power meters across a power profile assessment.

	Effort	n	LeMond MPO	SRM MPO	CV (%)	r	Bias ×/÷ Error
Mean	5 s Stand	8	907 ± 181	975 ± 191	10.6	0.86	0.93 ×/÷ 1.24
	5 s Roll	9	1111 ± 177	1120 ± 196	4.0	0.98	1.00 ×/÷ 1.04
	15 s	9	800 ± 133	764 ± 103	4.2	0.99	1.04 ×/÷ 1.08
	30 s	9	558 ± 116	537 ± 100	4.1	0.99	1.03 ×/÷ 1.08
	60 s	9	390 ± 94	376 ± 80	5.1	0.99	1.03 ×/÷ 1.09
	240 s	9	246 ± 81	235 ± 70	6.1	0.99	1.04 ×/÷ 1.10
	600 s	9	213 ± 69	205 ± 58	6.1	0.99	1.03 ×/÷ 1.10
	All efforts > 5 s	45	441 ± 240	423 ± 224	5.3	0.99	1.03 ×/÷ 1.08
	Mean < 700W	37	355 ± 160	344 ± 154	4.5	0.99	1.03 ×/÷ 1.09
	Mean > 700W	25	959 ± 191	969 ± 209	8.1	0.93	0.99 ×/÷ 1.18
Peak	5 s Stand	8	1158 ± 178	1240 ± 260	10.6	0.86	0.93 ×/÷ 1.21
	5 s Roll	9	1227 ± 212	1298 ± 286	4.0	0.98	0.99 ×/÷ 1.08
	15 s	9	798 ± 253	833 ± 281	3.5	0.99	1.04 ×/÷ 1.08

Key: CV = coefficient of variation; MPO = mean power output n = number of efforts; r = Pearson's Correlation.

Similar to the Kingcycle, Axiom Power Train and Velotron cycle ergometers, the LeMond Revolution typically overestimated data when compared with a SRM power meter. Specifically, it was previously shown that the Kingcycle overestimated power data compared to SRM during a 16.1 km time-trial by +10 ± 7% (Balmer et al., 2000), while the Velotron cycle ergometer has been shown to overestimate mean measures of power output across a 30 km time-trial by +3.7 ± 1.9% (Abbiss et al., 2009). Further, the Axiom Power Train overestimated values during a 10 min all-out effort by 12% (Bertucci et al., 2005). Comparatively, the LeMond revolution only overestimated mean measures of power output (+3 ± 8%) across a wide range of all-out efforts (15-600 s). As such, the LeMond Revolution is a valuable tool for the assessment of a power output across a wide range of all-out cycling tests.

While the mean bias of the LeMond Revolution during the incremental test was +19 ± 11 W, it is important to note that the level of bias was much lower during the initial stages (<10 W) and much greater during the final stages (>30 W) of the test. Heteroscedasticity was also present across all efforts of the PPA. As such, both tests have identified that the LeMond Revolution produces more valid measures at lower power outputs with increased hysteresis at greater power outputs. This device appears to be most suitable for tests requiring relatively low and consistent power outputs.

The LeMond Revolution's overestimation of power output is likely to be caused by inaccuracies of the power prediction equations used by the LeMond Power Pilot head unit. The LeMond prediction equations are based on the speed of the flywheel, temperature and altitude. In comparison, the SRM measures the deflection between the crank axle and chain ring interface through a number of strain gauges as well as the angular velocity of the cranks as measured by cadence. As such, the SRM system is likely to be more sensitive to sudden fluctuations in power output.

In respect to the underestimation of power output by the LeMond Revolution that was noted for measures of peak power output, there are several possible explanations. Firstly, the speed of the LeMond's flywheel is an important component of the algorithm that calculates power output, however, as it is located at the rear of the drivetrain, it is more susceptible to variation in drivetrain vibrations and force dissipation through the mechanical structures of the chain ring and chain. Comparatively, the SRM only requires measures of force and cadence which are measured within the first sections of the drivetrain (chain ring housing and crank arm, respectively). In particular, the greatest level of error in both mean and peak measures occurred during the 5 s effort that began from a stationary start (-7 ± 24%). This large level of error would be considered unacceptable for training and testing applications for well-trained sprint cyclists. Importantly, during these efforts, it was observed that the belt drive of the LeMond Revolution frequently slipped during the first three seconds, meaning that it did not fully engage with the freewheel. Slippage of the belt drive also occurred within the 5 s rolling start effort for several of the cyclists who were able to achieve very high peak power outputs (>1500 W). Slippage was not observed for any cyclist who demonstrated a lower peak power output during these trials (<1100 W). Belt slippage was less frequent during the rolling start efforts compared to the stationary start efforts, which explains why such high bias and random error were not present. Therefore, the LeMond Revolution appears to be limited in its use for high-intensity sprint efforts by well-trained sprint cyclists.

It is clear that the accuracy of the LeMond Revolution varies depending on the type of cycling effort and the peak power output capacity of the cyclist being assessed. Further research is required to determine whether significant variability exists between LeMond Revolution cycle ergometers, as only a single device was used in the current study. It should be noted that a significant drawback of the LeMond Revolution as well as many other ergometers is that dynamic calibration is not possible. For example, if a dynamic calibration rig were attached to the unit, it remains impossible to adjust the slope/calibration within the head unit. As such, the measurements of the device would need to be calibrated against a SRM system or dynamic calibration rig on a regular basis so that measurements calculated by the LeMond Revolution's algorithm could be adjusted if any variance in the system develops over time.

Overall, the data showed that during maximal efforts from a rolling start, the LeMond revolution slightly overestimates mean power output when compared to the SRM power meter. Further, power measurements recorded by this device during human efforts below 700 W or longer than 15 s are more acceptable than several other ergometers that have been compared with a SRM power meter. In contrast, high-intensity efforts from a stationary start produce underestimated values for measures of peak and mean power output, likely due to drivetrain slippage. As such, the LeMond Revolution appears to be a valid cycling ergometer for the measurement of mean power outputs below 700 W or longer than 15 s, but may not be suitable for power output measurements during short-duration high-intensity sprint efforts.

Practical applications

The LeMond Revolution is a cost effective and portable cycle ergometer that provides acceptable measures of power output when compared to the SRM power meter across a range of efforts that are typical of cycling training and performance testing. In particular, the LeMond Revolution allows cyclists to use their exact training bicycle when training and testing and it appears to be best suited for measures of mean power output during consistent efforts that are characteristic of endurance cycling. However, well-trained sprint cyclists should be aware of the limitations of this cycle ergometer given the progressive error that occurs at greater power outputs and during efforts that require a rapid acceleration from stationary start.

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