BOOK OF ABSTRACTS
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Validation of a new pedal sensor to measure torque, power and work during pedaling.

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Abstract

Background: In the field of biomechanical analysis of pedaling motion, researchers studied the relationship between cost energy and cycling technique for optimal use of the force applied to the pedals, to improve cycling velocity for minimal energy cost or to compute the joint powers according to the resistive load. For that, numerous measuring devices have been developed and investigated to evaluate resultant torque and/or power output. Recently, new pedal sensors I-Crankset (ICS) are sold to measure the forces applied to the pedals and to calculate the torque and/or power output produced during cycling. These pedals' sensors were calibrated and certificated, but it was essential to check if these devices still measured accurately after their integration on an ergometer.

Purpose: The aim of this study was to compare dynamically this new device for measuring crankset's resultant torque, mechanical power and work outputs.

Methods: A subject (Male, 75 kg, 1.82 m, trained rider) took part to this study conducted ethically according to international standards. The rider adjusted the cycle ergometer according to its personal settings. Figure 1 described the test bench. It was composed of: a chainring (A) was used to connect the ergocycle to the bench through a chain and a flywheel (D) associated with a mechanical braking device (E) composed of a tray with additional masses.
The evaluation protocol was implemented to achieve three pedaling conditions and so to cover the usual torque and power ranges (Table 1). For each condition, the subject produced a pedaling torque to overcome that resistive load during one trial of 90 seconds. Feedback of cadence was displayed on the "Power Control" SRM bicycle computer.
The torque reference sensor (model 1641/1648, Lebow) named RTSL (C) was installed on the axis (B). The scientific version SRM sensor was mounted on the crankset of the ergocycle. The ICS sensors were fixed at each pedal. The relative pedal to crank and the crank to ergometer angles were measured using encoders.

Analyzed parameters: As all the signals are acquired at 200 Hz and synchronized, for each cycle and for each acquisition system, we had the same number of acquisitions samples. According to the sample rate and protocol used, more than 12 000 instantaneous measures will be available for the comparison of several devices.
Three power outputs were computed through these equations: (1) $P^{RTSL} = \tau^{RTSL}\omega^{RTSL}$ with $\omega^{RTSL} = k\omega^{ICS}$, k is the reduction coefficient between SRM and bench chainrings, ratio of the two diameters. (2) SRM: $P^{SRM} = \tau^{SRM}\omega^{SRM}$, ω^{SRM} is the average angular velocity of the crankset over the cycle. (3) ICS: $P^{ICS} = \tau^{ICS}\omega^{ICS}$, ω^{ICS} is instantaneous angular velocity of the crankset computed from encoders measures. The mechanical work outputs ($W^{RTSL}, W^{SRM}, W^{ICS}, W^{SRM*}$) were given by integration over the time of the power outputs. By design, the SRM only measures an average angular velocity, so we computed mechanical work firstly considering this constant angular velocity (W^{SRM}) and secondly considering instantaneous angular velocity provided by ICS encoders (W^{SRM*}).
Statistical analysis: For each condition, the same analysis was performed on torque, power and work outputs obtained from the different sensors. These instantaneous parameters, once pedaling cycles normalized, were compared using a coefficient of multiple correlation inter-protocol (CMC_{ip}) to appreciate the similarity of the instantaneous measures waveforms given by various sensors in a single acquisition of the same parameter. For each condition (n=30 cycles) and for all conditions (n=90 cycles), the averaged torque and power output were computed over each cycle and then these values were compared pairwise of sensors (A Bland-Altman analysis). A global normalized averaged torque evolution over cycles was also computed for condition 1 and for each sensor using.

Results:
Mechanical power output comparisons: Table 2 reports all the data for the comparison of the averaged power output measured by the three sensors, for the each condition and all conditions. Especially for condition 3, we note an increase for the power output of the mean bias and error range between SRM and RTSL against those computed for the torque [mean bias: -4.4 ±2.3% for the power vs -1.20 ±0.53% for the torque; error range: 29 W (9.2%) for the power and 0.79 Nm (1.9%) for the torque]. This is not the case for ICS. The figure 3 confirms these results with a 95% limits of agreement larger for the SRM than ICS [respectively -1.81; 7.37 W and -20.70; 9.48 W for ICS and SRM].
Mechanical work output comparisons: Table 3 shows the difference of cumulative output work over thirty cycles between ICS and RTSL then SRM and RTSL for each condition. The differences are also expressed as the percentage of the total cumulated work. To analyze the influence of the angular velocity, we integrated power output over time to compute the work output in using i) the torque and angular velocity measured by SRM (W^{SRM}) and ii) the SRM torque multiplied by ICS angular velocity (W^{SRM*}).
These results are presented at the last lines of table 4. The relative error is under 2% whatever the conditions, excepted for condition 3 between SRM and RTSL (5.26%). This error can be reduced by using ω^{ICS} provided by ICS to compute the W^{SRM*} (1.44 %).

Discussion: Power output discussion. For the power output, we note high values of CMC_{ip}^{P} between ICS and RTSL (Table 3). For the steady state condition (C1: 210 W), ICS power mean relative error (0.1 ±0.5%) is better than [1] when comparing Velotron cycle ergometer (-0.8% for constant 250 W trial) with a test bench. For condition 2 (150 – 250 W, 80 rpm), ICS results (1.8 ±0.5%, Table 2) are closed to power mean relative error reported by [4] when comparing Powertap (-1.5 ±0.6% for 50-1000 W at 100 rpm trial) with a test bench. As SRM is considered as a gold standard [5], we will try to position ICS against SRM. Before that, we check that SRM results are consistent with literature. The mean relative errors reported by [1] (0.18%) and [4] (0.1 ±1.1%) are lower than errors of the present study (respectively 0.8 ±1.2% for condition 1 and -0.8 ±2.1% for condition 2). These differences can be related to the possibility of the test bench used by [6] to maintain a constant pace along all the cycle unlike the protocol of this study (mean cadence: 8.3 ±0.2 rad/s for conditions 1 and 2). Indeed, it's difficult for a rider to produce a constant crankset angular velocity like the motorised test bench used by [1] and [3]. [1] shows that a rapidly increasing angular velocity results in a more inaccurate power measurement (mean relative error: -3.3 %; CI = -8.1 to 1.5 %). This is closer to the results for condition 3 (-4.4 %; CI = -9 to 0.2 %). This condition accentuates the inability of the SRM to record, by design, instantaneous crankset angular velocity. For a similar pedaling cadence and power output, the relative mean error (1.2 %) between Powertap ergometer and SRM reported by [2] is comparable with the relative error between ICS and SRM computed for condition 1 (0.9%, Table 3). However, ICS seems to be more accurate than SRM when looking at the individual results obtained for SRM (-2.4%) and ICS (1.2%) against RTSL for all conditions. Consequently, as for the torque, ICS can be considered sufficiently accurate.

Work output discussion: Table 3 show the requirement to precisely measure the instantaneous values of crankset angular velocity to calculate the work as part of an energy study of the pedaling motion. Thus, when pedaling with constant angular velocity, the power output computed by SRM (P^{SRM}) is enough accurate to calculate the work output (W^{SRM}). For the conditions 1 and 2, the error respectively equal to 0.98% and 1.16% is acceptable. But when the angular velocity is variable, the error becomes equal to 5.26% for the SRM while it is still under 2% for ICS. This result confirms those obtained by [1] which indicates that a rapidly increasing angular velocity causes an inaccuracy in calculating the SRM power. This error is reduced to 1.44% when the torque measured by SRM (τ^{SRM}) is multiplied by the instantaneous angular velocity measured by ICS (ω^{ICS}). So, ICS should be preferred for power and work outputs investigations.

Conclusions: The study showed that ICS sensor was an accurate powermeter comparable to a standard reference sensor and to SRM regardless the pedaling cadence (56 to 90 rpm) and the resistive load (18 to 42 Nm). However, ICS was more efficient than SRM for evaluating the work particularly when the pedaling angular velocity various significantly. This study showed that it was therefore essential to measure both instantaneous torque and angular velocity in order to conduct an energy analysis of the pedaling motion.

Conditions (Powers)	**C1 (≈210W)**	**C2 (≈150 – 250 W)**	**C3(≈250 – 400 W)**
Resistive load	26 Nm	18 to 30 Nm	42 Nm
Pedaling cadence	80 rpm	80 rpm	56 to 90 rpm

Table 1: The pedaling conditions used in the present study.

Figure 1: Placement and description of the three devices used in the present study

Conditions	**Comparisons**	**Slopes**	**R²**	**Mean bias ±1SD (W)**	**Relative mean bias ±1SD (%)**	**Error range (W)**	**Relative error range (%)**	CMC_{IP}^{P}
C1	SRM vs RTSL	1.070	0.976	-1.7+/-2.6	-0.8+/-1.2	12.0	5.5	0.986
C1	ICS vs RTSL	0.993	0.994	0.2+/-1.1	0.1+/-0.5	5.0	2.3	0.997
C1	ICS vs SRM	0.911	0.978	1.8+/-2.5	0.9+/-1.2	12.0	5.6	0.984
C2	SRM vs RTSL	0.977	0.976	-1.5+/-3.7	-0.8+/-2.1	14.0	7.8	0.981
C2	ICS vs RTSL	1.010	0.999	3.3+/-0.9	1.8+/-0.5	3.5	1.9	0.995
C2	ICS vs SRM	1.020	0.981	4.8+/-3.4	2.7+/-1.9	14.0	8.0	0.977
C3	SRM vs RTSL	1.080	0.980	-14.0+/-7.3	-4.4+/-2.3	29.0	9.2	0.981
C3	ICS vs RTSL	1.020	0.999	4.9+/-1.5	1.5+/-0.5	5.5	1.7	0.996
C3	ICS vs SRM	0.928	0.982	18.0+/-6.6	5.9+/-2.1	27.0	8.6	0.973
All	SRM vs RTSL	0.935	0.990	-5.6+/-7.5	-2.4+/-3.2	39.0	17.0	0.983
All	ICS vs RTSL	1.020	0.999	2.8+/-2.3	1.2+/-1.0	10.0	4.3	0.996
All	ICS vs SRM	1.080	0.989	8.4+/-8.6	3.6+/-3.6	42.0	18.0	0.978

Table 2 Statistical results (regression slope, correlation coefficient, mean bias, error range, coefficient of multiple correlation inter-protocol) for the comparison of averaged power outputs between each sensor (I-Crankset, SRM and Reference torque sensor), for each condition (n=30 cycles) and all conditions (n=90 cycles).

Conditions	C1		C2		C3	
Parameters	Work (J)	*(%)*	Work (J)	*(%)*	Work (J)	*(%)*
$W^{RTSL} - W^{ICS}$	1.63	*0.03*	74.27	*1.88*	117.44	*1.56*
$W^{RTSL} - W^{SRM}$	46.25	*0.98*	45.72	*1.16*	396.77	*5.26*
$W^{RTSL} - W^{SRM*}$	38.42	*0.81*	39.37	*1.00*	108.28	*1.44*

Table 3 Total difference of cumulative work output (J and %) for each condition (n = 30 cycles), between ICS and RTSL and between SRM and RTSL.

References

1 Abbiss CR, Quod MJ, Levin G, Martin DT, Laursen PB. Accuracy of the Velotron ergometer and SRM power meter. Int J Sports Med 2009; 30: 107–112

2 Bertucci W and col. Validity and reliability of the PowerTap mobile cycling powermeter when compared with the SRM Device. Int J Sports Med 2005; 26: 868–873

3 Bini RR, Hume PA. Between-day reliability of pedal forces for cyclists during an incremental cycling test to exhaustion. Isokinet Exerc Sci 2013; 21: 203–209

4 Gardner AS and col. Accuracy of SRM and power tap power monitoring systems for bicycling. Med Sci Sports Exerc 2004; 36: 1252–1258

5 Hopker J and col. Validity and reliability of the Wattbike cycle ergometer. Int J Sports Med 2010; 31: 731–736

6 Woods GF and col. The dynamic calibration of cycle ergometers. Int J Sports Med 1994; 15: 168–171

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