Differences between sprint tests under laboratory and actual cycling conditions

W. BERTUCCI 1-2, R. TAIAR 2, F. GRAPPE 1

Aim. The aim of this study was to compare the maximal power output (PO peak) and force-velocity relationships in sprint cycling obtained from a laboratory protocol and from a field test during actual cycling locomotion.

Methods. Seven male competitive cyclists performed 6 sprints (3 in the seated position and 3 in the standing position) on an ergo-trainer (Tacx, Netherlands) and 6 sprints during actual cycling locomotion in a gymnasium. The bicycle was equipped with the SRM Training System (Schoberer Rad Messtechnik, Germany) to measure (200 Hz) the power output (PO, W), the pedalling cadence (rpm), and the velocity (km·h⁻¹). From these measurements, the maximal force on the pedal (F max), the theoretical maximal force (F o, N) and the theoretical maximal pedalling cadence (V₀, rpm) were determined. During each sprint test the lateral bicycle oscillations were measured from a video analysis.

Results. During standing and seated sprints in the gymnasium, F o and F max were significantly higher (p<0.05) compared with sprints on the ergo-trainer (+12% and +32%, respectively). The PO peak during sprints in seated and standing positions in the gymnasium was significantly lower (-4%) compared with the ergo-trainer. For standing position in the gymnasium the kinematics analysis indicated a 24° mean lateral bicycle oscillation compared with 0° on the ergo-trainer.

Conclusion. The results of this study indicate that PO peak, F o, and time to obtain PO peak were different between laboratory and actual cycling conditions. To obtain a valid estimation of the maximal power output, it is necessary to perform sprint tests during actual cycling locomotion. Thus, in the laboratory, it is advisable to use a cycle ergometer that enables natural lateral oscillations.

Key Words: Cycling - Maximal power output - Field test - Laboratory test.

The difference between the first and the second placed cyclist for track cycling is very small. During the 2002 world track championship (Ballerup/Copenhagen, Denmark, 2002) in the 1 000 m time trial, the difference between the first and the second cyclist was only 0.001 s. For track cycling competitions the capacity to produce a high peak power output (PO peak, W) is a major determinant of the performance. Several studies have shown that the ability to produce the highest PO peak at the start of the track competition (1 000 m and 4 000 m time trial) corresponds to the optimum race strategy. The time of the first lap (250 m) of the 1 000 m time trial was highly correlated to the final time. The capacity to produce a high PO peak depends essentially on the force-velocity relationships of the cyclist. Thus, it is important to measure the PO peak, the speed of the rider and the force applied on the pedal in order to optimise the performance (for example to determine the optimal gear ratio).

Several protocols have been used to measure the PO peak of the lower limb: force-velocity tests on the cycle ergometer, jump tests, squat jump, counter movement jump, and staircase. On ergometer tests,
PO peak is obtained at combined optimal values of force (N) and pedal velocity (rad s⁻¹). Martin et al.⁷ have also shown that for the cycle ergometer, the crank length, and pedalling cadence were important determinants of the PO peak.

Recently, both scientists and coaches have developed and employed mathematical models to estimate the PO requirements of different track cycling events.²⁻¹¹ These models have taken into account the kinetic energy variations and the metabolic energy production system (aerobic and anaerobic).², ³ However, they are more suitable to estimate the PO at steady state velocity. Craig et al.¹ used the SRM crank dynamometer (Schoberer) to measure the PO, the cycling velocity (m s⁻¹), the pedalling cadence (rpm), and the heart rate (beats · min⁻¹). They have shown that during a 200 m flying qualification sprint at a world cup event, the PO peak and mean power output (PO mean) generated by a female cyclist was 1 020 and 752 W, respectively. Moreover, at the end of the 200 m, PO was 568 W, which equates to a 44% drop from the peak power. The peak velocity and pedalling cadence was 63.5 km h⁻¹ and 150 rpm, respectively. To the best of our knowledge, there is no sprint test protocol to estimate PO peak in actual cycling locomotion (on the track) without using a crank dynamometer like the SRM system and no study has shown the accuracy between the PO peak measured in laboratory and in actual cycling locomotion.

We hypothesised that the mechanical variables obtained with the sprint tests on an ergo-trainer were different compared with those in the actual cycling locomotion. This study can be divided into 2 parts. In the first part we have compared the mechanical variables obtained with the SRM crankset powermeter during a standard laboratory protocol for PO peak determination, with those from a field test that measures the PO mean and PO peak in actual cycling locomotion. In the second part we have determined the relationships between the different mechanical variables and the equation which computes PO mean by considering only the variation of the kinetic energy of the accelerating cyclist over the sprint distance. Thus the aims of this study were to determine: 1) if the laboratory standard protocol can provide valid results when compared with the field protocol, and 2) if the equation based on classical dynamics can provide valid results when compared with the SRM measurements.

**Materials and methods**

**Subjects**

Seven male competitive cyclists ranging from regional to national level volunteered to take part in this experiment. Each subject was informed of all the test details and signed an informed consent. All subjects were well trained at the time of the experiment, which was conducted at the end of their competition period.

**Instrumentation**

During this study each subject rode on a classic race type bicycle (9 kg) equipped with “clipless” pedals, race saddle, and race handlebars. The bicycle tyre pressure was inflated to 700 kPa. Before beginning the test, the cyclist adjusted the bicycle to his usual cycling position. The bicycle used for all tests was equipped with the SRM Training System (professional model, Schoberer Rad Messtechnik, Germany, 2% accuracy). The SRM device is a precision strain-gauge-based crank and sprocket dynamometer that radio-transmits data to a unit display fixed on the handlebars. The SRM sampled (10 Hz) and stored the PO, the pedalling cadence (rpm), and the velocity (km h⁻¹). The validity of the SRM has been previously demonstrated by Martin et al.,¹⁰ Jones¹² and Passfield et al.¹³ Before the experimental procedure, the SRM was calibrated according to the manufacturer's recommended procedures. The test in the laboratory conditions was performed on a classic race type bicycle using an ergo-trainer T1670 Basic (Tacx, Netherlands). The resistance on this ergo-trainer was obtained by an electromagnetic brake applied to a roller in contact with the rear wheel. In this study all maximal PO tests were performed on the highest brake of the ergo-trainer. A front wheel support was used in order to permit cycling in horizontal position.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>22</td>
<td>4</td>
<td>18-27</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179</td>
<td>5</td>
<td>171-184</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>71.2</td>
<td>7.7</td>
<td>61-81.1</td>
</tr>
<tr>
<td>Relative body fat (%)</td>
<td>12.3</td>
<td>2.8</td>
<td>9-16</td>
</tr>
<tr>
<td>Distance to training (km)</td>
<td>9 429</td>
<td>1 988</td>
<td>7 000-12 000</td>
</tr>
</tbody>
</table>

Table I.—Anthropometric characteristics of the subjects.
Test protocol

The study included 12 sprint tests. After a standardised warm-up, the subjects performed 6 tests under laboratory conditions (on a Tacx ergo-trainer) and 6 tests in a gymnasium (55 m length) with actual cycling, from a static start. Under each laboratory and actual cycling condition the cyclists performed 3 tests in the seated position and 3 tests in the standing position. In the seated and standing positions the subjects performed in a randomised order 3 sprints on ergo-trainer against 3 different resistive loads (0.4, 0.6, 0.8 N/kg).

The determination of the gear ratio according to each resistive load was performed during a short exercise (<15 s) according to the subject’s mass and a computed PO reached on the SRM® screen display at a given pedalling cadence according to the method of Ravier \textit{et al.} \cite{14,15}

In actual cycling locomotion (gymnasium), the gear ratio’s according to the 3 different resistive loads were determined with computations of crank inertial loads of 40, 55 and 80 kg m\(^2\). The crank inertial load was computed from the equation elaborated by Fregly \textit{et al.} \cite{16}

\begin{equation}
\text{Crank inertial load:}
\end{equation}

\[
I_f + (R_f/R_g)^2[R_d^2(m_a + m_c + 2m_d + m_g) + (2I_d + I_g)]
\]

With: \(m_a, m_c, m_d, m_g\): respectively mass of the bicycle frame (5.8 kg), the rider, each bicycle wheel (1.18 kg), and the freewheel (0.32 kg), respectively; \(m_f\): mass of the chainrings, crank arms, and pedals (7.66 kg); \(I_d\): rotational inertia of each bicycle wheel about its rotation axis (0.1 366 kg m\(^2\)); \(I_f\): combined rotational inertia of the chainrings, pedals, and crank arms about the crank axis (0.0355 kg m\(^2\)); \(R_d\): rotational inertia of the freewheel about its rotation axis (0.0003 kg m\(^2\)); \(R_d/R_f\): gear ratio.

In this condition the crank inertial load represents the cyclist inertial resistance and in other words “the resistive load” for the sprints in the actual cycling locomotion. The subject performed a 10 min standardised warm-up period before the first test. Tests in the gymnasium were performed over a distance of 25 m. Before the beginning of this test the subject clipped his pedal and was maintained horizontally by an experimenter. The start was given by verbal command. The subjects were rigorously encouraged to reach the PO\(_{\text{peak}}\) as soon as possible. The recovery period between all trials was 5 min. The cyclist chose the same lower limb position for the start of all sprint tests (crank arm with a 45° crank angle and pedal in front position).

Mechanical variables measured

The PO, the pedalling cadence, and the cycling velocity were measured according to the time (200 Hz). The mechanical variables were thereafter averaged every 0.1 s. The PO\(_{\text{peak}}\) was determined by the maximal force on the pedal (\(F_{\text{max}}\)) was determined:

\[
F_{\text{max}} = \frac{PO}{[\text{crank arm length (m)} \times \text{pedal velocity (rad·s\(^{-1}\})}]}
\]

The pedalling cadence and force values were used to calculate the force-velocity relationship (Figure 1). The first value made at very low pedalling cadence was not taken into account in order to calculate the force-velocity relationship.

\begin{equation}
V_o \quad \text{and} \quad F_o \text{ values were determined from this relationship (Table II). } V_o \text{ represents the theoretical maximal pedalling cadence (with no resistive load), and } F_o \text{ represents the theoretical maximal force of the cyclist.}
\end{equation}

In order to determine estimated PO during the sprint tests on the gymnasium we used a basic fundamental equation. The PO produced by a cyclist during the acceleration phase (from a static start) can be obtained from the derivative of energy expenditure (PO = \(\frac{de}{dt}\)).

Our hypothesis considered only kinetics energy, and neglected aerodynamics and rolling resistance.
To estimate the $PO_{\text{mean}}$, the final equation is:

$$\text{Estimated } PO_{\text{mean}} = \frac{1}{2} m a V$$  \hspace{2cm} (2)$$

With $m$, the mass of the bicycle and the cyclist, $V$ the maximal velocity obtained at the end of the test (at 25 m, after static start), and $a$ the mean acceleration of the cyclist (between 0 to 25 m). $a$ was determined from the following equation: $a = \frac{V}{\text{time of the sprint [s]}}$. $V$ and the time of the sprints were obtained from the SRM measurements.

**Kinematics analysis**

The sprint tests were videoed by 2 cameras (JVC DVX-400EG marks) at a frequency of 25 Hz with a speed of 4000th of a second shutter speed on a numeric support. The simultaneous registration of both cameras was achieved with an infrared remote control. For the picture video we used the frame field to get 50 pictures per second. Both cameras were on each side stationary to 3.40 m of the axis of race and to 28 m of the start line. The optic axis of each camera formed an angle of 45°, therefore in the line with the axis of the cyclist’s displacement (Figure 2).

**Video data treatment**

The video images were numerised with a pinnacle studio DV8 card. The images were digitised using the Kinematic software (3D Vision). For each frame, 16 points on the cyclist body (tips of the middle fingers, elbows, shoulders, ankles, knees, toes) and 4 points on the bicycle were semi-manually digitized. In this study only the 4 points of the bicycle were taken. These points were studied in order to observe the influence of the different bicycle oscillations on the athlete’s performance.

**Statistics**

The mechanical variable values of the 3 sprints for 1) seated on ergo-trainer 2) standing on ergo-trainer, 3) seated in gymnasium and 4) standing in gymnasium were averaged. A Wilcoxon matched-pairs test was used to determine differences in mechanical variables between the different experimental conditions: 1) gymnasium vs ergo-trainer, 2) seated position vs standing position. Regression analyses were used to estimate the relationships between the mechanical variables (force-velocity, $PO_{\text{peak}}$, $PO_{\text{mean}}$, estimated $PO_{\text{mean}}$, actual $PO_{\text{mean}}$). Bias, limits of agreement and 95% confidence interval (95% CI) \(^{18,19}\) were further estimated in order to quantify the differences between estimation of PO by the basic physical equation and SRM measurements. Significance was set at $p<0.05$. Data are presented as mean values±standard deviation.

**Table II.—Mechanical variables in seated and standing positions on the ergo-trainer and in the gymnasium conditions.**

<table>
<thead>
<tr>
<th></th>
<th>Ergo-trainer Seated position</th>
<th>Ergo-trainer Standing position</th>
<th>Gymnasium Seated position</th>
<th>Gymnasium Standing position</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PO_{\text{peak}}$ (W)</td>
<td>881±135</td>
<td>913±149</td>
<td>843±137 a</td>
<td>973±153 bc</td>
</tr>
<tr>
<td>Time to $PO_{\text{peak}}$ (s)</td>
<td>1.78±0.73</td>
<td>1.57±0.63</td>
<td>2.96±0.54 a</td>
<td>2.69±0.7 bc</td>
</tr>
<tr>
<td>Cadence at $PO_{\text{peak}}$ (rpm)</td>
<td>139±2±18</td>
<td>133.2±13 a</td>
<td>93.6±16 a</td>
<td>96.6±16 b</td>
</tr>
<tr>
<td>$F_{\text{max}}$ (N)</td>
<td>465±64</td>
<td>471±69</td>
<td>661±110 a</td>
<td>722±116 bc</td>
</tr>
<tr>
<td>$V_{\text{o}}$ (rpm)</td>
<td>720±95</td>
<td>743±100</td>
<td>800±112 a</td>
<td>857±154 bc</td>
</tr>
<tr>
<td>$V_{\text{o}}$ (rpm)</td>
<td>262±29</td>
<td>259±35</td>
<td>248±48</td>
<td>281±68</td>
</tr>
</tbody>
</table>

a: different ($P<0.05$) to seated position on ergo-trainer; b: different ($P<0.05$) to standing position on ergo-trainer; c: different ($p<0.05$) to seated position in the gymnasium.

![Figure 2.—Position of the cameras in the gymnasium.](image-url)
Results

During sprints for both standing and seated positions in the gymnasium, $F_o$, $F_{max}$, and time to $PO_{peak}$ were significantly higher ($p<0.05$) compared with sprint on ergo-trainer (Table II). However, the $PO_{peak}$ during sprints in seated and standing positions in the gymnasium was significantly ($p<0.05$) lower (-4%) and higher (+6%) respectively, compared with ergo-trainer. $F_o$, $PO_{peak}$, and $F_{max}$ during the sprints in seated position in the gymnasium, turned out to be significantly lower ($p<0.05$) compared with the values obtained in the standing position. For sprints on ergo-trainer, only the pedalling cadence was different between the seated and standing positions.

The linear force-velocity relationships in the different experimental conditions were obtained with correlation coefficients ($r$) between 0.86 and 0.99 ($p<0.05$).

The relationship between the $PO_{mean}$ measured during the sprints in the gymnasium and the estimated $PO_{mean}$ (obtained with the basic physical equation) was obtained with a correlation coefficient of 0.99 ($p<0.001$) (Figure 3). The $PO_{mean}$ measured during the sprints in the gymnasium was close to the estimated $PO_{mean}$ ($746±159$ vs $756±161$ W, respectively). The basic physical equation over-estimates PO measurements only by $1±0.02%$. The limits of agreement between the estimated $PO_{mean}$ and SRM PO during the sprint test are presented in Figure 4. The mean PO difference between estimated $PO_{mean}$ and SRM PO±1.96 SD (calculated bias), was: $8.96±24.52$ W. The 95% CI for the mean differences in PO measurements are between 5.08 and 12.84 W. Seventy percent of data points lay inside this interval.

In our study the $PO_{mean}$ and $PO_{peak}$ were linked (Figure 5) with a high correlation coefficient ($r=0.93$, $p<0.001$). $PO_{peak}$ was 20% higher ($p<0.05$) compared with the $PO_{mean}$ ($902±150$ W vs $748±157$ W, respectively). The relationship between these 2 variables was determined by the following regression equation:

$$PO_{peak}=0.8896\ PO_{mean}+236.5$$  (3)

The kinematics analysis showed that the lateral oscillations of the bicycle during the test sprints in the gymnasium were $6.1±1.2$ and $24±2.1$ (p<0.05) in seated and standing positions, respectively (Figure 6). However, lateral oscillations during sprints on ergo trainer were close to $0^\circ$. 

---

Figure 3.—Relationship between the SRM $PO_{mean}$ measurement during sprints in the gymnasium and $PO$ predicted by the mathematical model.

Figure 4.—The limits of agreement of the SRM PO and the estimation PO obtained from the basic equation during the field sprint tests.

Figure 5.—Relationship between the $PO_{mean}$ and $PO_{peak}$ during the sprints in the gymnasium conditions.
The first aim of this study was to compare the mechanical variables obtained during sprints on ergo-trainer and in the gymnasium conditions. The most important finding of this study indicates that during sprints in the gymnasium in standing position, $PO_{peak}$, $F_o$, $F_{max}$, and time to PO peak were higher compared with sprints on ergo-trainer. During the sprints in the gymnasium the cyclist was naturally able allow lateral oscillations ($\angle \approx 25^\circ$), contrary to ergo-trainer conditions. Thus, in standing position, the cyclist was able to orient his lower limbs with respect to the pedal and crank arm. In this condition the cyclist can apply a more perpendicular force to the crank arm, and thus create a greater propulsive force when compared with the ergo-trainer conditions. On ergo-trainer there is no significant difference in $PO_{peak}$ and $F_{max}$ between the seated and standing positions, but there is a difference ($p<0.05$) in the gymnasium (Table II). These results suggest that the possibility to laterally oscillate the bicycle is a factor that can improve the performance during the short time sprint exercise in standing position. That is in agreement with the results of Reiser et al. and Baker et al. who have demonstrated the effective role of the arms and upper body in the mechanics of cycling. Baker et al. have shown that $PO_{peak}$ during 20 s sprint on an ergometer was significantly ($p<0.05$) lower (-28%) when the cyclist was not allowed to use the traditional grip on the handlebars. This study indicated that the handgrip strength influenced the leg $PO_{peak}$ and can permit the cyclist to increase the force on the pedal by pushing or pulling actions on the handlebars.

However, in the seated position the $PO_{peak}$ on ergo-trainer was higher ($p<0.05$) when compared to the gymnasium. This result suggests that the capacity to generate oscillations side to side during the short time sprint in seated position is not a factor that can increase the performance. It is possible that the static sprint start in the gymnasium requires concentration to maintain balance (especially at very low cycling velocities) which may disturbs the cyclist. Also performing the static start in the seated position is not a standard strategy. Habitually in track competition during the sprint start or during the 1 000 m time trial the cyclist uses the standing position contrary to our sprint test.

In our study the relationships between force and velocity are similar to those previously reported. In the gymnasium conditions (seated and standing positions) $F_o$, $F_{max}$, and the time to obtain $PO_{peak}$ were higher ($p<0.05$) compared with the ergo-trainer conditions (+12%, +32%, and +41%, respectively). Compared to the ergo-trainer conditions, the $F_{max}$ measured in the gymnasium represents a higher percentage of the $F_o$ value obtained by the force-velocity relationships (64% and 84%, respectively). These results indicate that the cyclist can produce a higher force in the gymnasium conditions, that modifies the force-velocity relationships. The results obtained in laboratory conditions are different than the ones obtained in actual cycling. This suggests that sprint tests in actual cycling locomotion are more suitable (than laboratory conditions) for measuring the mechanical variables with higher accuracy.

The estimated $PO_{mean}$ was linked to $PO_{mean}$ ($r=0.99$, $p<0.001$). The 95% CI for the mean difference between the estimated $PO_{mean}$ and the SRM measured $PO_{mean}$ revealed that more than 70% of samples were inside this interval. This suggests that the model is valid to estimate the $PO_{mean}$ during a short sprint in gymnasiun. The basic physical equation used in this study could be used by coaches in a training program.

Our results indicate that the $PO_{mean}$ was highly correlated ($r=0.93$, $p<0.001$) with the $PO_{peak}$ and that $PO_{peak}$ was 20% higher than $PO_{mean}$. The relationship between these 2 mechanical variables (Figure 6) could be easily used by a coach to estimate the $PO_{peak}$ from the estimated $PO_{mean}$. The sprint test protocol used in this study could be used: 1) to determine the optimal gear ratio and crank length for the static start phase of the 1 000 m time trial or the Olympics team sprint, 2) as training test during the season for the
analysis of the force-velocity relationships. The force-velocity relationships can also be used to determine the resistive load for a strength training program. Indeed, Fo corresponds to the maximal theoretical isometric force of a lower limb. To improve Fo, Carpinelli et al.25 suggest performing strength training between 70% to 100% of the maximal theoretical isometric force. Moreover, to take into account the bilateral deficit of the lower limb 26, 27 the track cyclist should perform strength exercises alternatively with each lower limb.

Conclusions

In conclusion, the results of this study indicate that PO peak, Fo, and time to obtain PO peak were different between laboratory and actual cycling conditions. To perform a valid estimation of the PO peak in the seated and standing positions in laboratory it would be necessary to use the personal bicycle of the cyclist and a set-up that permits lateral oscillations. However, the better sprint tests seem to be those performed in actual cycling.

Acknowledgements.—Authors would like to thank Ms Catherine Capitan for her technical help in this study, and Mr Jean Noel Pernin for his advice.

References