Laboratory Versus Outdoor Cycling Conditions: Differences in Pedaling Biomechanics

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The aim of our study was to compare crank torque profile and perceived exertion between the Monark ergometer (818 E) and two outdoor cycling conditions: level ground and uphill road cycling. Seven male cyclists performed seven tests in seated position at different pedaling cadences: (a) in the laboratory at 60, 80, and 100 rpm; (b) on level terrain at 80 and 100 rpm; and (c) on uphill terrain (9.25% grade) at 60 and 80 rpm. The cyclists exercised for 1 min at their maximal aerobic power. The Monark ergometer and the bicycle were equipped with the SRM Training System (Schoberer, Germany) for the measurement of power output (W), torque (N-m), pedaling cadence (rpm), and cycling velocity (km-h⁻¹). The most important findings of this study indicate that at maximal aerobic power the crank torque profiles in the Monark ergometer (818 E) were significantly different (especially on dead points of the crank cycle) and generate a higher perceived exertion compared with road cycling conditions.

Most investigations and performance tests in cycling have been conducted in laboratory conditions. The research is done on cycle ergometers (e.g., Kautz et al., 1991; Caldwell et al., 1998; Li & Caldwell, 1998; Padilla, et al., 1999; Swain & Wilcox, 1992) but also on treadmills (Bertucci, Duc, et al., 2005; Heil, 1998; Hansen, et al., 2002, 2002a) or on roller cylinders (Boulourchi & Hull, 1985). Performance tests like maximal aerobic power (VO₂max), time trial (Coyle et al., 1991; Hawley et al., 1997; Smith et al., 1999), or maximal power output tests (Hintzy et al., 1999; Van Soest & Casius, 2000) are always performed on cycle ergometers for the elite cyclist.

However, the ergometers do not have the same mechanical properties (stiffness and damping) as a classical race bicycle (Fregly et al., 2000). Moreover, physical laws indicate that the simulation of the cyclist’s kinetic energy (J) and the crank inertial load (or effective inertia, kg-m²) are not similar to road cycling conditions owing to the inertia of the Monark ergometer flywheel (Fregly et al., 2000). In road cycling locomotion, the kinetic energy varies according to the cycling velocity (m-s⁻¹) and the mass (kg) of the cyclist, whereas the rotational kinetic energy in ergometer cycling varies with inertia (kg-m²) and the rotational speed (rad-s⁻¹) of the flywheel. The crank inertial load varies with the gear ratio and the mass of the cyclist (Fregly et al., 1996; Fregly et al., 2000; Hansen et al., 2002; 2002a), but, unlike road cycling, the gear ratio cannot be changed.
in cycle ergometers. Most ergometers do not permit adjustment of rotational kinetic energy or the crank inertial load. In previous studies in the laboratory, several authors have shown that a variation of kinetic energy or crank inertial load (Fregly et al., 2000; Hansen et al., 2000, 2002a) could generate a modification of freely chosen pedaling cadence, and of crank torque profile for the same pedaling cadence. Also, Hansen et al. (2002) suggest that a crank inertial load variation could produce a modification of the cyclist's perceived exertion. The perception of exertion can be considered as a constellation of sensations: strain, aches, and fatigue involving the muscles and the cardiovascular and pulmonary systems during exercise. These sensations are generally classified (Borg, 1998) as being derived from either cardiopulmonary (e.g., heart rate, oxygen uptake) or peripheral factors (e.g., blood lactate concentration, mechanical strain).

To the best of our knowledge, a comparison of crank torque profile and perceived exertion between the Monark ergometer and road cycling has not been conducted. Therefore, the aim of this study was to compare the crank torque profile and the perceived exertion between the Monark ergometer conditions and two outdoor cycling conditions: level ground and uphill road cycling in seated position (most used in the laboratory). In the laboratory, the crank inertial loads were between 4 and 18 times lower than the road cycling conditions. It could be hypothesized that the resulting differences in crank inertial load between Monark and road cycling could lead to a different crank torque profile and perceived exertion. It was hypothesized that under the laboratory conditions the pedaling would be more jerky and that the rating of perceived exertion would be higher compared with the road cycling conditions.

**Methods**

**Subjects**

Seven male competitive cyclists (age: 25.5 ± 4.9 years, height: 1.78 ± 0.04 m, body mass: 70.6 ± 5.0 kg, maximal aerobic power [MAP] 322 ± 40 W) in their preparative training period (for the race season) participated in the study. Each subject was informed of all details of the testing and signed an informed consent agreement.

**Instrumentation**

In the road cycling conditions, the subject rode on a classical race bicycle (10.2 kg) equipped with clipless pedals. The bicycle tire pressure was inflated to 700 kPa. In the laboratory, the cyclist performed tests on a modified Monark ergometer (818 E; Varberg, Sweden). A race saddle, and race handlebars (Ergostem system; Look, France) permitted a better adjustment of the cyclist’s habitual position. The bicycle and the Monark ergometer were equipped with the SRM Training System Powermeter (scientific model; Schoberer, Germany). The standardized calibration (i.e., the resetting of the SRM “frequency versus torque” slope) was performed just a few days before our first test day by the manufacturer and resulted in an accuracy of ±0.5% (the manufacturer’s data). The SRM sampled (10 Hz) and stored the power output (W), the pedaling cadence (rpm), the cycling velocity (km·h$^{-1}$), and the propulsive torque (N·m, 200 Hz) using the Bertucci, Grappe, et al. (2005) methods. The propulsive torque takes into account the combined muscular work of the two lower limbs during a crank cycle.

**Tests Protocol**

On the first test day, the subjects performed in the laboratory a continuous incremental test to determine MAP. The subjects rode at a pedaling cadence of 80 rpm on the Monark ergometer for 2 min at 120 W, after which the power output was increased by 30 W every 2 min until exhaustion. Maximal aerobic power was determined as the final power output during which at least 1 min of exercise was maintained. In the laboratory, a ventilator placed in front of the cyclist cooled him.

On the second test day, three test sessions on the Monark under laboratory conditions at 60 rpm (Lab$\text{_{60}}$), 80 rpm (Lab$\text{_{80}}$), and 100 rpm (Lab$\text{_{100}}$) were performed at MAP during 1 min.

On the third test day, the experimental protocol in the field was composed of four test sessions that were performed at MAP during 1 min: two tests on level ground at 80 rpm (L$\text{_{80}}$) and 100 rpm (L$\text{_{100}}$), and two tests on uphill ground (9.25% grade) at 60 rpm (U$\text{_{60}}$) and 80 rpm (U$\text{_{80}}$).

Subjects performed a standardized 5-min warm-up period before the first laboratory (Lab$\text{_{60}}$, Lab$\text{_{80}}$, Lab$\text{_{100}}$) and field tests (L$\text{_{60}}$, L$\text{_{100}}$, U$\text{_{60}}$, U$\text{_{80}}$). In order to avoid possible fatigue effects, all these tests were
performed during a short period (1 min) in the seated position at MAP. The recovery period between trials was 5 min. Participants were also required to maintain the same body position (hands on the brake hoods). The test sessions during the laboratory and the field test day were randomized. If the average MAP during the 1-min test was not within ±10 W of the desired power output, the test was not taken into account. In this case, another test was performed. In the laboratory, the mean temperature was 22 ± 1 °C. In the field, the mean temperature was 22 ± 2 °C and the wind velocity (varying from 0 to 1.4 m·s⁻¹) was measured by means of an anemometer (Jules Richard; France, accuracy ±2%).

Mechanical Variables Measured

The power output, the pedaling cadence (CA, °), and the cycling velocity were measured and averaged during the last 30 s of the 1 min of exercise at MAP. The crank angle at 0° corresponded to the vertical position of the left crank (pedal in high position). The measurement of propulsive torque and the crank angle were made with respect to the lower limb using the method described by Bertucci, Grappe, et al. (2005). The torque values were measured at CA of 0, 45, 90, 135, and 180° corresponding to the pedaling power phase. The maximal torque value (T_peak, N·m) and crank angle corresponding were measured. The minimal torque (N·m) and the corresponding CA values at the beginning of left pedal downstroke (T_min1 and CA_min1, respectively) and at the end of left pedal downstroke (T_min2 and CA_min2, respectively) were measured. The difference between T_peak and T_min1 were calculated (T_delta = T_peak − T_min1) (Hansen et al., 2002).

According to Fregly et al. (2000), the Monark crank inertial load value is 5.2 kg·m². In the field, the cyclist crank inertial loads were calculated from the equation elaborated by Fregly et al. (2000) using the inertial values of the bicycle mechanics according to Hansen et al. (2002, 2002a).

Perceived Exertion and Pedaling Sensations Measurements

At the beginning of each test (Lab_60, Lab_80, Lab_100, L_60°, L_80°, L_100°, U_60, U_80, U_100), the subjects were provided with a typewritten set of standardized instructions explaining how to complete Borg’s perceived exertion (RPE) scale (Borg, 1998). This RPE scale is a 15-point single-item scale ranging from 6 to 20 that assesses levels of perceived exertion. It ranges from no exertion at all (at 6) to maximal exertion (at 20). The subjects were instructed to give an overall RPE immediately at the end of each test.

Statistical Analysis

A Wilcoxon matched-pairs test was used to determine the differences in mechanical and perceptual (RPE) variables between the different experimental conditions: (1) Lab_60 vs U_60° (2) Lab_80 vs U_80° (3) Lab_90 vs L_90°, and (4) Lab_100 vs L_100°. Significance was set at p < 0.05. Data are presented as M ± SD.

Results

The mean power outputs measured for Lab_60, Lab_80, Lab_90°, U_60°, U_80, L_90° and L_100° were 321 ± 40, 323 ± 36, 321 ± 32, 325 ± 43, 325 ± 39, 322 ± 40, and 325 ± 35 W, respectively. The mean pedaling cadences for Lab_60, Lab_80, Lab_100°, U_60°, U_80, L_90° and L_100° were 60 ± 1, 81 ± 1, 100 ± 2, 61 ± 2, 81 ± 2, 82 ± 2, and 99 ± 1 rpm, respectively. For all experimental conditions, there was no significant difference of propulsive torque at CA of 0, 45, 90, 135, and 180° between the road cycling and Monark conditions. The T_peak and T delta during U_60° were significantly higher (+7.7% and +9.4%, respectively; p < 0.05) compared with Lab_60 (Table 1). The CA_min1 during Lab_60 was significantly lower (−4.1°; p < 0.05) compared with U_60°. The CA_min2 during Lab_60° was lower (−6.8°; p < 0.05) compared with L_60°. The T_delta during Lab_100° was lower (−30%; p < 0.05) compared with L_100°. In the field setting, the mean cyclist crank inertial loads were 21.8, 36.6, 137.2, and 93.1 kg·m² for U_60°, U_80°, L_60°, and L_100°, respectively.

The RPE in laboratory conditions were significantly higher (p < 0.05) compared with all outdoor cycling conditions (Figure 1).

Discussion

The most important findings of this study indicate that the laboratory conditions (Monark 818 E) are associated with an alteration of the crank torque profile and a higher perceived exertion for the participants compared with road cycling conditions.

Values for T_min1 during Lab_60 and Lab_100 were significantly different (+2% and −30%, respec-
Table 1  Mechanical Variables of the Crank Cycle in Laboratory (Monark 818 E) and on Uphill and Level Terrain, $M \pm SD$

<table>
<thead>
<tr>
<th>Cycling condition</th>
<th>$T_{\text{peak}}$ (N m)</th>
<th>CA at $T_{\text{peak}}$ (°)</th>
<th>$T_{\text{min1}}$ (N m)</th>
<th>CA$_{\text{min1}}$ (°)</th>
<th>$T_{\text{min2}}$ (N m)</th>
<th>CA$_{\text{min2}}$ (°)</th>
<th>$T_{\text{delta}}$ (N m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab$_{60}$</td>
<td>78.7 ± 14.0</td>
<td>88.1 ± 8.4</td>
<td>12.0 ± 2.2</td>
<td>4.3 ± 10.8</td>
<td>10.6 ± 4.0</td>
<td>188 ± 2.6</td>
<td>66.7 ± 13.5</td>
</tr>
<tr>
<td>U$_{60}$</td>
<td>84.8 ± 18.0</td>
<td>90.1 ± 10.5</td>
<td>11.8 ± 2.6</td>
<td>8.4 ± 4.9</td>
<td>9.6 ± 0.9</td>
<td>189.5 ± 4.4</td>
<td>73.0 ± 16.6</td>
</tr>
<tr>
<td>Lab$_{80}$</td>
<td>57.3 ± 8.4</td>
<td>88.7 ± 13</td>
<td>12.8 ± 6.3</td>
<td>13.6 ± 13.5</td>
<td>12.8 ± 5.5</td>
<td>190.1 ± 6.6</td>
<td>44.5 ± 11.1</td>
</tr>
<tr>
<td>U$_{80}$</td>
<td>59.2 ± 10.1</td>
<td>90.7 ± 11.5</td>
<td>10.5 ± 4.3</td>
<td>10.7 ± 11.4</td>
<td>9.3 ± 2.8</td>
<td>191.4 ± 10.3</td>
<td>48.7 ± 11.4</td>
</tr>
<tr>
<td>L$_{80}$</td>
<td>60.1 ± 12.5</td>
<td>95.0 ± 11.8</td>
<td>11.5 ± 5.9</td>
<td>15.3 ± 5.9</td>
<td>9.8 ± 4.2</td>
<td>196.9 ± 6.0</td>
<td>48.5 ± 15.6</td>
</tr>
<tr>
<td>Lab$_{100}$</td>
<td>48.8 ± 8.4</td>
<td>100.7 ± 12.3</td>
<td>8.8 ± 5.1</td>
<td>25.0 ± 10.3</td>
<td>9.9 ± 5.6</td>
<td>205.7 ± 6.1</td>
<td>39.9 ± 14.9</td>
</tr>
<tr>
<td>L$_{100}$</td>
<td>49.1 ± 8.1</td>
<td>97.3 ± 10.7</td>
<td>11.4 ± 7.2</td>
<td>24.6 ± 10.8</td>
<td>9.8 ± 4.7</td>
<td>209.3 ± 8.2</td>
<td>37.7 ± 13.9</td>
</tr>
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</table>

$T_{\text{peak}}$: peak propulsive torque (N m), $T_{min1}$: torque at top dead point (N m), $T_{min2}$: torque at bottom dead point (N m), $T_{\Delta}$: the difference between the $T_{\text{peak}}$ and the $T_{min1}$ (N m). U$_{60}$: Uphill terrain at 60 rpm, U$_{80}$: Uphill terrain at 80 rpm, L$_{80}$: level terrain at 80 rpm, L$_{100}$: level terrain at 100 rpm, Lab$_{60}$: Monark ergometer at 60 rpm, Lab$_{80}$: Monark ergometer at 80 rpm, Lab$_{100}$: Monark ergometer at 100 rpm, CA: crank angle (°), CA$_{\text{min1}}$: crank angle at $T_{\text{min1}}$ (°), CA$_{\text{min2}}$: crank angle at $T_{\text{min2}}$ (°).

a: significantly ($p < 0.05$) different from the Lab$_{60}$.
b: significantly ($p < 0.05$) different from the Lab$_{80}$.
c: significantly ($p < 0.05$) different from the Lab$_{100}$.

Figure 1 — Mean rating scale values of perceived exertion during the exercise at maximal aerobic power (MAP) on uphill and level terrains and in the laboratory conditions at different pedaling cadences. Brackets represent 1 standard deviation. U60: uphill terrain at 60 rpm, U80: uphill terrain at 80 rpm, L80: level terrain at 80 rpm, L100: level terrain at 100 rpm, Lab60: Monark ergometer at 60 rpm, Lab80: Monark ergometer at 80 rpm, Lab100: Monark ergometer at 100 rpm, RPE: rating of perceived exertion. *$p < 0.05$.

RPE tively) compared with U$_{60}$ and L$_{100}$. The value for $T_{\text{min2}}$ during Lab$_{80}$ was significantly higher (+25%) than U$_{80}$ and L$_{80}$ (Table 1). Thus, the crank torque profile was altered in the laboratory conditions. The mechanical differences between the Monark ergometer and the field road cycling conditions might originate in differences in crank inertial load. On the Monark ergometer, the crank inertial load was only 5.2 kg⋅m$^2$ compared with values from 21.8 kg⋅m$^2$ to 137.2 kg⋅m$^2$ in the road cycling conditions.
These differences may result in an alteration in the crank torque profile similar to those observed in a previous study using an ergometer (Patterson & Pearson, 1983). During a treadmill exercise test, Hansen et al. (2002) have shown that the crank torque profile could be affected by a change of crank inertial load. In line with our results, Fregly et al. (1996) found that changes in crank inertial load have significant effects when crank torque profile values are low (as in our study at CA_{min1} and CA_{min2}). The crank torque profile differences between the laboratory and the field conditions could also be explained (although with a minor effect) by differences (stiffness and damping) in the mechanical characteristics of the Monark’s frame and the bicycle race (Fregly et al., 1996).

As far as RPE is concerned, our results are in accordance with previous published studies reporting that perceived exertion and discomfort are linked to the feeling of strain in the working muscles and joints (Ekblom and Goldbarg, 1971; Pandolf and Noble, 1973). In addition, the results of the present study indicate higher values of RPE in all laboratory conditions compared to the field conditions. These results are also in accordance with the data from Patterson et al. (1983). After exercising, participants in this study reported that they preferred the smooth pedaling characteristics of the heavy flywheel (thus with high crank inertial load value). When the inertia flywheel was low (e.g., Monark 818E), the subject had to compensate a balancing movement of the body by supplementary work of the muscles of the hands, arms, and shoulders. Voigt and Kiparski (1989) have shown that a change in flywheel rotational energy affected the heart rate response (load pulse sum). The supplementary work may then be thought to have an effect on the physiological and the perceptual responses.

Another hypothesis is that RPE may be influenced by the changes in mechanoreceptor stimulation in the lower limbs caused by pedaling on the Monark ergometer. The mechanoreceptor stimulation difference could be due to the crank torque profile modifications between the laboratory and the road cycling conditions. In the Monark ergometer, the cyclists did not exercise in their usual pedaling conditions (i.e., lower T_{peak} for Lab_{60} and higher T_{min1} and T_{min2} for Lab_{90} and Lab_{90}), and this may have affected their RPE. In order to investigate more accurately the cycling laboratory and outdoor cycling conditions, it could be interesting to measure the nonpropulsive force applied in the pedal and the internal work (e.g., balancing movements of the body). It is highly likely that perceived exertion is influenced by these nonpropulsive forces. Unfortunately, the investigated variables in the present study do not support this hypothesis.

Further investigations using the same experimental protocol that would also include measurements in level terrain at 60 rpm and in uphill terrain at 100 rpm are needed to determine more accurately the variables affecting RPE during pedaling on a Monark ergometer. Another possible reason why RPE were found to be different in the laboratory vs outdoor cycling conditions relates to the different exercise environments. As stated by Rejeski (1981), the preference of an individual for a particular mode of exercise is a major potential influence on perceived exertion. Indeed, if an individual views a particular activity as distasteful (exercising in laboratory conditions is usually considered an aversive task), he might rate that activity as more effortful than another activity of equal intensity. Future research might address this issue. For example, video-assisted techniques (e.g., lightweight head-mounted video camera) could be used to record the cyclists’ visual field while training in their usual environment. These visual records could then be shown in the background of the laboratory when exercising on cycling ergometer. Also, it could be interesting to use separate RPE scales that would allow us to assess three main types of related responses: (1) the overall RPE (e.g., tired, worn out), (2) the muscular RPE (e.g., muscular sensations, weak or heavy legs), and (3) the cardiopulmonary RPE (e.g., cardiopulmonary sensations, short of breath, panting).

In conclusion, our results suggest that the pedaling exercises at MAP on the Monark 818 E generate a modification of crank torque profile (especially at CA_{min1} and CA_{min2}), and a higher perceived exertion compared with outdoor exercises performed on level ground and uphill road cycling.

Acknowledgments

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References


