Short-Term Power Output in 9-Year-Old Children: Typical Error Between Ergometers and Protocols

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This study investigated the differences in short-term power output (STPO) using three different cycle ergometers in 9-year-old children. A total of 31 children participated in three cycle ergometer sprint tests of 20 s duration: a modified friction braked Monark, a modified friction braked Ergomeca cycle ergometer, and a SRM isokinetic ergometer. Common indices of peak and mean power, peak pedal rate, time to peak power, and pedal rate were recorded. Indices of peak power 1 s for the Monark, Ergomeca and SRM ergometer were found to be 299 ± 55, 294 ± 55, 297 ± 53 W and mean power 20 s to be 223 ± 40, 227 ± 43 and 216 ± 34 W, respectively. The time to peak power was found to be 3 ± 2, 6 ± 2, 5 ± 3 s, respectively. The standard error of measurement was lower in mean 20-s power compared to 1-s peak power. Despite instrumentation and protocol differences these results demonstrate reproducibility in 9-year-old children that will allow researchers confidence in comparing STPO data obtained from different ergometers.

A French medical student named Bouny is credited with developing the first cycle ergometer in 1896 (14). Shortly after that time, investigators such as Atwater, Benedict, Zuntz, and Haldane continued to develop this early prototype. It was not until the early 1950s, when based on prototypes by Fleisch (10) and von Döbeln (6), that friction braked cycle ergometers became universally available. Unlike some of the early prototypes that utilized mechanical (1) or electromagnetic brakes (3), the friction braked ergometer was simple to operate and inexpensive. In the 1970s the developments in electronics and computers led to the first fully computerized cycle ergometer (14). In the last two decades developments that have enhanced cycle ergometry include the use of a motor for isokinetic testing (22) and the use of strain gauges within pedal cranks (SRM, Julich, Germany).

Despite this sporadic approach to the development of the assessment of short-term power output (STPO), there has been a resurgence of interest in the performance of young people’s muscle power. Research into STPO of young people...
tends to be divided into groups using ergometers that utilize single resistance settings (12,16), multiple sprints at different resistances (26), and isokinetic devices (5,23,24). However, common to all these studies is the use of the cycle ergometer and in pediatric exercise science the utilization of friction braked cycle ergometers, such as the Monark or Ergomeca, are the most common. There are now additional cycle ergometers that have begun to report STPO in young people (29). Therefore, it would be useful for researchers to know how comparable performance scores are when obtained by non-friction braked ergometers. The purpose of this study was to measure STPO (20 s) in 9-year-old children using three different ergometers. Specifically, we aimed to report the typical error between ergometers, as well as to report strengths and weaknesses of each ergometer.

**Methods**

**Subjects**

Fourteen boys (age 8.9 ± 0.3 y, stature 1.46 ± 0.05 m, and body mass 37.3 ± 6.0 kg) and 17 girls (age 9.0 ± 0.3 y, stature 1.46 ± 0.05 m, and body mass 41.1 ± 8.3 kg) volunteered to participate in the study. The participants were all volunteers from a local primary school located in the Exeter area. Prior to the start of the study, parents and all children completed a consent form. The ethics committee of the University approved the project.

All testing took place over three consecutive mornings and to take account of diurnal variations all testing took place at the same time of day (±30 min). To negate the chances of a learning effect during sprint cycling, all three tests were randomly ordered and counterbalanced. Because each ergometer utilizes slightly different protocols (e.g., the Ergomeca usually uses 3 sprints of 6–10 s), it was decided to standardize part of the protocol for the three ergometers, and a 20-s all-out maximal sprint was utilized. A 20-s test was chosen to ensure parity of time between the three test protocols, to still allow measurement of mean power over 20 s (MP), and to reduce the duration of the test so as to limit fatigue and aerobic contribution in children (4).

On all three tests each participant completed a standardized 2-min warm-up, pedaling at approximately 30–60 W interspersed with two to four maximal sprints of 3–4 s duration. Three different researchers conducted one each of the three cycle tests.

**Monark Ergometer**

**Modifications.** The Monark cycle was a Model 814 E modified to allow for high precision data integrated selectively over 1-s or 5-s time periods. A voltage generator attached to the flywheel measured the pedal revolutions. The flywheel inertia was determined by horizontal suspension of three parallel wires and is reported more fully by Chia et al. (4).

**Test Protocol.** After the standardized warm-up, the specific protocol for the Monark ergometer consisted of pedaling at 60 revs per minute (~30-40 W, weight pan lifted). After attaining a constant pedal rate, the “rolling start” was initiated with a countdown of “3-2-1-GO”; on the word “GO” the load was lowered and the timer started. The time from acceleration to the load being lowered
and the timer being started was ~3 s. All participants pedaled maximally against a braking load of 50 g · kg⁻¹ body mass (BM). Toe clips were worn during all the tests.

**Computation of Power.** The power variables were computed as follows:

\[ \text{Adjusted power output } [P_{\text{adj + int.res.}}] = \varpi (T_i + T_r) = \varpi [I(d\varpi/dt) + L_{\text{plus9%}} r] \]

\[ I = \text{flywheel, sprocket and chain inertia} \]

\[ \varpi = \text{angular velocity} \]

\[ d\varpi/dt = \text{angular acceleration of the flywheel} \]

\[ T_r = \text{resistive torque as a result of the product of } L_{\text{plus9%}} \text{ and } r \text{ (the } L_{\text{plus9%}} \text{ is the applied resistance plus frictional losses in overcoming the internal resistance of the ergometer and } r \text{ is the radius of the flywheel)} \]

\[ T_i = \text{the inertial torque of the flywheel} \]

The inertia of the chain and sprocket was assumed to be 0.01 kg · m⁻², for fuller details see Chia et al. (4).

**SRM Ergometer**

**Modifications.** The SRM Performance Ergometer was developed in cooperation with the University Hospital Freiburg, the German Cycling Federation, and the British Cycling Performance Director, Peter Keen. The ergometer is built of high-strength aluminum and weighs approximately 100 kg, thus ensuring stability. The participant’s position on the ergometer can be optimized using the adjustable saddle, vertical or horizontal handlebar height, as well as an adjustable crank length. The isokinetic ergometer has a transmission that comprises an eddy current brake and oscillating mass. The eddy current brake is controlled by the power supply (24 V) external to the ergometer, thus eliminating the need for current to be directed inside the ergometer. The ergometer has a mounted powermeter that is responsible for measuring the power output. The powermeter transmits a particular frequency (500–12000 Hz) proportional to the actual torque and also a frequency proportional to the angular velocity via a transmitter to a receiver located on the frame of the ergometer. If there is no torque on the chain, the powermeter measures no frequency, which means the angular velocity is zero. During a test, around the crank axle torque is generated and is measured by 20 strain gauges positioned between the chain-rings and the crank arms. This arrangement detects the net torque generated from the forces applied to both cranks. The strain is processed “on board” the crank unit and transmitted as a continuous analogue signal, the frequency of which is directly proportional to the torque, is generated. Torque and a small data logger located on the cycle collects velocity data from the power crank. Mean data over intervals of 1 s or longer can be stored and downloaded to a PC. A powercontrol box mounted on the handlebars is responsible for storing the measured data controlling the eddy current brake and transmitting signals to the computer via a serial cable.

**Test protocol.** After the standardized warm-up, the SRM protocol consisted of a stationary start; the participant placed the right pedal approximately 20° from
the upright position to allow for a positive first down stroke. The instructions to the participant were “READY-GO,” and on the word “GO” the timer was activated for the 20-s test. The recording of the torque and velocity data began once the subject initiated the movement of the pedal cranks. The test was completed on the sound of an audible signal from the PC. Toe clips were worn during the test.

**Computation of power.** The power output is calculated as follows: Average torque of a full crank rotation x average angular velocity of a full crank rotation = average power of a full crank rotation. Average values are calculated on the time basis of one second. The basis of performance calculations, therefore, is always full rotations that are calculated on a time basis (1 s).

**Ergomeca Ergometer**

**Modifications.** The friction-loaded ergometer (Ergomeca, Sorem, Toulon, France) has a crank length of 0.17 m, an excursion of 6.12 m at the perimeter of the flywheel per pedal revolution, an arm balance allowing frictional forces between 0-196.2 N, and a mass and radius of the flywheel of 15.6 kg and 0.24 m, respectively. Two optical sensors were mounted on the ergometer to detect the onset of the crank gear rotation cycle and the measurement of the rolling speed of the flywheel (11). Values of instantaneous velocity, force, and power were calculated four times per flywheel revolution (16 counts per pedal revolution) and averaged per half a pedal revolution.

**Test protocol.** After the standardized warm-up, each participant had to perform one “all-out” sprint against a braking load of 50 g · kg⁻¹ body mass (BM). From a stationary start, the participant was asked to produce the highest acceleration and to pedal as fast as possible during 20 s. All participants had to stay seated on the saddle throughout the test, and toe clips were used.

**Computation of power output.** During the acceleration of the flywheel, the participants had to produce a total external force dependent on two components: (i) a constant frictional force (Ff) against the braking load applied to the flywheel and (ii) an inertial force (Fi), necessary to accelerate the flywheel and dependent on the variation of the kinetic energy of the latter. The instantaneous power output (P_inst, in W) generated during the sprint was computed as the product of total external force and cycling velocity. Therefore, from a single sprint, concomitant measurements of force, velocity, and power were obtained, and maximal power was attained during the acceleration phase (Figure 1). According to Lakomy (19) the flywheel inertia is calculated from the linear relationship between the free deceleration of the flywheel and the friction force applied. For the present cycle ergometer, the relationship between force (N) and acceleration (rpm · s⁻¹) was found to be:

\[ F = (0.780109 \cdot \text{acceleration}) - 3.004758 \]

Cycling peak power (PP) was defined as the maximal value of power, averaged per half-pedal revolution, obtained during the twenty seconds sprint. Optimal velocity (v_opt), and force (F_opt) correspond to velocity and force measured at PP. Moreover, the time to reach PP was also measured.

Throughout all three cycle tests, all participants were given verbal encouragement. A 1-min cool down was incorporated on completion of all tests, and no
adverse effects were reported by the children. One child completed one test but was unable to complete the second and third due to other school commitments. Two children on the SRM test were unable to complete the test satisfactorily due to the saddle stem being unable to go any lower with respect to their stature. Data from two children were lost due to technical difficulties on the Ergomeca test.

**Statistical Analyses**

Descriptive data are presented as means and standard deviations, as well as 95% confidence intervals. Intraclass correlations were calculated to assess the relationship between the ergometers. However, to estimate the typical error, several methods are presented. Firstly, the change in the mean value between the two ergometers and, secondly, the standard error of measurement (i.e., the difference scores for each participant) were calculated, and the standard deviation of the difference scores divided by $\sqrt{2} \left( s_{\text{diff}}/\sqrt{2} \right)$ was computed to estimate the typical error (15). The peak (PP) and mean power (MP), as well as the time to PP, were selected for the calculation of the typical error as these variables are common to all three ergometers and are also the most reported in the literature. In all calculations confidence limits have been generated.
Table 1 Short-Term Peak and Mean Power, Time to Peak Power, and Peak Pedal Rate Data for the Three Ergometers (Mean ± SD and 95% Confidence Limits)

<table>
<thead>
<tr>
<th>Ergometer</th>
<th>PP L &amp; L corr (W)</th>
<th>Time to PP L &amp; L corr (s)</th>
<th>MP L &amp; L corr (W)</th>
<th>PPR (revs · min⁻¹)</th>
<th>Time to PPR (s)</th>
<th>Peak Speed (km · h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monark Cycle Ergometer</td>
<td>299 ± 55</td>
<td>3 ± 2</td>
<td>223 ± 40</td>
<td>118 ± 10</td>
<td>6 ± 3</td>
<td>43.7 ± 3.7</td>
</tr>
<tr>
<td>SRM Cycle Ergometer</td>
<td>294 ± 55</td>
<td>5 ± 3</td>
<td>227 ± 43</td>
<td>111 ± 10</td>
<td>7 ± 3</td>
<td>43.7 ± 3.7</td>
</tr>
<tr>
<td>Ergomeca Cycle Ergometer</td>
<td>406 ± 108</td>
<td>6 ± 2</td>
<td>297 ± 53</td>
<td>116 ± 2</td>
<td>6 ± 2</td>
<td>43.7 ± 3.7</td>
</tr>
</tbody>
</table>

Results

Table 1 presents mean, standard deviation, and 95% confidence intervals of all variables. The three ergometers for PP and MP produced very similar mean values. The time to PP for the SRM and the Ergomeca produced similar mean values, but the value for the Monark ergometer was lower. Table 2 presents the change in the mean values, as well as the typical error for the PP and MP and the time to PP. The typical error for the PP between the three ergometers was similar, 34 W between the Ergomeca and the Monark ergometer, 32 W between the Ergomeca and the SRM ergometer, and 27 W between the Monark and the SRM ergometer. The typical error for MP was not dissimilar between the ergometers ranging from a low of 23 to a high of 29 W. The error for the time to PP ranged from 1.2 to 2.5 s. The intraclass correlations were moderate for both PP and MP but were lower for time to PP ranging from \( r = 0.53–0.24 \).

Discussion

The purpose of this study was to compare three cycle ergometers to determine the STPO of boys and girls aged ~9 years. Although there is some limited data using the SRM pedal cranks with adults (17,18) and children (29), this is the first known
data published on the SRM high performance ergometer. To the best of the authors’ knowledge this is the first inter ergometer study to examine STPO in children. The main finding of this study is that despite differences in the protocols, instrumentation, and data analyses between the three ergometers, there was similar within-subject variation (typical error of measurement) in relation to the measurements of STPO for 9-year-old children.

Table 2 Reproducibility Indices Between Ergometers for Peak Power 1 s, Mean Power 20 s and Time to Peak Power 1 s

<table>
<thead>
<tr>
<th></th>
<th>Ergomeca-Monark</th>
<th>Monark-SRM</th>
<th>Ergomeca-SRM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power 1 s (W)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in mean</td>
<td>1</td>
<td>−10</td>
<td>7</td>
</tr>
<tr>
<td>CL</td>
<td>(−18, 19)</td>
<td>(−25, 5)</td>
<td>(−12, 25)</td>
</tr>
<tr>
<td>Typical Error</td>
<td>34</td>
<td>27</td>
<td>32</td>
</tr>
<tr>
<td>CL</td>
<td>(27, 46)</td>
<td>(21, 37)</td>
<td>(25, 44)</td>
</tr>
<tr>
<td>Intraclass r</td>
<td>0.60</td>
<td>0.77</td>
<td>0.66</td>
</tr>
<tr>
<td>CL</td>
<td>(0.29, 0.79)</td>
<td>(0.56, 0.89)</td>
<td>(0.36, 0.84)</td>
</tr>
<tr>
<td>Mean Power 20 s (W)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in mean</td>
<td>9</td>
<td>3</td>
<td>−12</td>
</tr>
<tr>
<td>CL</td>
<td>(−3, 21)</td>
<td>(−12, 18)</td>
<td>(−28, 5)</td>
</tr>
<tr>
<td>Typical Error</td>
<td>23</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td>CL</td>
<td>(18, 31)</td>
<td>(21, 36)</td>
<td>(23, 40)</td>
</tr>
<tr>
<td>Intraclass r</td>
<td>0.62</td>
<td>0.60</td>
<td>0.45</td>
</tr>
<tr>
<td>CL</td>
<td>(0.34, 0.80)</td>
<td>(0.29, 0.80)</td>
<td>(0.08, 0.71)</td>
</tr>
<tr>
<td>Time to Peak Power 1 s (s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in mean</td>
<td>−3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>CL</td>
<td>(−4, −2)</td>
<td>(0.4, 3)</td>
<td>(−0.2, 2)</td>
</tr>
<tr>
<td>Typical Error</td>
<td>1.3</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>CL</td>
<td>(1, 1.7)</td>
<td>(2.0, 3.4)</td>
<td>(1.6, 2.9)</td>
</tr>
<tr>
<td>Intraclass r</td>
<td>0.53</td>
<td>0.24</td>
<td>0.43</td>
</tr>
<tr>
<td>CL</td>
<td>(0.19, 0.75)</td>
<td>(−0.14, 0.56)</td>
<td>(0.48, 0.70)</td>
</tr>
</tbody>
</table>

We chose to examine the issue of reproducibility within STPO of different ergometers by utilizing the within-subject standard deviation or standard error of measurement. Although recently there has been a number of studies that have utilized the technique advocated by Bland and Altman, in classical measurement studies, however, the standard error of measurement is the more common statistic to examine reliability and reproducibility. Hopkins (15) has discussed the merits of the standard error of measurement, a term referred to as the typical error. Hopkins (15) argues that values of the limits of agreement are dependent on the sample size, such that the limits are biased. This is an important issue in sports science, as typically reliability is often conducted on small sample sizes (e.g., less than 30). The typical error is not affected by the size of the sample. Additionally, Hopkins
argues that “the use of 95% confidence limits to represent the precision of the estimate of population parameters is not a basis for using 95% to define agreement limits for an individual participant’s difference scores” (p. 4). Hence, using similar measures of STPO between the ergometers, three indices of reproducibility have been presented in this study: the change in the mean value, the typical error, and finally the intraclass correlation.

The PP and MP output scores of ~300 and 220 W are in agreement with previous studies of boys and girls aged 10 years (8, 9, 30). The counterbalanced and random assignment of the children to the order of testing was successful in balancing any learning effect, as it has been shown that practice can increase power output in adults (21) and children (20). Therefore, the scores obtained over three consecutive days are supportive of consistent maximal efforts. There is, however, a lack of information about repeated sprints over set days or weeks in children. One study which investigated WAnT PP and MP tested 1 week apart found a coefficient of repeatability in the range of 44–50 W PP and 34–42 W MP for 9–10-year-old children (25). In the present study the typical error for the PP, expressed as a coefficient of variation ~11%, was similar between the three ergometers. It is difficult to distinguish between the biological and technical error, but when accounting for the potential error across three different ergometers on 3 different days, using children who are not as reliable as adults, and three different operators testing the participants, the low error scores are encouraging.

The typical errors for MP ranged between 23 and 29 W and were lower than for PP and suggest better stability in performance across the three ergometers. The highest MP error of 29 W for the Ergomeca and SRM ergometers possibly reflects the difference between isokinetic and friction braked systems. The children pedaling on the SRM remarked that the “feeling” or kinaesthetic feedback received from the SRM was very different to the Monark and Ergomeca ergometers, and this might account for a slightly higher error score. The intraclass correlations for both PP and MP between the three ergometers were moderate (range \( r = 0.45–0.77 \)) and are not dissimilar to other studies examining reproducibility with the WAnT (13). However, caution must be used with correlations as the heterogeneity (spread) of the values between participants, and the magnitude of the measured values can easily influence the coefficient.

Despite the differences in the ergometers, differences might have also been due to the protocols such as the inertia within the systems and the braking forces. For the Monark, inertia through friction on the crank sprocket and the chain need consideration. Manufacturers estimate that a correction factor of 9% would correct losses through the chain, pedal, and cranks. In contrast, the SRM ergometer does not determine the power through the flywheel. Instead it possesses 20 strain gauges in the crank unit, and therefore the losses through the chain and sprocket will be minimized compared to friction braked ergometers. For friction braked ergometry, adjustments need to be made for inertia and loading as demonstrated by Chia et al. (4) and Doré et al. (7), who found significant differences in PP of 9-year-old and 13 year-old children, respectively. The PP was found to occur earlier in the WAnT, and scores were 20% higher when correction of the inertia and load data was applied. Considering the simplicity of the technique it is surprising that more corrected data is not available.

Doré et al. (8) has demonstrated that the standard Wingate test load (75 g - kg\(^{-1}\) BM) was too high in prepubertal children to achieve a cycling peak
performance. In the present study the load of 50 g per kg BM, plus the flywheel inertia, allowed the children to overcome resistive forces on the Ergomeca cycle (8). Although two of the ergometer protocols used a stationary start and the other a rolling start, the attainment of PP either over a full revolution or per 1 s time basis was remarkably similar. On the Monark, the “rolling” start allowed for the initial overcoming of the flywheel inertia and acceleration towards PPR as the timing of the test is begun. This difference in protocol might explain why the times to reach PP were shorter with the Monark protocol than the other two. This is a reflection of the stationary start, which results in delaying the PP score. However, if the duration of the rolling start and the dropping of the weight pan to coincide with the data capture (< 3 s) and the Monark’s mean time at PP are added, a similar value as the SRM and Ergomeca (mean 5–6 s) is achieved. Thus, the Monark’s duration and timing of the “rolling start” appears consistent, even though the first few seconds are not represented in the analyses.

The typical error for the time to PP tended to be more variable between the ergometers, Ergomeca-Monark 1.3 s, Monark-SRM 2.5 s, and Ergomeca-SRM 2.1 s. The variation is likely due to the difference in the Monark’s “rolling” versus the “stationary” start of the Ergomeca and SRM. The variable relationship between the times to PP of the three ergometers is also reflected in the moderate to weak correlations (range $r = 0.53–0.04$) and the wider confidence limits. One way to limit variability is to ensure a stationary start and hence eliminate timing errors of initiating the load and the computer simultaneously. However, such factors as the load acting on the flywheel and the ability of young children to initiate the pedaling action from a stationary start need consideration.

The Ergomeca data analyses program is able to calculate the $V_{opt}$ $98 \pm 10$ revs · min$^{-1}$; however, this measurement is not interchangeable with the PPR. $V_{opt}$ is the velocity at peak power, but PPR is not velocity at PP because the time to PPR is not the same as time to PP on the Monark and SRM. Previous literature using the Ergomeca ergometer with a 17-cm pedal arm crank has produced $V_{opt}$ for 9-year-old children of 100 revs · min$^{-1}$ (9). In an earlier study Van Praagh (27), using an Ergomeca ergometer, found $V_{opt}$ to be between 110–115 rev · min$^{-1}$ using a crank pedal arm equal to 13 cm. The PPR between the Monark and SRM were similar and compared favorably to previous publications that have reported that children’s $V_{opt}$ for PP is achieved between a range of 110–120 revs · min$^{-1}$ (23,29). This observation is likely to be as a result of the lower load on the Monark compared to the standard 75 g per kg body mass WAnT load, which was originally devised to measure mean power.

On the Ergomeca cycle, inertia adjusted peak power is typically measured from two or three sprints of 6 to 10 s, with different braking loads (8). This method has the advantage of providing a power-velocity relationship (Figure 1) with numerous points at low and high velocities (when high and low braking forces are used) and provide a better reproducibility of peak power measurement than only one sprint (unpublished observation). This protocol is less fatiguing that the 30-s WAnT, especially in children. In the present study a 20-s test was a compromise to ensure parity between the three different protocols and to allow the measurement of mean power over 20-s, which has been shown to have a significantly lower aerobic contribution than a 30-s test (4).

In conclusion, these results demonstrate reproducibility of STPO as assessed by three protocols and contrasting ergometers. STPO in 9-year-old children were
found to have similar typical errors of measurement in PP, MP, and time to PP. These results will allow investigators in STPO to compare different studies even though there might be some subtle differences in methodology and ergometer. Investigators of STPO in children should continue to appropriately detail such information as the flywheel mass, inertial characteristics, starting protocols, and data capture to allow comparisons to be made informatively. In addition, these results should enable investigators to design studies that have adequate precision of STPO values and the appropriate sample size.

References


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