A comparison of cycling SRM crank and strain gauge instrumented pedal measures of peak torque, crank angle at peak torque and power output

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Abstract

Our aim was to compare an SRM® torque analysis system with a strain gauge instrumented pedals system for right and left peak crank torque, crank angle of peak torque and power output. Seven competitive cyclists performed an incremental test to exhaustion on a stationary cycle ergometer equipped with an SRM® torque analysis system and a strain gauge instrumented pedals system (SGI pedals). The SRM® torque analysis system measured net torque while the SGI pedals measured the normal and anterior-posterior force applied on the pedal surface. Forces on the pedal surface were resolved into forces on the cranks (tangential and radial). Crank torque was measured by the pedals using the tangential force on the cranks and crank length. Power output was calculated from crank torque and angular velocity of the crank (calculated from pedalling cadence). All data were acquired between the 20th and the 40th seconds of each stage of the incremental test. Magnitudes of differences between outputs from the SGI pedals and the SRM® torque analysis system were assessed by effect sizes. Power output was higher for the SRM® torque analysis system than the SGI pedals. Peak torques were lower for the SRM® torque analysis system compared to the SGI pedals. The angle of the right and left peak torque increased for the SRM® torque analysis system compared to the SGI pedals. The SRM® torque analysis system overestimated power output, underestimated peak torque and increased the angle of peak torque compared to the SGI pedals. Where possible a strain gauge instrumented pedals system should be used to measure performance variables of cyclists rather than the SRM® torque analysis system.

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Keywords: Power meter; pedal force; crank torque

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1. Introduction

Cycling exercise intensity load monitoring has changed from the measurement of heart rate to power output because power output measurements are not affected by temperature or hemodynamic effects [1, 2]. Therefore, the use of power meters in bicycles has become an important instrument during cycling training. Reliability of power output measurements of the most used device (SRM®) was confirmed by previous studies [3, 4]. The SRM® power meter is a strain gauge instrumented crank set that measures the deformation on the shafts of the crank set resulting from the torque applied at the cranks. The SRM® power meter records net torque between right and left cranks and computes power output using reed switch triggers to measure pedalling cadence. The SRM® power meter has a head unit to measure power output, while the SRM® torque analysis system is an additional device that enables the acquisition of torque from the SRM® power meter through an analog board with easier synchronization with other analog devices (e.g. reed switches for cadence measurement). The SRM® torque analysis system hardware converts the torque measures from Hz units used by the power meter controller to analog voltage. Aside from power output measurements, the SRM® torque analysis system has been used to compute peak torque on the crank for the analysis of bilateral symmetry [5] and pedalling technique [6]. However, no study has compared peak torque measurements from the SRM® torque analysis system to a strain gauge instrumented pedals system (SGI pedals). In this regard, pedals instrumented with strain gauges have been able to provide crank torque measurements independently for right and left legs, which are expected to offer a more reliable measure then the SRM® torque analysis system. Therefore a comparison of power output and peak crank torque between a SRM® torque analysis system and SGI pedals was our aim.

Nomenclature

<table>
<thead>
<tr>
<th>ES</th>
<th>Effect sizes</th>
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<tr>
<td>SGI pedals</td>
<td>Strain gauge instrumented pedals</td>
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</table>

2. Methods

2.1. Participants

Four male and three female athletes with competitive experience in cycling and triathlon were invited to participate on the study (mean ± SD: 30 ± 7 years old, 71.3 ± 13 kg, 5.6 ± 1.7 week training hours, 29.7 ± 9.4 km·h⁻¹ average speed at self-selected racing events) and signed an informed consent form in agreement with the research ethics committee of the institution where the study was conducted.

2.2. Protocol

At the start of the evaluation session body mass and height were measured (Secca scales) and self-reported age, week training hours and average speed at self-selected racing events were recorded. Participants’ saddle height and horizontal positions were measured to set up the stationary cycle ergometer (Velotron, Racemate, Inc). The athletes performed an incremental cycling exercise on the cycle ergometer with three minutes of warm-up at 100 W and pedaling cadence visually controlled at 90 ± 2 rpm. Workload was then increased to 150 W and remained increasing in a step profile of 25 W·min⁻¹ until athletes’ exhaustion. A script was configured in the Velotron CS2008 software (Velotron, Racemate, Inc) for automatic control of the cycle ergometer workload in a constant load mode with cycle ergometer...
2.3. Data acquisition

Normal and anterior-posterior forces were measured using a pair of strain gauge instrumented pedals (SGI pedals) [7], with pedal-to-crank angle measured using angular potentiometers. The cycle ergometer was equipped with a science version of the SRM® power meter (Schoberer Rad Meßtechnik, Jülich, Germany) and the SRM® torque analysis system. The SRM® torque analysis system hardware converted the torque measures from Hz units used by the power meter controller to analog voltage. Pedal force data passed through an amplifier (Applied Measurements, Australia) and were recorded using an analog to digital board (PCI-MIO-16XE-50, National Instruments, USA) at 600 Hz per channel using Matlab (Mathworks Inc, MA). Data were acquired between the 20th and the 40th second of each step of 50 W (i.e. 100 W, 150 W, 200 W, 250 W and 300 W).

2.4. Data analysis

Forces on the pedal surface were resolved into forces on the cranks (tangential and radial) using angular potentiometers attached to pedal spindle for the measurement of the pedal-to-crank angle. Crank torque was measured by the SGI pedals using the tangential force on the cranks and crank length, and by the SRM® torque analysis system. The pedals were previously calibrated for normal and anterior-posterior force components applying known loads, and angular potentiometer were calibrated using a manual goniometer. The SRM® torque analysis system was also calibrated following procedures described by Wooles et al. [8]. A frequency to voltage conversion factor of 400e-6 and frequency to torque factor gathered at the calibration trial were used to convert torque measurements from voltage to N.m. A reed switch attached to the bicycle frame detected the position of the crank in relation to the pedal revolution and enabled separate torque data for every crank revolution. Power output was calculated from the effective force on the crank, crank arm length and angular velocity of the crank (calculated from pedaling cadence) for the SGI pedals and the SRM® torque analysis system. Peak crank torque and crank angle of peak torque were averaged over five complete pedal revolutions for both cranks for the SGI pedals and the SRM® torque analysis system.

2.5. Statistical analysis

Average and standard deviations for power output (W), peak crank torque (N.m) and the crank angle of the peak torque (°) for right and left cranks were calculated for the seven athletes and were compared between the SGI pedals and the SRM® torque analysis system as percentage differences for the five stages of the incremental test (100 W, 150 W, 200 W, 250 W and 300 W) using effect sizes [9, 10]. Effect sizes were rated as trivial (< 0.25), small (0.25 - 0.49), moderate (0.5 - 1.0), and large (> 1.0) [11].

3. Results

Ensemble results from the SGI pedals and the SRM® torque analysis system for five pedal revolutions for one representative cyclist showing smaller peak crank torque and delayed crank angle of the peak torque for the SRM® torque analysis system are shown in Figure 1.
Fig 1. Crank torque measured by the pedals (right, left, and right + left) and by the SRM torque analysis system. Data are from five consecutive revolutions for one representative cyclist at 300 W of workload and 90 rpm of pedalling cadence. Arrows indicate peak torque and crank angle of peak torque for the strain gauge instrumented pedals and the SRM® torque analysis system.

Power output was ~21% higher (ES = 1.0) for the SRM® torque analysis system than the SGI pedals. Peak torques were lower for the SRM® torque analysis system (right crank ~8%, ES = 1.5; left crank ~7%, ES = 1.0) compared to the SGI pedals. The angle of the right and left peak torque were greater for the SRM® torque analysis system compared to the SGI pedals (right ~37°, ES = 3.5; left ~21°, ES = 1.7) (see Table 1).
Table 1. Average ±SD of power output (W), peak crank torque (Nm) and the crank angle of the peak torque (°) for the five stages of the incremental test (100 W, 150 W, 200 W, 250 W and 300 W) (N = 7). Percentage differences and effect sizes for comparisons between the SRM® torque analysis system and the SGI pedals.

<table>
<thead>
<tr>
<th>Stages of the incremental test/ Variables</th>
<th>100 W</th>
<th>150 W</th>
<th>200 W</th>
<th>250 W</th>
<th>300 W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power output – Pedals (W)</td>
<td>80 ± 11</td>
<td>130 ± 18</td>
<td>173 ± 21</td>
<td>215 ± 19</td>
<td>265 ± 27</td>
</tr>
<tr>
<td>Power output – SRM (W)</td>
<td>111 ± 55</td>
<td>161 ± 61</td>
<td>205 ± 62</td>
<td>259 ± 69</td>
<td>343 ± 73</td>
</tr>
<tr>
<td>Power output – Pedals vs. SRM (%; effect sizes)</td>
<td>31 ± 6; 0.92, moderate</td>
<td>20 ± 4; 0.78, moderate</td>
<td>16 ± 4; 0.78, moderate</td>
<td>17 ± 3; 0.99, moderate</td>
<td>26 ± 2; 1.56, large</td>
</tr>
<tr>
<td>Right crank torque – Pedals (Nm)</td>
<td>32 ± 4</td>
<td>41 ± 6</td>
<td>49 ± 7</td>
<td>56 ± 9</td>
<td>67 ± 4</td>
</tr>
<tr>
<td>Right crank torque – SRM (Nm)</td>
<td>16 ± 7</td>
<td>25 ± 10</td>
<td>35 ± 13</td>
<td>45 ± 16</td>
<td>65 ± 17</td>
</tr>
<tr>
<td>Right crank torque – Pedals vs. SRM (%; effect sizes)</td>
<td>17 ± 1; 2.85, large</td>
<td>10 ± 7; 1.91, large</td>
<td>7 ± 6; 1.46, large</td>
<td>4 ± 6; 0.84, moderate</td>
<td>1 ± 7; 0.22, trivial</td>
</tr>
<tr>
<td>Left crank torque – Pedals (Nm)</td>
<td>33 ± 10</td>
<td>39 ± 12</td>
<td>42 ± 14</td>
<td>47 ± 12</td>
<td>49 ± 9</td>
</tr>
<tr>
<td>Left crank torque – SRM (Nm)</td>
<td>16 ± 6</td>
<td>23 ± 9</td>
<td>29 ± 10</td>
<td>40 ± 11</td>
<td>51 ± 15</td>
</tr>
<tr>
<td>Left crank torque – Pedals vs. SRM (%; effect sizes)</td>
<td>16 ± 15; 1.97, large</td>
<td>11 ± 13; 1.48, large</td>
<td>6 ± 11; 1.09, large</td>
<td>3 ± 8; 0.57, moderate</td>
<td>1 ± 7; 0.16, trivial</td>
</tr>
<tr>
<td>Right crank angle of peak torque – Pedals (°)</td>
<td>96 ± 10</td>
<td>94 ± 9</td>
<td>92 ± 7</td>
<td>91 ± 8</td>
<td>93 ± 3</td>
</tr>
<tr>
<td>Right crank angle of peak torque – SRM (°)</td>
<td>138 ± 22</td>
<td>136 ± 13</td>
<td>123 ± 20</td>
<td>127 ± 10</td>
<td>127 ± 11</td>
</tr>
<tr>
<td>Right crank angle of peak torque – Pedals vs. SRM (%; effect sizes)</td>
<td>29 ± 12; 2.57, large</td>
<td>31 ± 8; 3.94, large</td>
<td>24 ± 10; 2.20, large</td>
<td>28 ± 6; 3.92, large</td>
<td>26 ± 6; 4.85, large</td>
</tr>
<tr>
<td>Left crank angle of peak torque – Pedals (°)</td>
<td>290 ± 14</td>
<td>287 ± 19</td>
<td>287 ± 16</td>
<td>288 ± 9</td>
<td>285 ± 10</td>
</tr>
<tr>
<td>Left crank angle of peak torque – SRM (°)</td>
<td>317 ± 16</td>
<td>313 ± 13</td>
<td>307 ± 15</td>
<td>306 ± 10</td>
<td>304 ± 8</td>
</tr>
<tr>
<td>Left crank angle of peak torque – Pedals vs. SRM (%; effect sizes)</td>
<td>8 ± 3; 1.75, large</td>
<td>8 ± 5; 1.62, large</td>
<td>6 ± 4; 1.25, large</td>
<td>6 ± 4; 1.85, large</td>
<td>6 ± 2; 2.09, large</td>
</tr>
</tbody>
</table>

SRM = SRM® torque analysis system; Pedals = strain gauge instrumented pedals system.

4. Discussion

Cycling training monitoring variables such as power output and peak crank torque have not been previously compared between instrumented pedals and the SRM® torque analysis system. We found ~21% greater power output for the SRM® torque analysis system compared to the strain gauge instrumented pedals. The benefit of the SRM® torque analysis system is it enables easier synchronization of the net torque between pedals measured by the SRM® power meter and any analog devices. However, lower results of peak torque for both cranks and delayed crank angle of the peak torque compared to instrumented pedals may suggest that the torque analysis system does not provide the most accurate measure of crank torque. One possible explanation is based on the hardware design of the SRM® torque analysis system, which converts torque measures from frequency to voltage unit, instead of the frequency
measurements used by the power control unit from the SRM® power meter. This frequency to voltage conversion may be affected by aliasing effects from hardware set-up (i.e., low pass filter in voltage signal output), which may reduce peak voltage readings. A second explanation may be that the SRM® power meter is limited to measure the net torque applied by the right and left legs, differently from the instrumented pedals. A lower estimative in peak crank torque may affect the identification of torque symmetry or accurate peak crank torque in the evaluation of cycling performance. Force symmetry assessed by measuring the total force applied on the pedals cannot be computed using the SRM® torque analysis system. Delayed estimates of crank angle of the peak torque may lead to wrong assumptions in pedalling technique (i.e., delayed pedal force application).

5. Conclusion

Where possible a strain gauge instrumented pedals system should be used to measure variables contributing to cyclists performance rather than the SRM® torque analysis system.

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References