A single-case study

A new approach to biomechanical analysis in cycling to introduce science to future data acquisition

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1. Cycling analysis, 2. Powermeter, 3. Cycling

1. Introduction

With the invention of power measurement systems for cyclists by Ulrich Schoberer in 1986, the training of riders and their equipment has been put to another level. Over time, more and more parameters for the assessment of physiological processes and biomechanical analysis have been established[1), 2), 3)]. Biomechanical factors play a more important role in defining new indicators to search for the smallest detail and advantage[4), 5), 6)]. The aim of this single case study is to show the improved power measurement and a possible significant research benefit that will come up in the future using a new development of SRM. It will be demonstrated by evaluating a ride on an Indoortrainer with an oval and round chainring and two rides of different training targets. The amount of the highly resolved recorded data has improved with the Powermeter prototype what may also lead to many exciting discussions and approaches to introduce or rethink parameters.

2. Materials and method

The 22-year-old, 1.87 m tall and 72.1 kg male participant in the present study has years of experience in competitive cycling and triathlon. Using a prototype of the new Powermeter invention this research is designed as a single case study. Shown will be a ride on an Indoortrainer with oval and round 56 teeth chainrings to proof the improved power calculation. For that, the rider executed a one-hour ride divided into two 30-minute parts at 250 $\pm$4 W and 73.5 $\pm$ 1 rpm cadence, changing between the round and oval chainring every five minutes to determine the better measuring method. The difference between the 30-minute parts was the recording of the data using the so-called IMU mode, where 200 Hz angular velocity and torque are recorded, and the rotation-based mode, where the average torque and angular velocity per full crank repetition are used to determine the power after one complete crank revolution. In order to neglect the acceleration of the flywheel mass the last four minutes of each interval were recorded. To get further usable data for this work the participant had to execute two outdoor bike rides on a BMC Teammachine SLR01. These two rides had a total length of 84.86 $\pm$ 0.82 minutes. One ride was completed as continuous riding averaging 218 W and an average cadence of 84 rpm. In the second ride the participant completed five six-minute intervals at 369 $\pm$ 2.59 W with a cadence of 89.07 $\pm$ 0.93 rpm and 3 minutes rest at 227 $\pm$ 6.9 W and a ten-minute effort of 322 W and 89 rpm with eight minutes rest at 203 W to the last six-minute effort. For the intervals the rider was supposed to find a flat road with as little turns as possible in order to keep a constant power output. Second by second power output and cadence have been displayed on a head unit to execute the given tasks. The power output has been measured by an SRM Spiderpowermeter prototype. Additionally, torque and angular velocity have been measured and recorded with associated angle every five milliseconds and have been stored in a mass storage device. To get the correct torque and angular velocity values the system needs to be calibrated which is done partly static and partly dynamic. Torque calibration is performed by loading the Powermeter with a gauged weight and taking the crankarm from the chainring size. Thereby, a calibration line is drawn from zero offset with and without load at both of the crank's dead spots. Angular velocity gets calibrated by putting the Powermeter in a lathe for 60 seconds telling the IMU sensor the correct data. SRM internal beta software was used to decode the recorded data into graphs and export them to Excel spreadsheets for further statistical analysis. With exporting the files to Excel to get the recorded data as well as the calculated respective current power, called "On Time Power" shown as their values, there have been several statistical analysis methods used to analyse the rides. For every file the mean and median have been calculated for every parameter. Because of the higher power, the intervals were looked at in more detail and highlighted in the analysis using the same statistical analysis methods.

3. Results

The most important finding of this paper is the more accurate power measurement as well as the increased amount of collected datapoints. Collected datapoints being 1,010,479 for each timestamp, torque, angular velocity and angle in the interval method and 1,029,519 for the continuous method in the new measuring method. Comparing at 60 rpm the new measuring method takes 720,000 datapoints per hour whereby the old method takes 3,600 datapoints per hour.

Table 1

(a)

No	Chain ring	Power /W	Cadence /rpm	Kin Energy Flywheel /J
1	Round	249	75	2024
2	Oval	247	75	2024
3	Round	251	74	1971
4	Oval	250	73	1918
5	Round	243	73	1918
6	Oval	243	72	1866

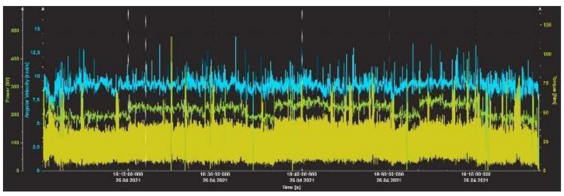
(b)

No	Chain ring	Power /W	Cadence /rpm	Kin Energy Flywheel /J
1	Round	246	72	1866
2	Oval	248	71	1814
3	Round	250	74	1971
4	Oval	259	74	1971
5	Round	250	74	1971
6	Oval	260	74	1971

Table 1 shows the measured power and cadence as well as the kinetic energy in the system of the Indoortrainer ride in the new IMU mode (table 1 a) and the old rotation-based mode (table 1 b). Noticeable is, that the measured power in the new IMU mode does not vary greatly in the mean value regarding the used chainring shape, each with 248 $\pm$ 3 W at a cadence of 74 $\pm$ 1 rpm for the round and 247 $\pm$ 3 W at 73 $\pm$ 1 rpm with the oval chainring. Also, kinetic energies are close to each other with 1936 $\pm$ 66 J riding the oval chainring and 1971 $\pm$ 43 J with the round one. In table 2 b is striking that the power output with the oval chainring is always higher being 256 $\pm$ 5 W at 73 $\pm$ 1 rpm. With the round one the rider hits 249 $\pm$ 2 W at also 73 $\pm$ 1 rpm. Although the kinetic energies do not differ so much in numbers with 1919 $\pm$ 74 J at the oval shaped and 1936 $\pm$ 49 J at the round shaped chainring the measured power is always different at a nearly same cadence. This can be attributed to the different measurement method used and shows the more accurate new method in table 1 a.

Figure 1

(a)



(b)

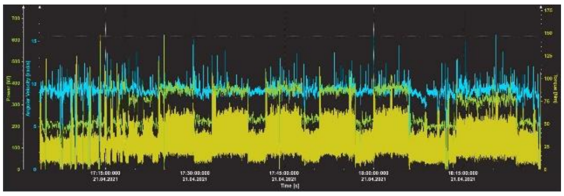


Figure 1 shows the graphic display from all datapoints of torque in yellow, angular velocity in light blue and power in green from both rides with (figure 1 a) being the continuous method and (figure 1 b) being the interval ride. One relevant aspect to address is the wide distribution of torque in every ride, whereby the angular velocity distribution takes place in a smaller range to get the nearly same power for a given time period.

Comparing figure 1 a and 1 b the angular velocity does not really change over duration neverminded the applied torque or produced power. In order to get the required power torque does keep the same level and range throughout the whole ride in the continuous method ride. Whereas, in the interval ride the torque increases as the intervals are ridden by the rider which is seen as the green power line raises but angular velocity stays nearly the same.

Table 2

	Torque [Nm]	
	Continuous method	Interval method
Mean	24.907	31.394
Median	24.813	29.5

Table 2 represents the mean and median for torque of both rides. In the continuous method ride the mean and median are close to each other with 24.907 $\pm$ 11.56 Nm and 24.813 Nm what might show an even ride. The mean torque with 31.394 $\pm$ 15.43 Nm is noticeably higher than the median with 29.5 Nm what shows that the ride might was not as even as the other one. This can also be seen in the previously shown diagrams.

Table 3

	On Time Power [W]	
	Continuous method	Interval method
Mean	218	286
Median	221	269

Taking a closer look at the calculated On Time Power output figures it is noticeable that the deviation of the mean and median value in the interval ride is higher just as in the torque recordings. The mean value with 286 $\pm$ 140 W is considerably higher in the interval ride than in the continuous effort with a mean of 218 $\pm$ 96 W. Yet, the median On Time Power of the continuous method is 221 W and thus 3 W higher than its mean opposite as in the correlating torque. Whereby in the interval ride the median is 269 and therefore 17 W lower than the mean value.

Table 4

(a)

No	Length [s]	Mean		
		Torque [Nm]	Angular Velocity [rad/s]	On Time Power [W]
1	360.29	38.750	9.47	368
2	361.10	40.309	9.17	368
3	360.92	39.470	9.35	369
4	359.09	39.560	9.34	368
5	360.33	40.356	9.31	374
6	600.38	34.746	9.31	322

(b)

No	Length [s]	Median		
		Torque [Nm]	Angular Velocity [rad/s]	On Time Power [W]
1	360.29	39.329	9.56	375
2	361.10	40.719	9.23	374
3	360.92	39.688	9.45	373
4	359.09	40.000	9.37	374
5	360.33	40.188	9.33	375
6	600.38	35.031	9.32	327

Table 4 shows mean (table 4 a) and median (table 4 b) of all completed intervals. For all intervals mean torque ranges around 38.865 $\pm$ 1.921 Nm and median is very similar at 39.159 $\pm$ 1.895 Nm. The angular velocity numbers with 9.32 $\pm$ 0.09 rad/s in mean and 9.38 $\pm$ 0.11 rad/s in median are also very equal. Comparing the six-minute efforts with a higher power output of 369 $\pm$ 2.59 W to the ten-minute effort with an average of 322 Watt the applied torque is only 4.943 $\pm$ 0.596 Nm higher despite a higher power output of 47 W average. Every calculated On Time Power output is lower in its mean value than in median, irrespective of the interval duration. To achieve the same performance, the rider can vary in torque and angular velocity, which is noticeable in the first two intervals where the torque is noticeably different but the angular velocity is only slightly different.

Figure 2

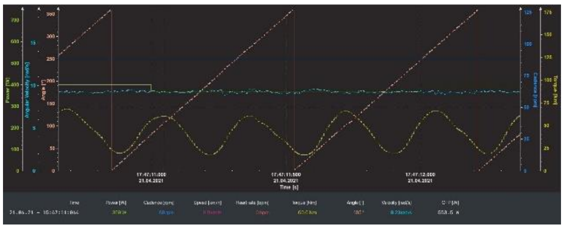


Figure 2 shows two crank repetitions as an example for the high resolution of the recorded data shown in a graph. Taken out of the third interval with a power output of 369 Watt at an 88 rpm cadence, it gets visible that the torque graph follows a sin function but is not even over the whole time. By definition, in the first 180 ° of a crank repetition the right leg is dominant and in the second 180 ° the left leg pushes the pedal down. The graph shows a higher unevenness for the left leg phase.

4. Discussion and practical applications

Some new findings can be derived from the results mentioned above. Most striking is the more accurate measurement of power with the IMU mode never mind if a round or oval chainring is used. Also, practical applications can be found and considered helpful for future research to get new parameters for cyclists training, rehab or else due to the 200 Hz resolution. Parameter ideas could be i.e. a normalized Torque, a ratio of angular velocity and torque or an algorithm for a more effective pedalling pattern. The highly increased amount of acquired data could also be used for a more detailed training evaluation or progress in rehab after injuries as well as for research. Therefore, studies can not only be executed under laboratory conditions but also outside with the same required data. Moreover, the high resolution of the recorded values shown in graphs can be used to optimise a riders' pedal pattern. The deviation of mean and median allow to analyse the evenness of a ride or interval. Peaks could play a role in sprints or track cycling. Due to a lack of prototypes no further research could be done on the track so far. Another possible use of the Powermeter could be found in the medical sector as already mentioned for rehab. A negative point of the Powermeter might be that it measures both applied torques at the same time and so only the sum of both values can be displayed. Therefore, it cannot be differentiated if one leg is applying more force or whether the other one is counteracting more or less.

6. Conclusion

To summarise this single case study, the new IMU based method in the Powermeter prototype calculates power more accurate and the collected data can be used to develop new parameters, indicators or even methods to improve the performance of a cyclist. Furthermore, it surely can find use in other sectors such as the medical. Future research needs to be done to find a scientific use of the values and to develop a user-friendly way to process and demonstrate all relevant data.

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