Aerobic and anaerobic power characteristics of off-road cyclists

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ABSTRACT

BARON, R. Aerobic and anaerobic power characteristics of off-road cyclists. Med. Sci. Sports Exerc., Vol. 33, No. 8, 2001, pp. 1387–1393. Purpose: The purpose of this study was to describe the relationship between anaerobic power at different pedaling frequencies (including the optimal cadence) and aerobic power in off-road cyclists (CYC; N = 25) and sports students, who did not perform specific cycle exercise more than two times per week (CON; N = 60). Methods: To describe the aerobic power, we measured the maximal power output (W_max) and the power output at the fixed lactate threshold at 4 mmol·L⁻¹ (W_L4) obtained during a maximal aerobic power cycling test. To describe anaerobic power output, we measured the average power output (IsoW_mean) over a range from 50 to 140 rpm by using a 10-s sprint on an isokinetic cycle ergometer. Results: For the 10-s anaerobic test, CON and CYC showed a peak power output (IsoW_peak) of 13.3 ± 1.4 and 14.9 ± 1.1 W·kg⁻¹, respectively. IsoW_peak corresponded to an optimal cadence of 100 ± 9.3 rpm for CON and 100 ± 8.7 rpm for CYC. There was a significant difference (P < 0.001) in the W_max:IsoW_peak (W_aerobic:W_anaerobic) ratio between CON (32 ± 4.5%) and CYC (38 ± 3.9%). Significant differences among group means were identified using an ANOVA test and a post hoc analysis. The off-road cyclists showed a significantly higher IsoW_mean at all pedaling frequencies and at the optimal cadence (P < 0.01). There was a modest relationship between W_max and IsoW_peak in both groups (CON r = 0.53; CYC r = 0.64; P < 0.01). Conclusion: Anaerobic power values are important components associated with cycle performance in both noncyclists and off-road cyclists. However, the results of the present study demonstrated the usefulness of the power index in the physiological evaluation of off-road cyclists, as it gives information on the proportion of aerobic to anaerobic energy contribution. Key Words: ISOKINETIC CYCLING TEST, OPTIMAL CADENCE, POWER INDEX, INCREMENTAL CYCLING TEST, PEAK POWER

During the last decade, off-road cycling (mountain biking) has become increasingly popular. The most popular off-road event is cross-country. A typical cross-country race may have a duration of approximately 2–3 h for men and 1 h and 45 min to 2 h and 25 min for women. Due to the duration of this event, the aerobic system of energy production is the dominant energy system. It has been shown that peak power output obtained during a maximal incremental cycle test can be used as a predictor of performance in endurance cyclists (3,7). Research (3,5) has also shown that running velocity and power output at the blood lactate threshold appear to be highly correlated with various types of endurance performance (r = −0.67; r = −0.88) and that power output at the blood lactate threshold has been cited as important variable for cycling performance (3,5).

An equally important performance component for the off-road cyclist is anaerobic power. The ability to generate relatively high power output of short duration plays a vital role for the off-road cyclist in a mass start event, during steep climbing, and when sprinting to pass slower riders or in sprints at the finish of a race. These specific aspects of off-road cycling involve short bursts of high-intensity anaerobic efforts. To measure maximal power, it is necessary to assess the relationships between force and velocity. Several methods have been described for the measurements of short-term anaerobic power output on a cycle ergometer: 1) standard braking forces (2) and forces related to body weight (19); 2) short maximal sprints against varied braking forces (11); 3) the inertial-load method (13); 4) a method that uses both frictional resistance and flywheel inertia (1,10,11); and 5) an isokinetic method (1,9,14,17). Only the last three methods, the inertial-load method, the method that uses both frictional resistance and flywheel inertia, and the isokinetic method have been shown to accurately assess peak and average power output (13).

There are very few studies that characterize the aerobic power of elite off-road cyclists (20). Several authors have studied the relation between the aerobic and anaerobic power of competitive road cyclists (5,19), triathletes (3), top-level sprinters (6), long-distance runners (6), and untrained students (6). To our knowledge, there are no published data that describe high-intensity, short-term power output of off-road cyclists, and therefore no data exist regarding the relation between aerobic and anaerobic power of off-road cyclists. Therefore the purpose of this study was to: 1) describe aerobic and anaerobic characteristics of off-road cyclists; 2) examine the relationship between the peak power output obtained during a maximal aerobic power cycling test, and mean power output obtained during a 10-s
cycling sprint on an isokinetic cycle ergometer; 3) determine the optimal cadence, defined as the pedaling rate at which the highest peak power is obtained; and 4) compare the results with those of a control group of healthy male sports students.

Hypotheses
We hypothesized that 1) in comparison to the control group of sport students, the off-road cyclists would have higher mean and peak power output obtained during a 10-s anaerobic cycling test (5,19).
2. There would be no relationship between the maximal power output obtained during a maximal aerobic power cycling test and the mean and peak power output obtained during a 10-s anaerobic cycling test (4).
3. There would be no differences in the optimal pedaling cadence between the off-road cyclists and the control group (12).
4. In the interest of confirming the results of Sargeant et al. (17), the maximal power output from the maximal aerobic power cycling test would be approximately 32% of the peak power at the optimal cadence obtained during the 10-s anaerobic cycling test, and that there would be no differences in this percentage between the off-road cyclists and the control group.

MATERIALS AND METHODS

Subjects
Sixty male sports students (CON; age = 24.5 ± 2.4 yr [mean ± SD], height = 179.7 ± 6.5 cm, body mass = 75.4 ± 6.8 kg, peak oxygen uptake 53.2 ± 6.4 mL·kg⁻¹·min⁻¹) and 25 off-road cyclists of elite national class (CYC; age = 22.5 ± 4.4 yr, height = 179.0 ± 5.1 cm, body mass = 69.4 ± 6.5 kg, peak oxygen uptake 68.4 ± 3.8 mL·kg⁻¹·min⁻¹) participated in the study. Ability levels ranged from national level competitors to World Cup competitors. There were eight World Cup participants with one of the eight participating at the 1996 Olympic Game. CYC had an average of 6.2 ± 2.6 yr of cycle training. All subjects were tested during the competitive cycling season. To be included in the study, subjects had to meet the following criteria: no present complaint of pain or injury to either hip, knee, or ankle. Subjects in CON who performed specific cycle exercise more than two times per week were excluded.

Materials
A commercially available isokinetic ergometer was used in this study (Fitrocycle, Fitronic, Bratislava, Czech Republic). The system uses an eddy current brake and measures the effective force (the component perpendicular to the crank) on the chain by means of a strain gauge tensiometer (i.e., it measures both braking resistance as well as resistance provided by the momentum of inertia of the accelerating flywheel). The revolution rate was recorded by means of an analog velocity sensor (tachodynamo). The position of the right pedal in the upward vertical position was obtained by means of an optical sensor (0° and 360°, respectively). The signals were AD converted (8 bit), sampled (100 Hz), and stored on an IBM compatible PC. The ergometer system has three operating modes, and it can be instantly switched from one to another. In addition to the isokinetic mode, one can choose a revolution dependent mode, in which power output is proportional to cadence, and a revolution independent mode, in which power output is constant. In all three operating modes, the effective forces are monitored by means of the strain gauge.

Protocol
10-s anaerobic power test. Tests were carried out on an isokinetic cycle ergometer (Fitrocycle, Fitronic). The ergometer was equipped with a racing saddle, toe clips, and competition handlebars and configured to match as closely as possible the dimensions of the subject’s own bicycle. The subjects had to stay seated on the saddle throughout the test. A 10-min warm-up period at the level of 1 W·kg⁻¹ body weight at 70–80 rpm was performed before the test, but the subjects were given a 1-min rest before the beginning of the all-out tests. The testing protocol of the all-out tests consisted of 10 randomized, 10-s bouts of maximal isokinetic cycling at cadences ranging from 50 to 140 rpm in 10-rpm increments. Recovery intervals between bouts were 4 min long during which the cyclists continued to cycle with a power output of one W·kg⁻¹.

Calculation of the average force (IsoFmean) and average power (IsoWmean) for the whole 10 s were made by the computer. The optimal cadence was determined. The optimal cadence (Copt) is the pedaling rate at which the highest peak power (IsoWpeak) is obtained. To determine whether there were significant differences between the left and right legs, calculations of mean power for each leg were made by the computer. To obtain the limb symmetry index (LSI) for IsoWmean, the mean of the left limb was divided by the mean of the right limb, and the result was multiplied by 100. The reliability of the 10-s anaerobic power test documented here has been previously documented (2).

Maximal aerobic power test. The test was carried out on a Fitronic cycle ergometer, the very same one used for the 10-s anaerobic power test. The saddle position, the foot-fixation, and the warm-up was the same as for the 10-s anaerobic power test. The incremental test started with 80 W after which power output was increased 40 W every 4 min until volitional exhaustion. Capillary blood samples from the hyperemized earlobe were obtained for the determination of blood lactate (Eppendorf, ESAT 6661, Hamburg, Germany). Blood was taken at rest, immediately after each 4-min stage, at exhaustion, and in the 1st, 3rd, and 6th minutes of recovery. The maximal power output in W (Wmax) and the submaximal power output in W at a blood lactate threshold of 4 mmol (WthL) were recorded. Maximal power output was calculated as follows:

\[ W_{\text{max}} = W_E + (40w/t \times t_0) \]
TABLE 1. Mean power output, peak power output, and the optimal cadence obtained during a 10-s anaerobic power test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>CON  (N = 60)</th>
<th>CYC  (N = 25)</th>
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<tbody>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;50 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>8.7 ± 1.6</td>
<td>10.4 ± 1.0*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;60 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>10.3 ± 1.6</td>
<td>11.9 ± 0.9*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;70 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>11.2 ± 1.7</td>
<td>13.0 ± 1.0*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;80 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>12.2 ± 1.7</td>
<td>13.9 ± 1.1*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;90 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>12.7 ± 1.6</td>
<td>14.5 ± 1.2*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;100 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>12.9 ± 1.7</td>
<td>14.7 ± 1.1*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;110 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>12.7 ± 1.7</td>
<td>14.4 ± 1.1*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;120 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>12.4 ± 1.3</td>
<td>13.9 ± 1.0*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;130 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>11.6 ± 1.3</td>
<td>13.0 ± 1.2*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;max&lt;/sub&gt;140 (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>10.3 ± 1.4</td>
<td>12.2 ± 1.1*</td>
</tr>
<tr>
<td>IsoW&lt;sub&gt;peak&lt;/sub&gt; (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>13.3 ± 1.4</td>
<td>14.9 ± 1.1*</td>
</tr>
<tr>
<td>Optimal cadence (rpm)</td>
<td>100 ± 9.3</td>
<td>100 ± 8.7</td>
</tr>
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</table>

IsoW<sub>max</sub>50–140, average power at different pedaling frequencies; IsoW<sub>peak</sub>, power at the optimal cadence.

*P < 0.01 indicates a significant difference between CON and CYC.

W<sub>max</sub> = maximal power output (W), W<sub>L4</sub> = power output of last complete stage (W), W<sub>E</sub> = workload increment, t = workload duration (seconds), and t<sub>5</sub> = duration of final stage (seconds). To determine the maximal power index (PI<sub>max</sub>), the mean of W<sub>max</sub> was divided by the mean of IsoW<sub>peak</sub> and the result was multiplied by 100.

### Procedures

The two tests in this study were separated by at least 48 h of rest. The order of testing (aerobic vs anaerobic and the 10 anaerobic sprints) was randomized. All participants received instructions for the anaerobic and aerobic cycling tests and were able to familiarize themselves with the protocol and practice under direct supervision of the same tester. Before any testing, informed consent forms were signed by all participants. The protocol of this study was approved by the Institutional Review Board at the Institute of Sport Science of the University of Vienna.

### Statistical Analysis

The statistical package Statistica (Version 5.1 StatSoft Inc.) was used for all statistical procedures. Descriptive statistics were expressed as mean values ± 1 standard deviation. Test data were analyzed with a one-way analysis of variance. Significant differences among group means were identified using Turkey (HSD) post hoc analysis. Pearson product moment correlations were performed to evaluate relationships between variables. Student’s paired t-test was used to make multiple comparisons across the 10 cadences of the 10-s anaerobic power test and a Bonferroni α-adjustment was used to control for the inflation of family-wise error rate. The level of significance was set at P < 0.01 for all statistical analysis.

### RESULTS

#### 10-s Anaerobic Power Test

Results revealed no significant differences between the left and the right legs. The limb symmetry index was 96.7 ± 9.2% for CON and 97.2 ± 8.1% for CYC. Table 1 shows the descriptive statistics for data obtained during the anaerobic cycling test. The power (IsoW<sub>max</sub>-cadence relationship was fitted using a second-order polynomial regression (CON r = 0.99 ± 0.03; CYC r = 0.99 ± 0.025 y = −0.0016x<sup>2</sup> + 0.3292x − 1.9612 (r = 0.99 ± 0.025) for CON and CYC, respectively. Values are mean ± SD.

### Maximal Aerobic Power Test

The results of the maximal aerobic power test are given in Table 2. There was a strong relationship between W<sub>max</sub> and W<sub>L4</sub> for CON (r = 0.85 P < 0.01) and CYC (r = 0.89 P < 0.01). The power index (PI) was 32 ± 4.5% and 38 ± 3.9% for CON and CYC, respectively (P < 0.01). There were highly significant bivariate correlations between W<sub>max</sub> and IsoW<sub>peak</sub> (CON r = 0.52; CYC r = 0.64) and W<sub>max</sub> and IsoW<sub>mean</sub> (CON r = 0.36–0.68; CYC r = 0.51–0.73) over the range of 50–140 rpm in both groups. Significant correlations were also observed between W<sub>L4</sub> and IsoW<sub>peak</sub> (CON r = 0.50; CYC r = 0.48) and W<sub>L4</sub> and IsoW<sub>mean</sub> (CON r = 0.32–0.63; CYC r = 0.45–0.64) over the range of 90–140 rpm in both groups.

### TABLE 2. Maximal and submaximal values obtained during a maximal aerobic power test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>CON  (N = 60)</th>
<th>CYC  (N = 25)</th>
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<tbody>
<tr>
<td>W&lt;sub&gt;max&lt;/sub&gt; (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>4.3 ± 0.7</td>
<td>5.5 ± 0.4*</td>
</tr>
<tr>
<td>W&lt;sub&gt;L4&lt;/sub&gt; (W·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>3.2 ± 0.7</td>
<td>4.7 ± 0.6*</td>
</tr>
<tr>
<td>Power index (%)</td>
<td>32.0 ± 4.5</td>
<td>38.0 ± 3.9*</td>
</tr>
</tbody>
</table>

W<sub>max</sub>, maximal power; W<sub>L4</sub>, power output at a blood concentration of 4.0 mmol·L<sup>-1</sup>; power index, ratio between W<sub>max</sub> and IsoW<sub>peak</sub>. Variables are mean values ± SD of variables.

*P < 0.01 indicates a significant difference between CON and CYC.
DISCUSSION

The first goal of this study was to describe aerobic and anaerobic characteristics of off-road cyclists of elite national class.

Maximal Aerobic Power Test

Although several studies have described the maximal power output of competitive road cyclists (18,20) and triathletes (3), there is only one study that has quantified submaximal and maximal exercise responses of elite off-road cyclists (20). Wilber et al. (20) reported that male athletes representing the United States National Off-Road Bicycle Association (NORBA) Cross-Country Team showed a maximal power output obtained during a progressive exercise cycling test of 5.9 W·kg$^{-1}$. In the present study, $W_{\text{max}}$ was 5.4 W·kg$^{-1}$ and agrees favorably with the findings of Wilber et al. (20). The slightly lower values may be due to the different test protocols and the differences in the subjects recruited.

Recently, cycling power output at the blood lactate threshold has been cited as an important predictor of cycling performance. Numerous definitions for lactate threshold have been published in the last decade, and there are a variety of terms describing the blood lactate response to exercise, including lactate threshold, aerobic threshold, individual anaerobic threshold, lactate breaking point, and onset of blood lactate accumulation (8). In this study, we evaluated the plasma lactate response to exercise using the fixed lactate threshold of 4 mmol·L$^{-1}$ as a predictor of endurance performance. Schwabeger et al. (18) evaluated 25 national road cyclists and reported an average $W_{\text{L4}}$ of 4.3 W·kg$^{-1}$. This is in good agreement with the results of the present study for the off-road cyclists ($W_{\text{L4}} = 4.6$ W·kg$^{-1}$).

A correlation coefficient of $r = 0.85$ ($P < 0.01$) for CON and $r = 0.89$ ($P < 0.01$) for CYC demonstrated that $W_{\text{max}}$ can be estimated from submaximal work load at $W_{\text{L4}}$ for both non cyclists and highly trained off-road cyclists. As would be expected, $W_{\text{max}}$ (22%) and $W_{\text{L4}}$ (31%) for the off-road cyclists in our study were significantly higher than those of the control group of healthy male sport students.

10-s Anaerobic Power Test

To describe the anaerobic power output of off-road cyclists and healthy male sport students, we measured peak and average power output over a range of pedaling cadences from 50 to 140 rpm. Our results are in good agreement with previous investigations in untrained subjects using an isokinetic cycle ergometer (9,14). There have been no studies investigating the maximal anaerobic power of highly trained cyclists in relation to different pedaling cadences using an isokinetic cycle ergometer. Therefore, the results of the current study for CYC cannot be compared easily with the results of other studies. The most frequently used test to describe anaerobic power and capacity is the Wingate test (2). But only a few authors have evaluated the anaerobic power of highly trained cyclists using the Wingate test (19). Tanaka et al. (19) described the anaerobic characteristics of United States Cycling Federation (USCF) road cyclists in different racing categories. He reported that peak power output in categories II, III, and IV was 13.9 W·kg$^{-1}$, 13.6 W·kg$^{-1}$, and 12.8 W·kg$^{-1}$ (load 0.095 kg/body weight), respectively. $IsoW_{\text{peak}}$ for the off-road cyclists (14.9 W·kg$^{-1}$) in the present study was much greater than the values for peak power reported in the literature. The higher anaerobic power values may be due to the differences in the subjects recruited and the difference in the method for the measurement of anaerobic power. The peak power values obtained during the Wingate test did not take into account the flywheel inertia. As reported by the literature (10,11), peak power output was ~11% higher on the average when taking into account the inertia, with an underestimation in a range between 3% and 20%.

As suggested by the literature (5,19), we hypothesized that the power output obtained during a 10-s maximal anaerobic cycling test would be higher compared with the control group of healthy male sports students. Results supported this hypothesis. $IsoW_{\text{peak}}$ as well as $IsoW_{\text{mean}}$ at all cadences from 50 to 140 rpm for the off-road cyclists were significantly higher than those of the sport students. Tanaka et al. (19) found that peak power output tended to increase with ability/category level. He stated that these higher anaerobic values may have resulted from years of strenuous interval training. Coyle et al. (5) evaluated the physiological and biomechanical responses of “elite-national class” and “good-state class” cyclists and found that “elite-national class” cyclists have the ability to generate higher peak vertical torques resulting in higher power output during a cycling downstroke. He stated that factors possibly contributing to this ability may be the higher percentage of Type I fibers and a higher muscle capillary density in “elite-national class” cyclists compared with “good-state class” cyclists. Additionally, he found a strong relationship ($r = 0.75$; $P < 0.001$) between years of endurance training and percent of Type I muscle fibers. Coyle et al. (5) concluded that the ability to generate higher “downstroke power” is possibly the result of adaptations stimulated by a greater number of years of endurance training. In the current study, we compared very good cyclists to noncyclists. Therefore, it is likely that the differences between CON and CYC reflect cycling skill and experience and could be a result of muscular adaptation, which may in turn depend on the type of training and the number of years in cycling training.

Up to now, there have been no studies investigating the maximal anaerobic power of highly trained cyclists in relation to the optimal cadence using an isokinetic cycling ergometer. Previous results have been obtained on the isokinetic cycle ergometer only in untrained subjects (14,17). Sargeant et al. (17) reported that maximal power output (averaged over a complete revolution) occurred at a mean optimal cadence of 110 rpm. McCartney et al. (14) recommended that cycling activity of less than 6–7 s should be performed at a pedaling cadence of 120 rpm to obtain maximal power output, and for efforts of slightly longer duration (10–20 s), the cycling activity should be performed.
at a pedaling cadence of ~100 rpm. The present data are in good agreement with the results of Sargeant et al. (17) and McCartney et al. (14). Our subjects demonstrated a $C_{opt}$ ranging from 80 to 120 rpm for CON and 80 to 110 rpm for CYC. The mean value for both groups was 100 rpm. Our results support the hypothesis that there would be no differences in the optimal cadence obtained during a 10-s anaerobic power test between the off-road cyclists and the control group. Marsh and Martin (12) reported that cyclists and noncyclists preferred similar cadences. They speculated that the need to optimize power output and minimize peripheral stress, and not the amount of previous cycling experience, is the key determinant of cadence selection. This hypothesis is supported by the results of Patterson and Moreno (16) that cadences of 90–100 rpm minimize peripheral forces and therefore peripheral muscle fatigue. In addition, our results are in agreement with the observation that elite cyclists uses cadences between 80 and 110 rpm during training and racing (12,14) and that the mean pedaling rate chosen for the world cycling record for distance achieved in 1 h is about 105 rpm.

The fact that there are no differences in the optimal cadence between the off-road cyclists and the control group means that specific cycling training did not influence $C_{opt}$ but trained cyclists are able to generate higher forces at the same cadence, resulting in higher peak power output. These findings are supported by the results of Coyle et al. (5), who reported that trained cyclists are able to generate higher peak vertical torques during a downhill stroke than untrained subjects. This ability to generate higher peak power output may enable an “elite-national class” cyclist to maintain a higher pedaling cadence during a 40-km time trial compared with a “good-state class” cyclist.

Several authors have studied the relation between aerobic and anaerobic power of competitive road cyclists (5,19), triathletes (3), top-level sprinters (6), long-distance runners (6), untrained students (6), and sedentary subjects without any prior experience in regular physical activity (4,9). There is a discrepancy of findings in the literature regarding the correlation between aerobic and anaerobic power output values. Boulay et al. (4) using untrained subjects found a positive correlation ($r = 0.63, P < 0.01$) between the anaerobic alactic power obtained during a Wingate test and the maximal aerobic power determined with a progressive work test. But the low common variance (40%) in this study between these two variables suggests that there is considerable specificity between these two properties. Similarly, Jones and McCartney (9) (using untrained subjects) also found a positive correlation ($r = 0.92; P < 0.01$) between the total work in 30 s obtained during an isokinetic cycling test with maximal effort at a cadence of 60 rpm and maximal oxygen uptake ($VO_{2\text{max}}$) test. Crielard and Pniry (6) reported a negative correlation ($r = -0.83; P < 0.05$) between aerobic power (obtained during a progressive exercise test on a treadmill) and anaerobic power (obtained on a bicycle ergometer during a force-velocity test against a load in the range of 4–7 kg) in top-level athletes but not in the control group of 32 students. In contrast, Tanaka et al. (19) ($r = 0.35; P > 0.05$) using competitive road cyclists and Bentley et al. (3) ($r = 0.26; P > 0.05$) using recreational triathletes did not found any correlation between aerobic and anaerobic power.

Our results do not support our hypothesis that was based on the findings of Boulay et al. (4), who reported that there was only a common variance (40%) between the aerobic values obtained during an incremental cycle test and the anaerobic values obtained during an all-out test lasting 10 s. In the current study there was a modest positive correlation between $W_{max}$ and $IsoW_{peak}$ (CON; $r = 0.52 P < 0.01$; CYC; $r = 0.64 P < 0.01$) and $W_{L4}$ and $IsoW_{peak}$ (CON; $r = 0.50 P < 0.01$; CYC; $r = 0.50 P < 0.01$) in both groups. This suggests that the ability to generate higher anaerobic power is associated with the ability to generate higher aerobic power.

It has been shown that peak power output obtained during a maximal incremental cycling test can be used as a predictor of performance in cyclists (3,7). Hawley and Noakes (7) found a highly significant correlation ($r = -0.91 P < 0.001$) between maximal power output during an exhaustive cycling test and 20-km cycling time, as maximal power output explained 82% of the variance in time for a 20-km cycle trial. Bentley et al. (3) reported a significant correlation ($r = -0.87, P < 0.01$) between maximal power output attained during an incremental cycling test to exhaustion and the overall cycling time during a short-course triathlon race. They concluded that maximal power output may be a good parameter for the assessment of cycling performance. Although it is well accepted that maximal aerobic power is a major determinant of success in endurance cycling, the results in the current study demonstrated the necessity to evaluate a cyclist’s performance not only in terms of aerobic components. Anaerobic power values are also important components for the development of cycle performance in both noncyclists and cyclists. Therefore, it is suggested that these variables should be optimally trained and routinely monitored.

Based on the findings of Sargeant et al. (17), we hypothesized that the maximal power output from aerobic sources (maximal aerobic power test) would be approximately 32% of the peak power output at the optimal cadence obtained during the 10-s anaerobic power test, and that there would be no differences in this percentage between the off-road cyclists and the control group. Our results support our hypothesis and the findings of Sargeant et al. (17) only partially. CON showed a power index of $32 \pm 4.5\%$, confirming the findings of Sargeant et al.(17), but CYC demonstrated a significant higher power index of $38 \pm 3.9\%$.

Up to now, there have been no investigations that reported the power index in competitive cyclists. To our knowledge, only one study (15) has investigated a peak anaerobic:peak aerobic ratio in highly trained athletes. Mercer et al. (15) evaluated this ratio, obtained during arm-crank exercise. The aerobic exercise test started with 30 W, after which power output was increased 30 W each minute until exhaustion. The anaerobic cycling test consisted of the
repetition of short maximal sprints (duration 6 s) against increasing braking forces of 2 kg (starting with a braking force of 1.0 kg) in a group of competitive sprint- and middle-distance swimmers. Mercier et al. (15) showed that sprint swimmers had a significantly higher anaerobic:aerobic power ratio than middle-distance swimmers. In addition he found a relationship between this ratio and the swim time (100 m: $r = -0.80, P < 0.05$). Therefore, Mercier et al. (15) concluded that differences in the ratio between competitive sprint- and middle-distance swimmers were related to specialization in competition and training programs.

In our study, the off-road cyclists showed a higher power index compared with a group of sports students. This would indicate that the power index is not an index of physical fitness but merely gives information on the proportion of aerobic to anaerobic energy contribution, which in turn depends on the specialization in training and competition. However, the interpretation of this index requires that the level of aerobic to anaerobic physical fitness be taken into consideration as the same power index can be obtained with high and low values of $W_{\text{max}}$ and $\text{IsoW}_{\text{peak}}$ (i.e., $W_{\text{max}}300$: $\text{IsoW}_{\text{peak}}1000 = 30\%$; $W_{\text{max}}360$: $\text{IsoW}_{\text{peak}}1200 = 30\%$).

Our experience in the use of the power index (unpublished data) indicates that there exists an optimal index of 40–45% in off-road cyclists. Cyclists with a power index of less than 40% have to improve primarily their aerobic power, and cyclists with a power index of more than 45% have to improve primarily their anaerobic power. But one should take into consideration that this percentage varies during the competitive season and that the power index will change in relation to the periodization of training and training emphases. At present, we are attempting to examine the power index in road and track cyclists. First results indicate that the power index is related to specific competitive cycling events. Road cyclists may have an higher power index than off-road cyclists, whereas road cyclists and off-road cyclists may have a higher power index than track cyclists. Our results are supported by the findings of Wilber et al. (20), who found that elite road cyclists (USCF) produced significantly greater absolute and relative aerobic power obtained during maximal exercise than elite off-road cyclists (NORBA). Therefore, in the use of the power index one should take into consideration: 1) the specific competitive cycling event; 2) the level of aerobic to anaerobic fitness; and 3) the timing of investigation (i.e., preparation phase, transition phase, or competitive phase). However, the results of the present study demonstrated the usefulness of the power index in the physiological evaluation of off-road cyclists, as it gives information on the proportion of aerobic to anaerobic energy contribution that is related to specialization in competition. In addition, the power index gives recommendations as to whether endurance training or specific strength and power training should be emphasized.

**CONCLUSION**

In conclusion, the differences in aerobic and anaerobic components of metabolism measured during a maximal aerobic power cycling test to exhaustion and a maximal 10-s anaerobic power test on an isokinetic cycle ergometer at cadences ranging from 50 to 140 rpm in sport students and off-road cyclists were significant. Anaerobic power values are important components for the development of cycle performance in both noncyclists and cyclists. Thus, the evaluation of either aerobic or anaerobic components alone is insufficient in the present study to assess the energy profile of sports students and competitive off-road cyclists in the laboratory. Our results demonstrated that the power index is not an index of physical fitness but gives information on the proportion of aerobic to anaerobic energy contribution. In addition, the power index gives information as to whether endurance training or specific strength and power training should be emphasized.

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