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Original Article

Cycling Power Characteristics between Instrumented and Favero Assioma Duo Road Power Meter Pedals

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Abstract: The purpose of this study was to evaluate the differences in power output measured by instrumented pedals and a pedal-based power meter during stationary cycling at multiple workloads. Nine healthy participants performed 2-minute trials at 1kg, 2kg, and 3kg workload conditions at 80 revolutions per minute on a cycle ergometer, with a commercial set of power pedals and customized instrumented pedals. A 3x2 (Condition x Pedal Type) ANOVA was used to determine differences in total, right, and left power output. No significant interaction or main effect for pedal type was found, but a significant workload effect was present for all variables. The percentage differences in measurement between the two pedals were approximately 3.6%, 1.3%, and 1.2% for average total power of 1kg, 2kg, and 3kg, respectively. This study provides evidence that the power output measured by Favero power meter adequately matched the total power output and individual limb power output obtained by gold-standard instrumented pedals during stationary cycling. These results indicate that the commercial power pedals can adequately match gold standard instrumented pedals in measuring bilateral power output in short sessions of low to moderate intensity stationary cycling. The power meter may be suitable to measure power output for endurance or clinical applications, but further research is needed to investigate these use cases.

Keywords: Cycling, Power Output, Crank Torque, Power Meter, Accuracy.

1. Introduction

Power output is a measure of energy over time during cycling and is a metric that has been investigated in healthy participants of varying experience and performance levels, and pathological population exercise interventions. Several studies have examined important topics such as comparison of power load asymmetry in individuals with injury or pathology, optimal cadence for power output as a function of cycling experience, and understanding the kinetic and kinematic effects of cycling at various power loads (Buddhadev, Crisafulli, Suprak, & San Juan, 2018; Hunt, Sanderson, Moffet, & Inglis, 2004; Hurworth, Evans, Gibbons, Mackie, & Edmondston, 2021; Marsh & Martin, 1997).

While traditionally restricted to laboratory use, commercial crank-based systems, such as the Schoberer Rad Meßtechnik (SRM GmbH, Jülich, Germany) Power Meter, allowed recreational and professional cyclists to obtain power data starting in 1989. Commercially available pedal-based systems have slowly become available since 2013 and provide flexibility by allowing users to switch them between bikes.

Systems such as the Favero Assioma Duo (FAD) pedals (Favero Electronics Srl, Arcade, Italy), provide independent power measurements for each pedal/limb and allow bilateral asymmetry to be assessed, which can be valuable for clinical applications (Buddhadev et al., 2018; Hunt et al., 2004). This is important because SRM and pedal-based power systems are historically strain gauge based, but pedal reaction forces (PRFs) can now be obtained from piezoelectric sensors which have the advantage of responsiveness to more dynamic and higher frequency applications (Fang, Fitzhugh, Crouter, Gardner, & Zhang, 2016; Soden & Adeyefa, 1979).

Yet, to our knowledge, comparisons between commercially available pedal-based power measurement systems and experimentally measured PRFs have not been conducted. Determining if commercial systems such as the FAD are comparable to PRFs in power output measurement is important for bringing cost effective, portable clinically relevant devices outside the laboratory. Previous literature has compared the validity and reliability of the FAD pedals against crank-based SRM systems for measuring total and bilateral power output (Montalvo-Pérez et al., 2021; Rodríguez-Rielves et al., 2021; Yeh et al., 2022). These studies provided evidence that supports good to excellent intraclass correlation coefficients with SRM measurements and almost no significant differences between measurements at widely ranging cadences and power settings that included maximal effort testing (Montalvo-Pérez et al., 2021; Rodríguez-Rielves et al., 2021; Yeh et al., 2022). There was underestimation of power output values at lower power settings that were statistically significant for SRM measurements, but not for FAD measurements (Montalvo-Pérez et al., 2021). The authors attribute, partially, differences in this specific measurement to material deformation of bicycle components that occur between the spindle and the pedal.

Therefore, the purpose of this study was to compare the total and bilateral power output measured by a commercially available set of pedal power meters and a set of instrumented pedals.

2. Materials and Methods

2.1. Participants

A total of ten healthy participants who engaged in moderate-to-vigorous recreational activity at least three times a week, participated in this study. Nine participants' data were used due to a technical difficulty in data collection for one participant (21±2 years, mass: 76±12 kg, height: 1.68±0.1 m, Female=6, Male=3). Participants had no lower extremity injuries in the past six months, were between the ages of 18 to 35, and no more than three hours of cycling experience of any kind per week. All participants signed the informed consent form approved by the University Institutional Review Board. Additionally, participants were only included if they answered no to each item on the first page of the Physical Activity Readiness Questionnaire+.

2.2. Instrumentation

Three-dimensional (3D) kinematic (240Hz) data from a 12-camera motion analysis system (Vicon Motion Analysis Inc., UK) and 3D PRF data from a pair of customized instrumented pedals (IP) (1200 Hz, Type 9027C, Kistler, Switzerland) were recorded using Vicon's Nexus software. Retroreflective markers were applied to the crank axis, pedals, and pedal spindle axis of both sides of the bike. For the IP, these markers were used to obtain pedal and crank angles and crank angular velocity. The power output data from the power meter, FAD, (Assioma Duo, Favero Electronics, Italy) were streamed via a Bluetooth connection to a Garmin Edge 1030 Plus and stored as average data at 1 Hz using a bike computer (Garmin, Olathe, Kansas), simultaneously. Total power and left-right balance, reported as a percentage per second, were the outputs of interest for the FAD pedals. Individual limb power output was obtained for the FAD by multiplying the left and right balance percentages by the total power. The IP had a toe cage, while the FAD had a flat, studded mountain bike style platform surface. A cycle ergometer (Model 818E, Monark, Varberg, Sweden) was used in testing.

2.3. Testing Protocols

All participants completed a standardized procedure to determine their proper bike fit. Saddle height was adjusted so that the participant's knee flexion angle was approximately 25-30° with the pedal at bottom dead center (180° of crank angle) , and measured using a goniometer (Bini, Hume, & Croft, 2011). The saddle fore-aft position was set at a position to align the patella with the pedal at bottom dead center, using a plumb bob (Fang et al., 2016; Gardner, Klipple, Stewart, Asif, & Zhang, 2016). The handlebar position was adjusted to ensure a trunk angle of 90°.

Participants attended one test session. They completed a three-minute cycle ergometer warm-up, at a workload of 0.5kg at a self-selected pace. They completed six 2-minute cycle testing conditions, with workloads of 1kg, 2kg and 3kg at 80 revolutions per minute (RPM), in each of the two pedal conditions, IP and FAD. 1kg, 2kg, and 3kg at 80 RPM equates to 78.5, 157, and 235.4 W, respectively. The pedal types were first randomized, and the workloads were further randomized within each pedal type, for each participant. Participants were provided a metronome set to 80 beats per minute but were allowed to decline it. Rest was allowed between conditions as needed but was always a minimum of 1 minute.

Data were collected during the last ten seconds of each condition. The Garmin Edge 1030 Plus was set to record FAD data immediately before the Vicon system recording began and ensure that the 10 second trial was captured.

2.4. Data and Statistical Analyses

Visual 3D (C-Motion, Inc., Germantown, MD, USA) was used to calculate pedal position and crank angular velocity for the IP conditions. PRF data were filtered using a fourth-order zero-lag lowpass Butterworth filter at a cutoff frequency of 6 Hz (Fang et al., 2016; Gardner et al., 2016). A customized script in Python (v3.11.6) was created to process Garmin .fit files and IP output files, calculate power output, and generate Bland Altman plots. Considering the lack of synchronization between the Garmin Edge 1030 Plus and the Vicon system, the first recorded total power data point from the FAD files was discarded and the subsequent four data points were used for further analysis. Each total power output data point from the Garmin was provided as the average total power output over a period of one second. FAD left and right powers were computed based on the left-right balance percentages and total power recorded by the Garmin bike computer. For the IPs, the first five consecutive crank cycles of the ten second trial were used for power output calculations over a time period of approximately 3.75 seconds. At 80 RPM, this method provides the best comparison to the 4-second data recorded by the FADs. Total power output for IP conditions was obtained from the summation of the right and left powers.

The power output for IP conditions was computed using a method adapted from Coyle et al (Coyle et al., 1991). The coordinate system has been adjusted to our equipment setup to allow for power calculations (Figure 1). First, tangential (F_y) and normal (F_z) crank force were calculated based on the pedal angle (β) and vertical and horizontal PRFs (Equations 1 and 2, Figure 1). Crank torque (T_c) was computed as a cross product of crank arm length (L_c) and crank force (F, Equation 3). The power output was computed as a product of crank torque (T_c) and crank angular velocity (ω) (Equation 4).

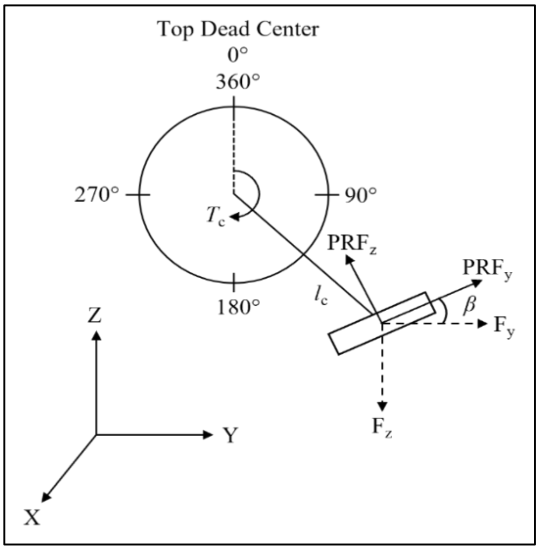

Figure 1. Diagram of the crank and pedal coordinate system adapted from Coyle et al. to determine power output.

$$F_y = PRF_y \cos(\beta) - PRF_z \sin(\beta)$$

Equation (1)

$$F_y = PRF_y \cos(\beta) - PRF_z \sin(\beta)$$

Equation (2)

$$T_c = \vec{l_c} \times \vec{F}$$

Equation (3)

$$Power\ Output = T_c * \omega$$

Equation (4)

Comparisons between variables obtained from both pedals were carried out with two-way (Pedal x Condition) repeated measures ANOVAs to determine if workload, pedal type, or interactions between workload and pedal type were significant with an α level set at 0.05 in SPSS (v29, IBM, Armonk, New York, USA). Variables only obtained from IPs were assessed with one-way repeated measures ANOVAs to determine the presence of significant workload effects. Bonferroni corrections were made in post hoc comparisons for both ANOVA models.

3. Results

No significant interaction effects were observed between workload and pedal type or for a main effect of pedal type. When comparing IP and FAD, there was a significant effect of workload after post hoc comparisons ($p<0.001$) and no significant effects ($p\geq0.14$) for pedal type (Table 1). A significant effect of workload was seen for all variables. IP derived peak crank torque, peak and average power output, and peak PRFs are available in Table 2.

Figures 2 and 3 display a normalized, ensemble curve of average right crank torque and right power output at 3kg for a single cycle of the IPs, respectively.

Bland-Altman plots for all three workloads were created for visual quantification of the agreement between IP and FAD for the right-side power measurements (Figure 4, 5, and 6). The mean measurement differences, or bias, revealed through the Bland-Altman plots between IP and FAD were 1.33, 2.62, and 7.67 W for the right power output 1kg, 2kg, and 3kg conditions, respectively. The 95% limits of agreement amongst these three conditions ranged from 11.57 W to 35.49 W.

Table 1. Descriptive statistics and repeated measures ANOVA of Total Power (W), Right Power (W), Left Power (W) across workloads: mean ± STD.

Variable	Pedal	1kg	2kg	3kg	Workload p (η^2_p)	Pedal p (η^2_p)	Interaction p (η^2_p)
Total Power$^{\alpha,\beta,\gamma}$	*IP*	96.17 ± 7.53	163.90 ± 11.26	248.31 ± 12.46	**<0.001**	0.716	0.719
	FAD	92.78 ± 9.82	166.00 ± 9.97	245.44 ± 18.40	(0.981)	(0.008)	(0.020)
Right Power$^{\alpha,\beta,\gamma}$	*IP*	47.62 ± 6.84	82.52 ± 8.53	120.65 ± 7.84	**<0.001**	0.193	0.427
	FAD	48.95 ± 7.52	85.14 ± 6.28	128.32 ± 13.13	(0.966)	(0.104)	(0.052)
Left Power$^{\alpha,\beta,\gamma}$	*IP*	48.54 ± 7.01	81.38 ± 10.82	127.65 ± 10.94	**<0.001**	0.140	0.226
	FAD	43.82 ± 8.53	80.86 ± 8.88	117.12 ± 12.83	(0.957)	(0.131)	(0.089)

Note: η^2_p - partial eta squared, STD - standard deviation, IP – instrumented pedals, FAD – Favero Assioma Duo Pedals, $^{\alpha}$ – significant difference between 1kg and 2kg, $^{\beta}$ – significant difference between 1kg and 3kg, $^{\gamma}$ – significant difference between 2kg and 3kg.

Table 2. Descriptive statistics and ANOVA of variables derived from the right instrumented pedal. Peak Torque (Nm), Peak Power (W), Average Power (W), Peak PRFy (N), Peak PRFz (N) across workloads: mean ± STD

Variable	1kg	2kg	3kg	Workload - p (η^2)
Peak Torque$_1$$^{\alpha,\beta,\gamma}$	35.01 ± 5.72	47.05 ± 6.04	58.52 ± 5.68	**<0.001** (0.754)
Peak Power$_1$$^{\alpha,\beta,\gamma}$	296.05 ± 49.64	394.71 ± 49.90	500.88 ± 51.28	**<0.001** (0.757)
Average Power$_1$$^{\alpha,\beta,\gamma}$	155.88 ± 20.46	203.89 ± 22.40	265.83 ± 18.71	**<0.001** (0.843)
Average Power$_2$$^{\alpha,\beta,\gamma}$	-63.98 ± 15.83	-42.46 ± 18.23	-28.62 ± 18.05	**<0.001** (0.440)
Peak PRF$_y$ $^{\alpha,\beta,\gamma}$	-19.56 ± 11.06	-24.12 ± 10.67	-32.86 ± 9.75	**0.039** (0.237)
Peak PRF$_z$ $^{\alpha,\beta,\gamma}$	206.73 ± 42.26	269.76 ± 45.51	338.11 ± 22.18	**<0.001** (0.691)

Note: η^2 - eta squared, STD - standard deviation, PRF – Pedal Reaction Force, $_1$ – indicates value obtained during the power phase of the cycle, $_2$ – indicates value obtained during the recovery phase of the cycle $^{\alpha}$ – significant difference between 1kg and 2kg, $^{\beta}$ – significant difference between 1kg and 3kg, $^{\gamma}$ – significant difference between 2kg and 3kg.

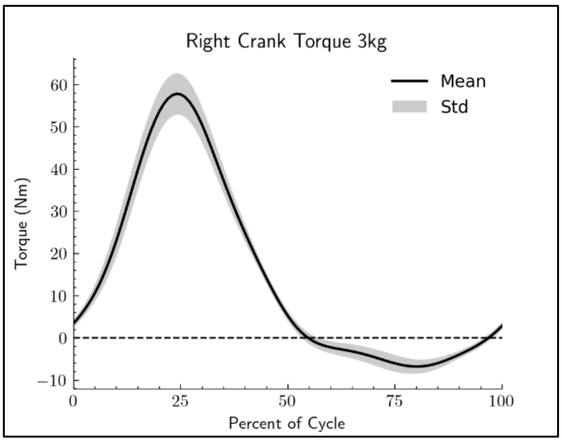

Figure 2. Ensemble curve of right pedal crank torque (Nm) during the 3kg condition for an entire cycle revolution.

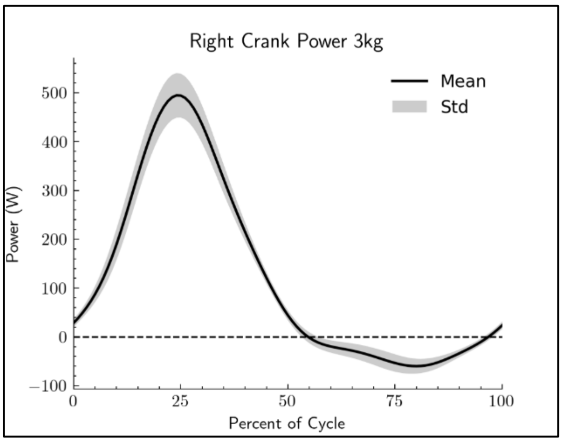

Figure 3. Ensemble curve of right pedal power output (W) during the 3kg condition for an entire cycle revolution.

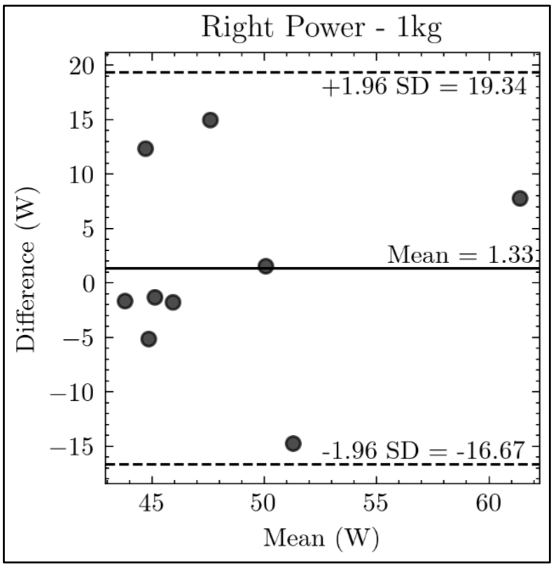

Figure 4. Bland-Altman limits of agreement plot comparing measured power output from the FAD and IP systems at 1kg for the right pedal.

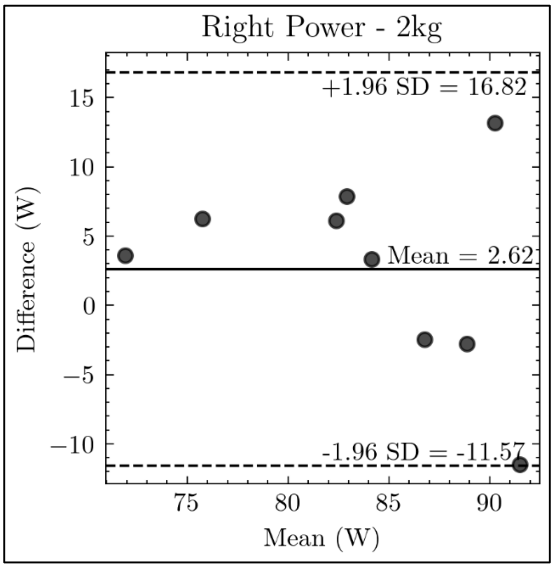

Figure 5. Bland-Altman limits of agreement plot comparing measured power output from the FAD and IP systems at 2kg for the right pedal.

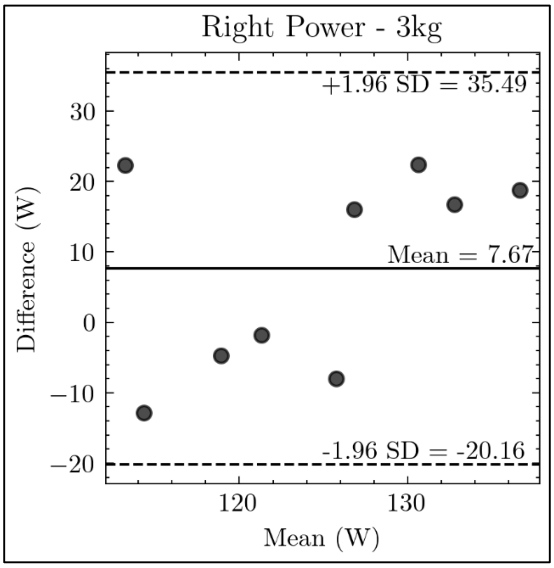

Figure 6. Bland-Altman limits of agreement plot comparing measured power output from the FAD and IP systems at 3kg for the right pedal.

4. Discussion

The purpose of the present study was to evaluate the measurements of total and bilateral cycling power during submaximal cycling between a commercially available system and a gold standard set of instrumented pedals. The repeated measures ANOVA revealed no significant effects of pedal type or interaction of pedal and workload were found for any variable in this study. The percentage differences in measurement between IP and FAD pedals were approximately 3.6%, 1.3%, and 1.2% for total power for 1kg, 2kg, and 3kg conditions, respectively while total power differences were approximately 3.4, 2.1, and 2.87 W at the 1kg, 2kg, and 3kg conditions, respectively. Results from this study agree with previous literature showing that there are no significant differences between the power measurement devices (Montalvo-Pérez et al., 2021). Percent power differences at 150 and 250 W (at 85 RPM) from previous works and our findings for total power (Power = braking load * RPM) at 80 RPM with resistances of 2kg (157 W) and 3kg (235 W), were similar and approximately 1.1 - 1.14% and 0.00 - 0.02%, respectively (Montalvo-Pérez et al., 2021; Rodríguez-Rielves et al., 2021). This similarity in results demonstrates that the FADs are capable of matching gold standard measurements at medium cadence and power setting ranges. Additionally, given that the right and left power contributions did not display a significant pedal type effect, it appears that the bilateral measurement capabilities of the FAD match the gold standard IP. Unilateral Favero pedal systems have also been evaluated for their ability to estimate power output (Valenzuela et al., 2022). While no significant differences were found when comparing unilateral to bilateral Favero systems, the authors did report 10-13% power output asymmetries at low power. As a result, the accuracy of total power output by unilateral Favero pedals is likely in question for rehabilitation settings where high power output or maximal effort cycling is not common. One of the main benefits of this finding is that the FAD power meter system seems to offer valid power output measurements, and it is more affordable for clinical applications and recreational use compared to more specialized lab equipment such as the IP system.

The Bland-Altman plots demonstrate a good agreement between the measurements with a small absolute mean differences between the pedal systems. The mean difference in power, shown in the Bland-Altman plots, did increase in value from the 1kg to 3kg condition, which may indicate a potential proportional bias in the power readings. For the right pedal, the mean difference in power output is greater for the FAD system during all conditions, but for the left pedal, this effect is reversed. Mean measurement bias for the right pedal in this study ranged from 1.33 to 7.67 W which were very similar to the findings by Rodríguez-Rielves and Montalvo-Pérez as both reported biases of less than 8 W. However, the reports from Rodríguez-Rielves and Montalvo-Pérez were based on total power output, instead of examining each pedal individually. Additionally, it should be noted that the two previously mentioned studies implemented graded exercise tests or sprints that had much higher intensity than the testing protocols used in this study (Montalvo-Pérez et al., 2021; Rodríguez-Rielves et al., 2021). Similar bias values reported in this study and related literature indicate that there is likely no propotional bias in power measurements.This conclusion is supported by the wide range of power settings (78.5-600 W) that have been evaluated in cycling literature on the Favero pedals. Proportional biases may be more obvious if measurements between the FAD and a gold standard increased with power output.

It has been reported that significant power output differences occur at lower power settings (Montalvo-Pérez et al., 2021), but our research did not show this with the lowest power setting being approximately 78.5 W (1kg) with a slightly elevated difference of 3.5% between IP and FAD pedals. The two devices do not appear to display significant measurement differences even though sampling frequency is considerably lower in the FAD system. This may be a result of the FAD recording more data for calculations, such as crank torque and angular velocity, than is reported to the user. It is surprising that the FAD pedals were able to approximately match the IP even with a large sampling frequency disparity of 1 Hz to 240 Hz, respectively.

The present study's limitations include small sample size, participant experience, cycling intensity, and cycling stance. While the sample size in this study was relatively small, Rodríguez-Rielves performed an analysis on 12 cyclists and Montalvo-Pérez recorded data on 33 cyclists. The use of more experienced cyclists may also have resulted in more consistency between the force application on the pedals and cadence, thus affecting the power output. Some studies have investigated sitting and standing on the bicycle at considerably higher intensities than what were implemented in this study. As a result, findings from this study cannot be extrapolated to bouts of intense cycling over 250 W. Additionally, more power meter systems could be used in the future to make comparisons more robust as opposed to only one system. Further research on pedal power meter validity could be conducted on other power meters.

Considering the level of congruence in this study's results with previous literature that compared the FAD to SRM-based power outputs, it appears that the FAD records total and bilateral power outputs adequately.

5. Practical Applications.

Findings from this study provide evidence for the use of FAD pedals in stationary cycling. These pedals can be used to measure bilateral power output adequately in those training at home, inside recreational facilities, or at rehabilitation clinics. This study supports the use of FAD pedals for short duration, seated cycling applications and did not investigate standing or long duration sessions. As a result, the authors cannot comment on the potential of measurement drift in the FAD system. However, coaches and practitioners can be comfortable using these pedals as benchmarks for power output during shorter duration trials.

The most significant limitation of this study is the lack of direct temporal synchronization between the IP and FAD systems. While it was a best attempt to align the two recordings by truncating the FAD data points, it is quite possible that the data recording started at different parts of the crank cycle for FAD data samples while the five IP data trials were averaged from the start to the end of crank cycle. However, the impact of this difference on the results is reduced as the results were reported over a 1 second period of each sample for FAD and five crank cycle trials for IP. Given that no main effect of pedal type was found in conjunction with comparable standard deviations, the synchronization method may have minimum effect on the results. In addition, the FAD system does not report angular velocity or applied torque which makes direct comparisons with our IP pedals impossible. Finally, with the limitation of 1 Hz output from the FADs their value is more conducive to longer stretches of cycling bout as opposed to detailed analysis of fewer crank cycles.

6. Conclusions

No significant differences were found when comparing average total, left, and right powers between gold-standard IP and FAD pedal types. This study provides evidence for the accuracy of a commercial pedal-based power system in cycling applications for recording total and individual power output outputs during low and moderate intensities in cycling. As a result of this work, the FAD system seems to be accurate and valid for measuring user power output and can be used for endurance training, rehabilitation tracking, and asymmetry identification applications. Future research may investigate whether pedal power measurements are consistent between sitting and standing cycle positions as well as endurance cycling trials.

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Conflicts of Interest: The authors declare no conflict of interest.

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