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A NEW PEDAL SYSTEM MEASURING FORCES IN THREE DIMENSIONS

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The purpose of this study was to analyse the accuracy of a new pedal system (CycPed) measuring forces in anterior-posterior, medio-lateral and vertical direction by using strain gauges. The forces measured with the pedal were compared in different dynamic situations with two different systems, SRM Powermeter and PowerForce. The CycPed data was converted in radial and tangential forces and pedal torque and power output were calculated. Pedal forces, torque and power output were in good agreement with the corresponding data gained from the SRM Powermeter and PowerForce. The pedal is light weight and data transmission could be implemented by using Bluetooth offering a good device for field measurements in cycling, which could be advantageous for athletes, coaches and scientist.

KEY WORDS: cycling, pedal force measurement, power output, accuracy.

INTRODUCTION: The analysis of pedal forces during cycling is an important factor for performance enhancement (Stapelfeldt, Mornieux, Oberheim, Belli, & Gollhofer, 2007) as well as for studying knee overuse injuries (Boyd, Hull, & Wootten, 1996). It was shown that the SRM Powermeter and the PowerTap system deliver reliable and valid power output data (Gardner, Stephens, Martin, Lawton, Lee, & Jenkins, 2004; Jones & Passfield, 1998). However, those systems do not measure the actual pedal forces. Several dynamometers for cycling exist (Boyd et al., 1996; Davis & Hull, 1981; Hull & Davis, 1981; Newmiller, Hull, & Zajac, 1988), but only a few studies realized a system for field measurements (Álvarez & Vinyolas, 1996; Rowe, Hull, & Wang, 1998). Stapelfeldt et al. (2007) developed a system measuring tangential and radial forces which can be mounted on any crank. This system is prepared for every pedal system to be screwed on (Stapelfeldt et al., 2007). However, so far it can only be used in a laboratory setting.
The aim was to create a pedal which is able to measure the forces in anterior-posterior, medio-lateral and vertical direction. Furthermore, the pedal should be light weight and suitable for both laboratory and field applications. The purpose of this study was to analyse the newly created CycPed system for its accuracy in respect to the dynamic comparison with the PowerForce and SRM Powermeter systems.

METHODS: Strain gauges were used to measure the forces in the three dimensions (Figure 1). Furthermore, each pedal is equipped with a rotary potentiometer for measuring the orientation of the pedal with respect to the orientation of the crank (pedal angle, PA). The pedal angle gained allows for calculating tangential and radial forces without an additional crank angle measuring device.

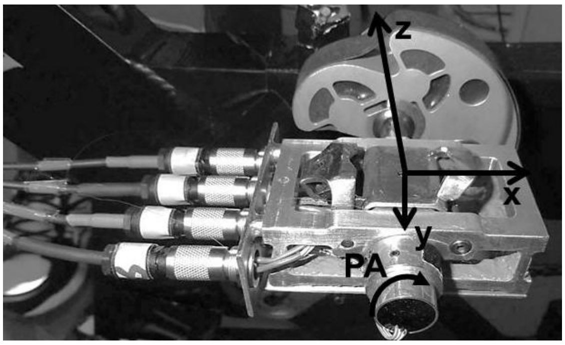

Figure 1: CycPed system for measuring forces in x- (anterior-posterior), y- (medio-lateral) and z- (vertical) direction as well as the pedal angle (PA).

Three subjects (29.0 ± 5.4yrs, 179.3 ± 4.5cm, 70.0 ± 3.3kg) were recruited and measured twice at a constant cadence of 70 rpm with power outputs of 100, 200 and 300 W. Afterwards, each subject performed cycling trials at a constant power output of 150 W with different cadences of 60, 70, 80, 90 and 100 rpm. Thirty revolutions were captured for each trial and results will be presented as the mean of these 30 revolutions. Subjects were recreational cyclists and used to click pedals. The forces measured with CycPed were compared with SRM Powermeter (Schoberer Rad Messtechnik SRM GmbH, Germany) and PowerForce (O-Tec, Germany). Data of each system was normalized to one crank revolution. In order to compare the forces measured by CycPed with the PowerForce system, tangential and radial forces were calculated. Following, pedal torque was calculated for CycPed and PowerForce to compare them with SRM Powermeter. Tangential forces of the x-component ($F_{T\,x}$) and the z-component ($F_{T\,z}$) of CycPed were calculated for each pedal as follows:

$$F_{T\,x} = F_x \cdot \cos{(PA)} \quad (1)$$
$$F_{T\,z} = F_z \cdot \sin{(PA)} \quad (2)$$

where PA is the pedal angle. $F_{T\,z}$ was multiplied by -1 to account for the fact that F_z is negative during the push phase. Following, the tangential force of CycPed ($F_{T\,CycPed}$) was calculated:

$$F_{T\,CycPed} = F_{T\,x} + F_{T\,z} \quad (3)$$

Radial forces were calculated by switching sine and cosine functions. From the pedal force data, measured with PowerForce, and from the converted force data of the CycPed, pedal torque (PT) was calculated as follows:

$$PT = \left(F_{T\,right} + F_{T\,left}\right) \cdot L \quad (4)$$

where $F_{T\,right}$ and $F_{T\,left}$ are the tangential forces of the right and left pedal, and L is the distance in meters from the crank axis to the pedal axis, which is not identical with the SRM crank length because of a virtual crank arm when the PowerForce system is mounted (Stapelfeldt et al., 2007). In the current study L was 0.174m. Pedaling cadence (Pc) defined in revolutions per minute (rpm) and recorded by the SRM ergometer was converted into angular velocity of the rotating crank (ω) expressed in radiands per second as follows:

$$\omega = \frac{Pc \cdot 2 \cdot \pi}{60} \quad (5)$$

Finally, the power output (P) expressed in Watts (W) was calculated as the mean value for a whole revolution from 0° to 360° crank angle:

$$P = PT \cdot \omega \quad (6)$$

Power output was found to differ between the set value and the one measured by the SRM Powermeter. Studies have shown that SRM Powermeter is a reliable power output measurement system (Gardner et al., 2004; Jones & Passfield, 1998). Therefore, power output results will be presented comparatively as the difference of the mean power output of CycPed and PowerForce in relation to the mean power output of SRM Powermeter.

RESULTS: Figure 2 shows the tangential and radial forces of the left pedal calculated for CycPed and measured with PowerForce for one subject at 100 W and 70 rpm. The difference in peak tangential force and peak radial force is 6.4 % and 4.3 %, respectively. While higher tangential forces were measured with PowerForce, higher radial forces were computed for CycPed, comparing both systems.

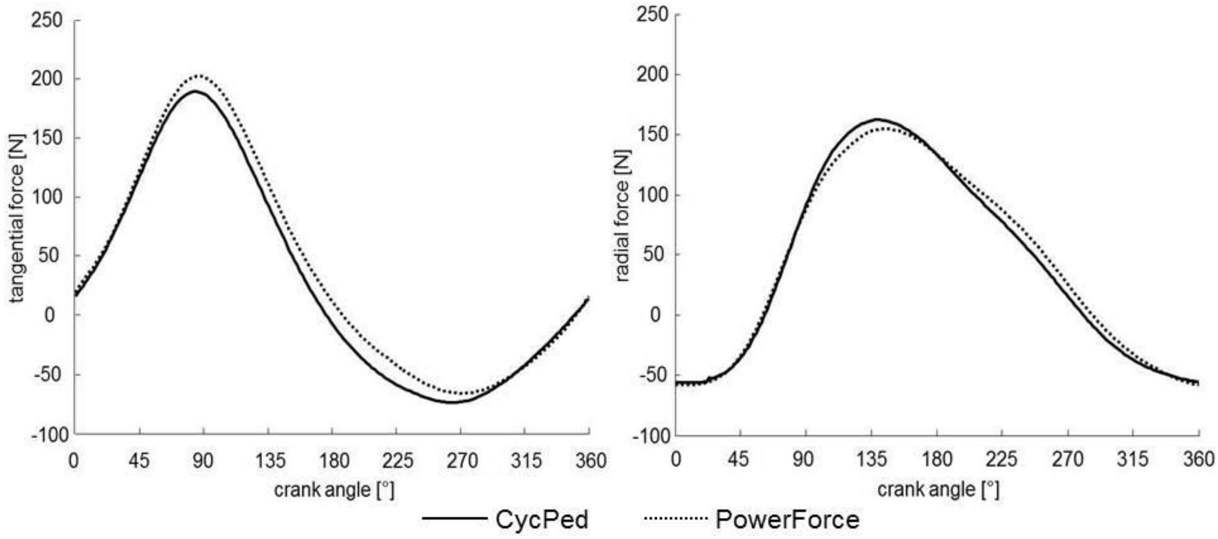

Figure 2: Comparison between CycPed and PowerForce with respect to tangential force (left) and radial force (right) for the left pedal. Values are means of 30 revolutions.

Figure 3 shows the pedal torque for CycPed, PowerForce and SRM Powermeter for one subject at 200 W and 70 rpm. Pedal torque data shows minimal differences between the data measured by SRM Powermeter and the pedal torque data calculated from CycPed. However, PowerForce data shows about 40% difference compared to the other systems at the minimums (Figure 2).

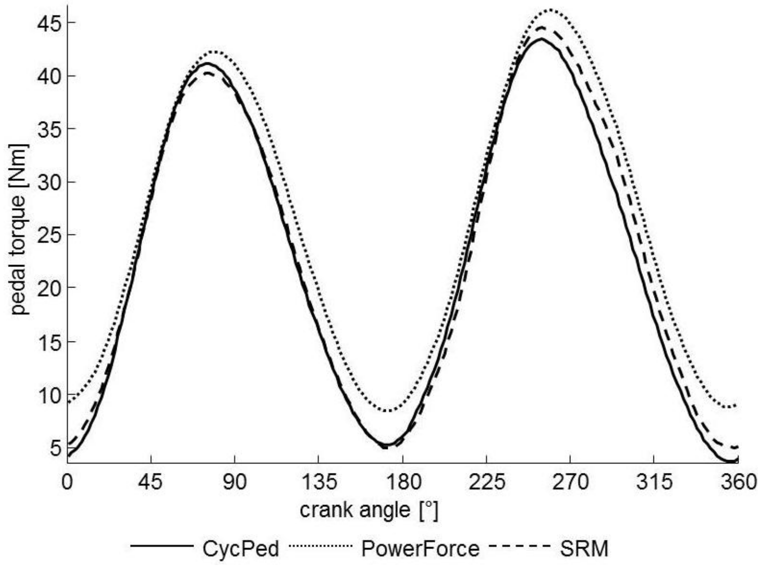

Figure 3: Pedal torque of CycPed, PowerForce and SRM. Values are means of 30 revolutions.

Table 1: Differences of the mean power output of CycPed and PowerForce in relation to the SRM Powermeter at diverse power outputs.

power	CycPed [W]		PowerForce [W]		CycPed [%]		PowerForce [%]	
[W]	mean	SD	mean	SD	mean	SD	mean	SD
100	2	2	12	3	3	2	15	4
200	4	1	16	3	2	1	9	2
300	7	5	21	5	3	2	7	2

The differences of the mean power output comparing CycPed and PowerForce in relation to the SRM Powermeter at different power outputs and different cadences are presented in Table 1 and Table 2, respectively.

Table 2: Differences of the mean power output of CycPed and PowerForce in relation to the SRM Powermeter at diverse cadences.

cadence	CycPed [W]		PowerForce [W]		CycPed [%]		PowerForce [%]	
[rpm]	mean	SD	mean	SD	mean	SD	mean	SD
60	3	2	13	2	2	1	10	2
70	1	2	16	3	1	1	12	2
80	1	1	19	4	1	1	15	3
90	4	3	22	8	3	2	18	7
100	10	3	24	13	8	2	20	12

DISCUSSION: The results showed that CycPed data can be accurately converted in radial and tangential forces and pedal torque and power output can be calculated. Furthermore, data measured with CycPed is in good agreement with the data from SRM Powermeter suggesting CycPed measures the aforementioned variables accurately. The percentage deviation between SRM and CycPed was < 3%, except for the condition at 150 W and 100 rpm. However, the higher deviation at 100 rpm might be explained by the fact that this was not a common cadence used by the subjects in their individual trainings. Therefore, before stating that CycPed is less accurate at higher cadences, further research with subjects accustomed to high cadences is required.
A synchronized crank angle measurement device is necessary to improve the accuracy of the pedal torque calculation. Furthermore, an accurate crank angle measurement device with a resolution of 1° might offer various new data collection possibilities. Further development of CycPed is necessary to enable field measurements. However, in general, CycPed is light weight and data transmission could be easily facilitated by using Bluetooth transfer protocols.

CONCLUSION: This study identified that tangential and radial forces as well as pedal torque and power output can be accurately calculated from the pedal forces. CycPed offers the possibility to be converted into a field-measuring device, which could be advantageous for athletes, coaches and sport scientist. Additionally, CycPed can be used in various different areas, ranging from rehabilitation to competitive sport, and offers a good potential for individual use.

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