Maximal intermittent cycling exercise: effects of recovery duration and gender

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INTERRUPTED ANAEROBOC ENERGY supply characterizes the type of metabolic pattern in many sports involving repetitive sprint exercises, such as soccer, rugby, tennis, hockey, basketball, and fencing. During such exercises, rapid changes in metabolism and muscle function result in an inability to maintain the required level of force or exercise intensity. The physiology of maximal intermittent exercise is complex, as the patterns of time course relationship between work and recovery period are not well defined. Over the last 10 years, numerous studies have focused on fatigue and recovery processes during sprints (1, 6, 7, 10, 11, 23). Some authors have investigated the effect of short recovery duration (30 s) on repeated sprint performance, on nonmotorized treadmill (17, 19), during over-ground sprints (2), and on cycle ergometer (18). These studies have demonstrated a decrease in performance closely related to the number of repetitions and exercise duration. During intermittent exercise, performance depends on the subject’s ability to recover from the periods of work. Therefore, performance depends on the duration of the rest between sets. In sporting events, there is a wide range of work-rest patterns that are all involved in the ability to sustain all-out effort. To our knowledge, no data are available on the minimal recovery duration needed between two short cycling sprints to maintain a given maximal performance in women.

Resting phosphagen stores of women (−80 mmol/kg dry muscle) are close to the values for men (6, 7, 10, 14). Moreover, no significant gender differences were observed for changes in ATP, ADP, IMP, and phosphocreatine (PCr) during sprint exercise (14). However, differences between men and women have been reported in their anaerobic metabolic properties (14, 15) and their hormonal responses (8). Women have been shown to have smaller cross-sectional areas of type II muscle fibers (15, 19, 31) and lower glycolytic enzymes activities (28, 31) than men. Moreover, during short sprints, greater adrenergic stimulation and muscle lactate accumulation were observed in men (8, 25, 33). These differences have been suggested to predict some of the differences in performance between genders (8, 15, 31). It could be presumed that differences in muscle characteristics, glycolytic contribution, and hormonal milieu would affect performance during repeated maximal exercises. In fact, glycolytic contribution accounted for >40% to the total ATP resynthesis during 6- to 10-s cycling sprints, whereas aerobic contribution remained very low (7, 18). A lower glycolytic contribution to ATP generation in women may be associated with a lower anaerobic capacity and a greater decrease in performance than men during the last part of sprints. There are no studies, to our knowledge, in which gender-related differences in the minimal recovery period without any sprint performance alteration have been addressed. However, women may recover rapidly, according to the two following observations. On the one hand, a lower muscle lactate accumulation has been described in women after 10- to 30-s sprints (14, 25). On the other hand, a smaller ATP reduction was observed in women during repeated Wingate tests and was attributed to a faster recovery of ATP between bouts (14).

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Therefore, the purposes of the present study were to examine changes in repeated sprint performance with various short recovery durations and to investigate gender differences in the recovery pattern of maximal anaerobic exercise. Bearing in mind literature data, the first hypothesis of the present study was that rapid recovery would occur between two short all-out exercise bouts. The second hypothesis was that women would perform less work and would have a smaller power output than men for a given sprint. The third hypothesis was that, owing to their glycolytic characteristics, women would have a lower anaerobic capacity and would be more fatigable than men within the same 8-s sprint but would recover quickly from one sprint to the subsequent one.

**MATERIALS AND METHODS**

**Subjects.** Physical education students (20 men and 13 eumenorrheic women) volunteered to take part in the study after giving written, informed consent. The experimental procedure was approved by the local scientific committee, and subjects were fully informed about procedures and risks. They were all physically active (physical activity: men, 11.8 ± 6.5 and women, 10 ± 4.2 h/wk) but not specifically trained at cycling to avoid any sport-specific adaptations. Subjects were asked to refrain from any form of intense physical exercise during the experimental period. Their anthropometric characteristics are listed in Table 1. Percentage of body fat was calculated from the method of Durnin and Rahaman (13). Lower limb lean volumes were determined by the method of Jones and Pearson (26). Significant differences between men and women are indicated in Table 1.

**Material.** Tests were conducted on a friction-loaded cycle ergometer (Monark 824 E, Stockholm, Sweden). The cycle was equipped with an optical sensor (OPB 815W, Optek Technology) to detect crank gear rotation cycles to calculate the pedal revolution velocity (51 counts/revolution) and the angular velocity of the flywheel. All signals were computerized via a specifically designed interface card (DAS-1801 ST, Keythley, Metrabyte). The flywheel diameter was 26 cm. In one pedal revolution, the distance traveled by a point on the perimeter of the flywheel was 6.12 m. The gear ratio of the cycle ergometer was 52/14. The cycle was equipped with toe clips to prevent the subject’s feet from slipping.

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
<th>P Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>20</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>22.7 ± 1.9</td>
<td>20.7 ± 0.8</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Height, cm</td>
<td>179.2 ± 7.1</td>
<td>165.3 ± 3.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>71.3 ± 8.8</td>
<td>55.1 ± 3.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>14.4 ± 4.7</td>
<td>20.5 ± 3.6</td>
<td>&lt;0.01</td>
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<tr>
<td>Lean body mass, kg</td>
<td>64.8 ± 6.7</td>
<td>43.6 ± 2.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lower limb lean volume, liters</td>
<td>7.9 ± 1.5</td>
<td>5.3 ± 0.4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>F-v relationships</td>
<td></td>
<td></td>
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<tr>
<td>Slope</td>
<td>–14.1 ± 2.9</td>
<td>–18.1 ± 2.4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Intercept</td>
<td>235.6 ± 11.4</td>
<td>196.2 ± 8.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>F opt, N</td>
<td>85.9 ± 11.9</td>
<td>52.9 ± 8.1</td>
<td>&lt;0.001</td>
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<tr>
<td>Power, W/kg lean body mass</td>
<td>17.1 ± 2.2</td>
<td>14.2 ± 2.1</td>
<td>&lt;0.01</td>
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<tr>
<td>Power, W/liters lean volume</td>
<td>141.2 ± 29.7</td>
<td>118.3 ± 24.3</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Values are means ± SD; n, no. of subjects. F-v, force-velocity; F opt, optimal force. R^2 range from 0.95 to 0.99

**Experimental procedure.** The protocol was separated into two parts. During the first visit to the laboratory, all subjects were familiarized with the ergometer and performed a force-velocity test (F-v) (35) to determine maximal cycling power and optimal force (F opt). In the following days, subjects performed intermittent exercise, including several series of sprints against F opt.

**F-v test.** Before the test, the seat height was adjusted for each subject, and a standardized warm-up was performed, consisting of 4-min pedaling at 70 rpm for men and 65 rpm for women, with a 6- to 8-s acceleration every minute. Workload ranged from 1 to 2 kg, depending on the subject’s characteristics (body mass and training condition). A 5-min rest separated the warm-up from the F-v. The F-v consisted of five short maximal sprints (8 s), from a stationary start, against increasing braking forces, with 4-min recovery between each sprint. Initial braking forces were 2 and 3 kg for women and men, respectively. The increment between two consecutive workloads ranged from 1.0 to 1.5 kg for women and 2.0 kg for men, according to the subject’s body mass and the flywheel velocity previously reached. Each sprint was initiated from the same position. Data logging was initiated 2 s before the subject was instructed to begin the sprint. During each sprint, subjects had to remain seated and were strongly encouraged to reach the maximal pedaling rate as quickly as possible.

For each sprint, the power output (P fric) was computed by using the braking force (F B) given by the friction of the belt and the angular velocity of the flywheel (ωf)

\[ P_{\text{fric}} = F_B \cdot \omega_f \]

The individual F-v relationships were calculated from the forces applied and the peak velocity (rotations/min) reached during each sprint. As described by Vandewalle et al. (35), during polycyclic and polyarticular movements, the relationship between the force and the velocity is linear (r > 0.98), and a parabolic relationship (second-order polynomial force-power relationship) exists for each subject between forces and corresponding power output. F opt is then defined as the force for which maximal power output is attained.

**Intermittent exercise.** After the standardized warm-up, subjects performed four series of two 8-s sprints (Sp1 and Sp2) against F opt. Each series was separated by a reference rest period of 240 s. In the series, 15-, 30-, 60-, and 120-s passive recovery separated the two sprints. Recovery periods started immediately at the end of the first sprint and were monitored. Subjects remained seated on the bicycle and were allowed to follow the countdown given by the experimenter. The series were carried out in a random order to compensate for any learning or fatigue effects. Strong verbal encouragement was provided throughout sprints.

For each sprint, peak power output (P peak), power at the 8th s (P w), total mechanical work (W) performed during the 8-s sprint, and time to reach P peak were calculated. Calculations were based on flywheel and crank inertial properties, flywheel and crank kinematics, and the load applied to the flywheel. Power calculation used the velocity of the flywheel and braking resistance, in addition to the inertial contribution of both flywheel and crank

\[ P(W) = P_{\text{fric}} + I_w \cdot \alpha_c \cdot \omega_w + I_c \cdot \alpha_c \cdot \omega_c \]

where \( I_w \) is the moment of inertia of the flywheel, \( I_c \) is the moment of inertia of the crank, \( \alpha_c \) is the angular acceleration of the flywheel, \( \alpha_c \) is the angular acceleration of the crank, and \( \omega_c \) is the angular velocity of the crank.

The moment of inertia of the flywheel (0.98 kg/m²) and crank (0.05 kg/m²) was calculated by a geometrical estima-
tion and the free deceleration of the flywheel with the crank jammed. The angular velocity of the flywheel was the product of the measured crank gear angular velocity by the gear ratio. Its angular acceleration was calculated from a fourth-degree polynomial regression based on the flywheel angular velocity. The W values were computed by numerically integrating the power output (P) during the 8-s exercise bouts.

Statistical analyses. Statistical analyses were performed on Statistica 5.5. Anthropometric characteristics of men and women were compared by using a Student t-test. Performances at the first sprints of each series were compared with an ANOVA with repeated measures. Effects of recovery duration and/or gender on performances were analyzed by using a three-way ANOVA with repeated measures (sprint number and recovery duration) and one group factor (gender). The rate of decrease over time in mechanical power output was analyzed in each sprint from Ppeak to P8s by using linear regression analyses. The slopes were also tested with a three-way ANOVA, as aforementioned. Newman-Keuls post hoc comparison located differences. Normality of distributions was checked, and the P values have been corrected for violation of the assumption of sphericity by using Huynh-Feldt adjustment when epsilon (ε) values were ε < 0.75, according to Vincent’s guidelines (36). Statistical significance was chosen as P < 0.05.

RESULTS

During intermittent exercise, no significant differences were observed in Ppeak (Fig. 1) and W (see Fig. 3) between the first sprints of each series.

Ppeak values of men were greater than those of women (P < 0.001; Fig. 1). Men had a greater lean body mass than women (64.8 ± 6.7 vs. 43.6 ± 2.6 kg; P < 0.001); however, differences between genders persisted when power output was expressed per unit of lean body mass and per unit of lower limb lean volume (P < 0.01; Table 1). A decrease in Ppeak values between the two sprints was only consistent after 15-s recovery in both men and women (−6.4 and −7.4%, respectively; P < 0.001; Fig. 1). When Ppeak Sp2 was expressed as %Ppeak Sp1, gender differences disappeared, but the main effect of recovery duration remained significant. Performance declined after 15- and 30-s recovery compared with other conditions (P < 0.001 and P < 0.05, respectively; Fig. 2). Time to reach Ppeak did not show any significant differences between recovery durations, but women reached their peak power more slowly than men (on average: 5.15 ± 1.2 vs. 3.8 ± 1.2 s; P < 0.01).

In each sprint, men performed a greater work in 8 s compared with women (P < 0.001; Fig. 3). Work decreased in both men and women (−9.4 and −6.8%, respectively; P < 0.001) only when the second sprint was performed after 15-s recovery (Fig. 3). When W Sp2 was expressed as %W Sp1, gender differences persisted (on average: 98.1 ± 3.2% in men vs. 94.7 ± 4% in women; P < 0.05).

A greater decrement in power output from Ppeak to P8s was observed in women than in men (P8s, %Ppeak: 69 ± 18.2% in women vs. 81 ± 11.2% in men; P < 0.01). In addition, linear regressions for each sprint (R2 range from 0.79 to 0.99) obtained between power (expressed as a percentage of Ppeak) and exercise time from Ppeak to P8s indicated a greater decrease in women than in men in Sp1 and Sp2 (−3.2 ± 2.9 in men vs. −6.3 ± 3.4 in women in Sp1, P < 0.05; and −3.8 ± 3.1 in men vs. −9.5 ± 4.8 in women in Sp2, P < 0.01; Fig. 4). How-

![Fig. 1. Peak power output (Ppeak) expressed in absolute values (means ± SD) for sprints 1 (Sp1) and 2 (Sp2) for men (M) and women (W). †Performance variation between Sp1 and Sp2 and Sp2 were significantly different from the 30-s condition for both men and women, P < 0.01. ‡Performance variation between Sp1 and Sp2 were significantly different from 60-, 120-, and 240-s conditions for both men and women, P < 0.001. Differences between men and women were P < 0.001.](Image)

![Fig. 2. Ppeak at Sp2 expressed as a percentage of Ppeak at Sp1 (means ± SD) for men and women. Main effect of recovery duration: *significantly different from 60-s condition, P < 0.05; †significantly different from 120- and 240-s conditions, P < 0.01; ‡significantly different from 60-, 120-, and 240-s conditions, P < 0.001. Differences between men and women were not significant.](Image)

![Fig. 3. Total work (W) expressed in absolute values (means ± SD) for Sp1 and Sp2 for men and women. †Performance variation between Sp1 and Sp2 was significantly different for 15-s condition for both men and women, P < 0.001. Differences between men and women were P < 0.001.](Image)
ever, no significant main effect of recovery duration was noted.

No significant interaction effects between gender and recovery duration were observed in any of the parameters studied.

DISCUSSION

The main salient observation of the present study was the subject’s ability to maintain the initial performance during a subsequent 8-s sprint, even if the recovery was shortened to 30 s, regardless of the gender. This result supported our first hypothesis. Most of the previous studies have analyzed physiological responses and muscle metabolism in men during and after two consecutive work bouts of longer duration (1, 6, 7, 11) or several sprints interspaced by fixed recovery periods (2–4, 16–18). The originality of the present protocol was to investigate the minimal recovery duration between two short sprints without any performance alteration and to assess gender differences in the recovery pattern of maximal power output. P_{peak} and W were only reduced by a few percent when recovery dropped off to 15 s (−7 and −8%, respectively). However, this variation has implication in the context of sport events. For example, a soccer player would be 5–7 m ahead of an opponent in a race for the ball. Our results disagreed with those of Cooke and Barnes (11). In fact, these authors showed that subjects could not maintain performance over two cycle ergometer sprints of longer duration (9–15 s), even with recoveries lasting 30, 60, and 90 s. In the study of Cooke and Barnes, 120-s recovery was necessary for the subjects to reproduce the initial peak power. In our study, subjects have been able to reach P_{peak} over two 8-s sprints with 30-s rest. Similarly, 40-m repeated running sprints (sprint time: 5.9 s) separated by 30-s recovery showed regular and significant decrement only from the fifth bout (3). Gaitanos et al. (18) also reported a reduction in P_{peak} from the fifth of ten 6-s cycle ergometer sprints separated by 30-s rest. Thus a 30-s rest period appears to be enough to restore power output in humans, at least for three or four 6-s sprints and for two 8-s sprints.

In the present study, the decrease in P_{peak} and W after 15-s recovery might be linked to a lesser efficiency of ATP turnover within muscles and/or to neuromuscular limitations. Gaitanos et al. (18) showed that phosphagen (PCr) utilization accounted for the major part of the ATP resynthesized during a single 6-s sprint. However, other sources of energy supply (anaerobic glycolysis and oxidative phosphorylation) also took part in ATP resynthesis. Our results indicated that 30-s recovery was sufficient to reproduce maximal performance during a second sprint, whereas theoretical PCr repletion time was unlikely to be reached. In fact, previous works have demonstrated that full PCr stores repletion to resting levels took >3 min to be achieved (7, 12, 30). Thus muscle phosphagen stores might not be fully used during the first sprint, and/or PCr pool after 30-s recovery might be sufficient to perform maximally. A study using vastus lateralis biopsies showed that, within a 6-s cycling sprint, muscle PCr and ATP concentrations dropped by ~57 and ~13%, respectively, compared with resting values (18). However, in the present study, power output decreased from P_{peak} to attain at the 8th s ~75% of the peak value. These results suggest that fatigue processes occur, whereas PCr depletion is not likely to be achieved. Other factors may be involved in fatigue processes. According to Cherry et al. (10), the initial rapid recovery of power may be related to ionic factors (intracellular K+ and Na+ concentrations) and neuromuscular limitation, including sarcolemma excitability, excitation-contraction coupling, and contractile mechanisms, especially when rest intervals are very short. Glycolysis contribution has been estimated to account for ~44% of total ATP resynthesis during one single 6-s sprint (18). According to Bogdanis et al. (7), after one single 10-s sprint, muscle pH decreased but remained unchanged during the first 2 min of recovery. Our data indicated that 30-s recovery was sufficient for the subjects to reproduce a given power output, whereas this time frame seemed too short to modify significantly acid-base balance. In the same way, Blonc et al. (4) reported that achievement of maximal power seemed independent from blood lactate values observed between each sprint. Aerobic metabolism may also supply energy during sprints. According to Bogdanis et al. (7), aerobic contribution accounted for 13% of ATP production during a 10-s sprint. Some authors reported a significant shift toward aerobic metabolism at the latter stages of intermittent exercise (4, 17, 18, 21). Presumably, in the present study, oxidative con-
tribution was negligible, considering the few numbers of repetitions in each series (i.e., 2), the short duration of sprints (i.e., 8 s), and the fact that subjects exercised in breath-holding conditions.

The second major finding of this study was that, despite a lower overall performance, women recovered the same as men. However, women took longer to reach peak power during 8-s cycling bouts and exhibited greater decline in power output after peak power was attained.

Men had significantly higher P\textsubscript{peak} and W than women and reached P\textsubscript{peak} more quickly. Our results are in agreement with literature data showing consistent higher performance in men than women (8, 19, 25, 33, 34). Muscle mass is an important factor of anaerobic performance; thus the influence of body dimensions on anaerobic performance must be taken into account. In this study, P\textsubscript{peak} was still higher in men than in women, even when corrected for lean body mass and lower limb lean volume (P < 0.01; Table 1). The average difference between genders in P\textsubscript{peak} (watts) was 37.2%. It was reduced to 16.8 and 16.2%, respectively, when expressed per unit of lean body mass and lower limb lean volume. During maximal cycling sprint, type II muscle fibers are activated to a great extent (5). Gender difference in P\textsubscript{peak} (even per unit of lower limb lean volume) may be linked to a smaller cross-sectional area of type II fibers in women than in men (5, 15, 19, 34). Morphological and biochemical gender differences in skeletal muscle were attributed to both the influence of sex hormones and differences in daily activity patterns (15, 31).

In the present study, women showed greater decrement in power output from peak values to P\textsubscript{Re} values compared with men (69 vs. 81%). In addition, relationships from P\textsubscript{peak} to P\textsubscript{Re} gave information on fatigue that occurred during sprints. Present results indicated significant gender differences in these regression lines. In fact, women had a greater loss of power (%P\textsubscript{peak}) during the last part of sprints. These results would suggest that women would be more fatigable than men during short sprints. Moreover, women performed lower amount of work (expressed as a percentage of W at first sprint) over 8 s. Thus the capacities of women to maintain maximal muscle performance seem to be lower than those of men. Glycolytic contribution to ATP synthesis and anaerobic capacity might be lower in women, which could explain part of present findings. In fact, earlier studies on muscle characteristics have demonstrated that activities of muscle glycolytic enzymes, especially lactate dehydrogenase (28, 34) and phosphofructokinase (31), are lower in women. Brooks et al. (8) observed higher levels of plasma epinephrine in men than in women during intermittent 6-s sprints (30-s recovery), corroborating previous observations of Sanchez et al. (33). In women, low concentrations of plasma epinephrine may be linked to the effect of estrogen (32). Therefore, the stimulating effect of epinephrine on glycolysis might be reduced in women, lowering lactate production during short-term exercises. In fact, during 10- and 30-s sprints, Jacobs et al. (25) indicated that women accumulate less muscle lactate than men. The sparing property of estradiol on muscle glycogen content and its inhibitory effect on glycolgenolysis is well documented (for review, see Ref. 9). Therefore, it might be hypothesized that, in women, less glucose would be available for energy supply during repeated sprints, lowering slightly female capacities to maintain maximal performance. Conversely, during longer sprints (30-s Wingate test), women have been shown to exhibit a lower decrease in P\textsubscript{peak} (14, 15). However, during the Wingate test, aerobic contribution averages at least 25% (20), and a greater aerobic contribution to the total energy supply has been observed in women (24).

Whereas gender differences in performance during maximal exercise are well established, little is known about gender differences in recovery patterns during two consecutive short sprints. Figures 1 and 2 show that both men and women were able to reproduce initial P\textsubscript{peak} after short recovery intervals (~98.6 vs. ~99% of the first sprint performance after 60-s recovery and ~95.1 vs. ~95.5% after 30-s recovery in men vs. women). These results point out that both genders were able to reproduce the P\textsubscript{peak} during a second sprint, even if the recovery dropped down to 30 s (Fig. 1).

In summary, patterns of power output recovery between two consecutive short bouts were similar in men and women, despite lower overall performance and greater fatigability during sprints in women.

REFERENCES


