Aerobic and Anaerobic Power Characteristics of Competitive Cyclists in the United States Cycling Federation

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Abstract

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The purpose of this study was to characterize the aerobic and anaerobic capabilities of United States Cycling Federation cyclists in different categories. To determine aerobic and anaerobic power, 38 competitive road cyclists (32 males, 6 females) performed a $\dot{V}O_2max$ test and a Wingate anaerobic test, respectively. Male cyclists in category II had the highest $\dot{V}O_2max$, both in absolute and relative terms. Their $\dot{V}O_2max$ was 6% and 10% higher than category III and IV cyclists, respectively (4.98 ± 0.14 vs 4.72 ± 0.15 vs 4.54 ± 0.12 l/min). A significant difference existed between category II and IV male cyclists ($p < 0.05$). $\dot{V}O_2max$ for female cyclists (3.37 ± 0.13 l/min) was significantly ($p < 0.05$) lower than those for males. The Wingate anaerobic test revealed that male cyclists in category II also had the highest anaerobic power output. The peak power output in category II, III and IV was 13.86 ± 0.23, 13.55 ± 0.25, and 12.80 ± 0.41 W/kg, respectively. The mean power output in category II, III, and IV was 11.22 ± 0.18, 11.06 ± 0.15, and 10.40 ± 0.30 W/kg, respectively. The difference in the mean power output between category II and IV was significant ($p < 0.05$). Female cyclists recorded significantly less peak and mean power output than their male counterparts ($p < 0.05$). However, when expressed relative to lean body mass, anaerobic power was similar for both sexes. No inter-correlation was found in any measurement between the aerobic and anaerobic power values. On the whole, category II male cyclists were characterized by higher aerobic and anaerobic power outputs. These results suggest that both aerobic and anaerobic power may be important determinants for competitive cycling performance.

Key words

Competitive cyclists, maximal oxygen consumption, Wingate anaerobic test, peak power output, mean power output

Introduction

In parallel to the growing popularity of cycling in the United States, the number of competitive cyclists has also increased over the past ten years. The national governing body of competitive bicycle racing in the United States is the United States Cycling Federation (USCF). Besides functioning for the preservation, development, and administration of bicycle races, this organization has constructed a bicycle racing category ranging from V to I for men and IV to I for women in an attempt to select and form the national team. A road rider's category can be upgraded by accumulating winning points gained in qualifying road races, and represents rider proficiency and performance (22).

One of the best determinants for success in competitive road cycling is maximal oxygen consumption ($\dot{V}O_2max$) (7, 8, 12). Although $\dot{V}O_2$ max values of elite cyclists have been reported (7, 8, 12, 13), very few studies have characterized the aerobic power of the sub-elite bicycle riders. Since these sub-elite cyclists in the USCF form a pool from which the top talent arises, a description of the $\dot{V}O_2max$ values may be desirable. In addition, since these licensed cyclists are frequently used as experimental subjects (8, 10, 14, 18), a categorization of their capability may facilitate inter-study comparisons.

Compared to aerobic power, less attention has been directed towards anaerobic power in competitive road cyclists (4, 23). However, explosive anaerobic power may play a significant role in break-away attempts, hill-climbing, and final sprints during competitive bicycle races. By riding in a pack, a cyclist in a mass start event may achieve as much as 39% reduction in energy expenditure (18). Therefore, the first cyclist across the line may not be the one with the highest aerobic power. It is possible that in a close cycling race, the order of the finish may be determined by sprinting ability. To our knowledge, Wingate anaerobic test results of competitive cyclists are extremely scarce (4), despite the fact that it is a sport specific test for cycling.

In many athletic events, an interplay of aerobic and anaerobic systems is involved (24). Since both energy systems are also of critical importance in bicycle road races, there is a need for normative values on sub-elite cyclists at all levels. We believe that the results obtained in this study would benefit sub-elite cyclists in evaluating their relative physiological abilities and help in grossly separating the top cyclists from others. Therefore, the purpose of this study was to describe aerobic and anaerobic characteristics of the USCF road cyclists in different

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racing categories. An additional purpose was to examine the inter-correlation between aerobic and anaerobic power values.

Methods

Subjects

Thirty-eight competitive road cyclists (32 males, 6 females), who were current members of the United State Cycling Federation, served as subjects. Nine, eleven and twelve cyclists represented the USCF categories of II, III, and IV. Female cyclists were combined into one group irrespective of their racing categories (2, 1, and 3 from category II, III, and IV, respectively). None of the subjects were track cyclists. Following a verbal and written explanation of the procedures and potential risks, an informed consent was obtained. All the subjects were tested during the competitive cycling season.

Physical characteristics of the subjects are presented in Table 1. Body composition was evaluated from the three-site skinfold thickness method (20). For females, the skinfold was taken from the triceps, abdomen, and suprailium. For males, the triceps, pectoralis, and subscapular sites were used. Percent body fat (% Fat) and lean body mass (LBM) were subsequently estimated from the sum of the skinfold measurements using the method of Pollock et al. (20).

Testing procedures

$\dot{V}O_2$max test

To determine $\dot{V}O_2$max, each subject performed a continuous, graded exercise test lasting between 8 and 10 minutes. A stationary cycle ergometer (Model 868, Monark, Sweden) equipped with a racing saddle, toe clips, and drop handlebars was used for the $\dot{V}O_2$max test. In an attempt to duplicate as closely as possible the subject's own bicycle, the saddle height and handlebar position of the cycle ergometer were carefully adjusted prior to the test. The initial exercise intensity was set at 160 W (80 rpm), and the work rate was increased thereafter by 40 W at 1 minute intervals. End-point determination of the maximal test was defined as volitional exhaustion (failure to maintain the pedal cadence above 65 rpm).

Oxygen uptake was monitored with either a Beckman metabolic cart or a Rayfield system. The Rayfield system consisted of an open circuit spirometer interfaced with an Apple computer. Inspired air volume was determined with a dry gas meter (Parkinson-Cowan CD4) calibrated against a 120 L Tissot spirometer. Gas fractions were analyzed with an Ametek S-3A O_2 analyzer and a Beckman LB-2 CO_2 analyzer. Prior to each trial, these gas analyzers were calibrated with known gases analyzed by the micro-Scholander technique.

Wingate anaerobic test

At least 24 hours following the $\dot{V}O_2$max test, the subjects returned to the laboratory for the Wingate anaerobic test (1). A cycle ergometer (Model 864, Monark, Sweden) used for this test was fitted with an weight pan and a magnetic counter on the crank. Prior to the test, each subject warmed-up for 10 minutes at approximately 50% of $\dot{V}O_2$max. After a 2 to 3 minute rest, the subject began unloaded cycling at the fastest possible cadence. At the moment the actual test began, a predetermined load of 0.932 Newton · kg body weight^{-1} (0.095 kg · kg body weight^{-1}) was applied. The test required a maximal effort for 30 seconds. The total power output during each 5 second interval was calculated from the following formula (2):

$$\text{Power (W)} = \text{Resistance (kp)} \times 11.76 \times \text{Pedal Revolutions in 5 seconds}$$

The resistance was determined from the weight placed in the pan attached to the bidycle ergometer, and pedal revolutions were counted by a magnetic counter interfaced to a micro-computer. Peak power, mean power and fatigue index (% fatigue) were subsequently computed from the obtained measurements. Peak power was defined as the highest power output during any 5 second interval, whereas mean power was the average power output throughout the entire test. Percent fatigue was the degree of power decline during the test (1).

Statistical analysis

Test data were analyzed with a one-way (1 × 4) analysis of variance. When indicated by a significant F-value, a post-hoc test using Fisher's protected LSD was performed to identify significant differences among group means. To examine the inter-relationship between aerobic and anaerobic power values, a correlation matrix consisting of Pearson correlation coefficients was also constructed. The level of significance was set at $p < 0.05$ in all comparisons. Descriptive statistics were expressed as mean ± SE.

Results

The mean age, height, body weight, LBM and % Fat of each group are presented in Table 1. The males in categories II, III and IV were similar in height, body weight, LBM and % Fat. There were no significant differences in any anthropometric measurements, but there was a tendency for % Fat to decrease from category IV to II. Males were significantly ($p < 0.05$) taller and leaner than females.

Table 1 Subject characteristics.

Category	II (male) (N = 9)	III (male) (N = 11)	IV (male) (N = 12)	Female (II–IV) (N = 6)
Age (yr)	23.0 ±0.86	27.0 ±1.30	25.9 ±1.31	28.2 ±2.12
Height (cm)	179.3 ±1.46	181.5 ±1.74	181.6 ±1.78	168.8 ±1.44*
Weight (kg)	71.8 ±2.27	72.9 ±2.65	72.0 ±2.87	64.6 ±2.45
LBM (kg)	67.3 ±6.13	68.1 ±7.86	66.5 ±7.69	54.3 ±4.22*
% Fat (%)	6.18±0.62	6.65±0.47	7.32±0.78	15.77±1.32*

All values are expressed as mean ± SE.
*significantly different ($p < 0.05$) from males (category II, III and IV)

[redacted]

Fig. 1 compares the maximal oxygen consumption values for the USCF cyclists in different categories. Category II cyclists had the highest $\dot{V}O_2$max values, both in absolute and relative terms. Their $\dot{V}O_2$max was 6 % and 10 % higher than category III and IV cyclists, respectively. Only the difference between category II and IV was significant ($p < 0.05$).

The Wingate anaerobic test data are presented in Table 2. The category II cyclists had the highest anaerobic power output. Peak power outputs in category II, III, and IV were 13.86 ± 0.23, 13.55 ± 0.25, and 12.80 ± 0.68 W/kg, respectively. These peak power output values tended to increase with advancing categories, although significance was not reached. Mean power outputs of 11.22 ± 0.18, 11.06 ± 0.15, and 10.40 ± 0.30 W/kg were obtained in category II, III and IV, respectively. There was a significant difference ($p < 0.05$) in mean power output between category II and IV. The peak and mean power output of the female cyclists were 12.17 ± 0.68 and 9.56 ± 0.46 W/kg. As expected, these peak and mean power output values of female cyclists were significantly ($p < 0.05$) smaller than those of male cyclists. However, when expressed relative to LBM, these peak power (14.32 ± 0.23 vs 14.43 ± 0.71 W/kg LBM) and mean power output (11.63 ± 0.16 vs 11.33 ± 0.44 W/kg LBM) were very similar for both sexes. There were no significant group differences in % Fatigue in either sex. Fig. 2 illustrates the decline in power output during the Wingate anaerobic test. As can be seen, the cyclists from the higher categories tended to have a higher power output throughout the 30 second testing period.

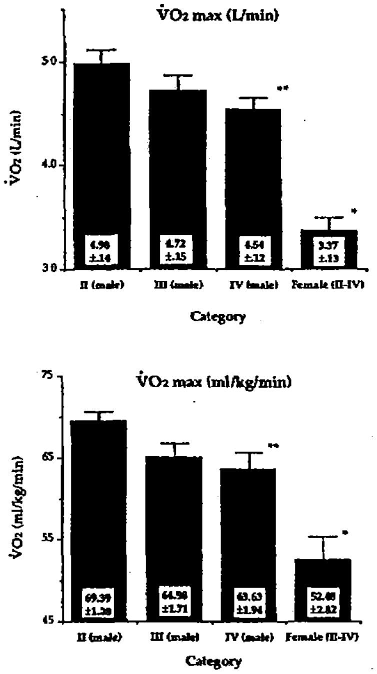

Fig. 1 Maximal oxygen consumption values (mean ± SE) for USCF cyclists in different categories. *denotes a significant difference ($p < 0.05$) from males (category II, III and IV) **denotes a significant difference ($p < 0.05$) from category II.

Table 3 shows a correlation matrix for aerobic and anaerobic power values. As expected, it was found that absolute and relative $\dot{V}O_2$max were positively correlated ($p < 0.05$). There was also a significant positive relationship ($p < 0.05$) between peak power and mean power output values. No significant correlation, however, was obtained in any measurement between aerobic and anaerobic power output.

Discussion

The primary purpose of this study was to describe the aerobic power and anaerobic power output of category II, III, and IV cyclists. The USCF road cyclists used in this study demonstrated high $\dot{V}O_2$max values comparable to other

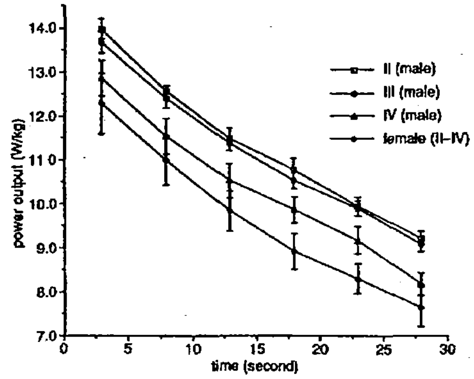

Fig. 2 Mechanical power output (mean ± SE) recorded during the Wingate anaerobic test for USCF cyclists in different categories.

Table 2 The three indices in the Wingate anaerobic test.

Category	II (male) (N = 7)	III (male) (N = 11)	IV (male) (N = 12)	Female (II–IV) (N =6)
Peak Power				
(W/kg)	13.86 ± 0.23	13.55 ± 0.25	12.80 ± 0.41	12.17 ± 0.68*
(W)	994.07 ± 38.00	985.17 ± 32.05	923.41 ± 44.66	783.67 ± 49.52*
Mean Power				
(W/kg)	11.22 ± 0.18	11.06 ± 0.15	10.40 ± 0.30**	9.56 ± 0.46*
(W)	804.05 ± 28.85	805.16 ± 28.24	749.45 ± 37.12	614.80 ± 30.61*
% Fatigue (%)	34.25 ± 0.76	33.46 ± 1.53	36.65 ± 1.73	37.80 ± 2.52

All values are expressed as mean ± SE.
*significantly different ($p < 0.05$) from males (category II, III and IV)
**significantly different from category II

Table 3 Correlation matrix for aerobic and anaerobic power.

	$\dot{V}O_2max$ (l/min)	$\dot{V}O_2max$ (ml/kg/min)	Peak power (W/kg)	Mean power (W/kg)	% Fatigue (%)
$\dot{V}O_2max$ (l/min)	1.00	.644*	.345	.470	−.106
$\dot{V}O_2max$ (ml/kg/min)		1.00	.487	.533	−.207
Peak power (W/kg)			1.00	.909*	.241
Mean power (W/kg)				1.00	.015
% Fatigue (%)					1.00

*indicates a significant correlation ($p < 0.05$)

endurance athletes (21). The mean values for category II, III, and IV were 4.98, 4.72 and 4.54 l/min, respectively. Category II cyclists had the highest $\dot{V}O_2max$, both in absolute and relative terms. Their $\dot{V}O_2max$ was 10% higher than category IV cyclists ($p<0.05$), but was not significantly different from category III. An inability to show a significant difference in $\dot{V}O_2max$ between category II and III cyclists may have been due to a physiological overlap between these categories.

Our values are consistent with other studies (8, 10, 12, 16) that have measured $\dot{V}O_2max$ in the licensed cyclists. $\dot{V}O_2max$ values of 4.99 l/min and 4.52 l/min have been reported in category I and II cyclists (10) and in category III and IV cyclists (16). It has been reported that $\dot{V}O_2max$ of the national team cyclists may exceed 5.0 l/min (8, 13, 21). Our mean value of $\dot{V}O_2max$ (3.37 l/min) in female cyclists is also in agreement with those obtained in women's national cycling team (3.52 l/min) (8) and female senior level cyclists (3.38 l/min) (25). Foster and Daniels (12) have reported $\dot{V}O_2max$ values of 5.21, 4.34, 3.96 and 3.63 l/min in category I, II, III and IV of the Amateur Bicycle League of America, the former name of the USCF. Although they (12) observed a direct relationship between $\dot{V}O_2max$ and racing categories similar to our study, their mean values were considerably different from the values obtained in the present study. Procedural variation, stage of training adaptation, small sample size (only 4 from each category) and other factors may have caused the large deviation. Nevertheless, data from these previous studies (8, 12), when combined with our data, suggest that traditional measurements of $\dot{V}O_2max$ would be useful for assessing the relative potential of sub-elite competitive cyclists.

However, it should be noted that $\dot{V}O_2max$ is not the sole determinant of success. Coyle et al. (9), for instance, reported that in a group of cyclists with similar $\dot{V}O_2max$ values, cycling performance was closely related to a high lactate threshold. Similarly, Bulbulian et al. (6), using a stepwise regression, showed that anaerobic work capacity significantly contributed to distance running performance in an aerobically homogeneous group. Other important factors for success in competitive cycling would be team work, aerodynamics, biomechanical skill, tactics, and experience acquired in years of road racing (10, 13, 17).

Although it is well accepted that aerobic power is a major determinant of success in endurance events, the anaerobic power of the competitive road cyclists in the present study was very high. These values were similar to those reported by Bell et al. (4) who found peak power of 13.27 W/kg and mean power of 10.14 W/kg in endurance cyclists. Interestingly, these values were much greater than other male athletes in various specialties (3). Peak power of 12.0–12.3 W/kg and mean power of 9.1–9.4 W/kg have been reported in 'anaerobic' athletes such as gymnasts and wrestlers (3). Female cyclists also showed extremely high values for both peak power and mean power output values. This may be partially due to the fact that the Wingate anaerobic test is a sport specific test for cycling. However, as shown in Fig. 2, there was a trend that cyclists in the higher category possessed higher peak and mean anaerobic power output values. These higher anaerobic power values may have resulted from years of strenuous interval training. It has been shown that both the peak and mean power output in the Wingate anaerobic test can be improved through strenuous interval training (19). These results indicate that the Wingate anaerobic test may be an important tool for assessing the relative potential of sub-elite competitive cyclists.

Although male cyclists achieved a 27% higher absolute mean power (W) and a 13% higher relative mean power (W/kg BW) than the females, the female group attained a very similar mean power value when expressed relative to LBM. These results are in accordance with a previous study (26) which reported that female speed skaters can exert the same power output per kilogram LBM as male speed skaters when measured on a bicycle ergometer. Our observations along with these (26) support the view that there may be no differences in anaerobic power outputs between males and females in the same athletic event when they are expressed relative to LBM. It should, however, be noted that anaerobic power is also subjected to genetics and muscle fiber types (3).

An additional purpose of this study was to examine the inter-correlation between aerobic and anaerobic power output values. At present, the relationship between aerobic power and anaerobic power output has not been studied extensively (5, 11, 14, 15) although the interplay is common to most sports. In the present investigation, no inter-correlation was obtained in any measurement between aerobic and anaerobic power values. However, Katch and Weltman (14) found a negative correlation between $\dot{V}O_2max$ and peak anaerobic power output in trained men. Similarly, Crielaard and Pirnay (11) found a strong negative relationship ($r = -0.83$) in highly trained athletes with various specialties. In contrast, Boulay et al. (5), using untrained subjects, reported a positive correlation between these measurements. Jones and McCartney (15) also found a strong positive relationship ($r = 0.92$) between aerobic power and the total work in 30 s maximal isokinetic cycling. It may be that the discrepancies between these studies are due to 1) characteristics of the subject population and 2) adjustments for body size. A study that examined sprint, middle-distance, and endurance runners found a negative correlation between aerobic power and anaerobic power (11), whereas studies using more homogeneous groups did not (5, present study). In addition, if aerobic power and anaerobic power are not adjusted for body weight, this yields positive correlations (15) since larger individuals would tend to have an increase in both of these variables. Nevertheless, this topic is still controversial, and additional study on the relationship between aerobic and anaerobic power is warranted.

In summary, we characterized aerobic and anaerobic power in competitive bicycle racers since both energy systems appear to be of critical importance in bicycle road races. There was a tendency for both aerobic and anaerobic power to increase from category IV to II. Female cyclists recorded significantly less peak and mean power output than their male counterparts. However, when expressed relative to lean body mass, anaerobic power was similar for both sexes. No inter-correlation was found in any measurement between the aerobic and anaerobic power values. These results suggest that both aerobic and anaerobic power may be important determinants for competitive cycling performance.

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