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Correlations between physiological variables and performance in high level cross country off road cyclists

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Objectives: To examine the relations between maximal and submaximal indices of aerobic fitness and off road cycling performance in a homogeneous group of high level mountain bikers.**Methods:** 12 internationally competitive mountain bikers completed the study. Maximum oxygen uptake ($\dot{V}O_{2max}$), peak power output (PPO), power output (PO), and oxygen uptake ($\dot{V}O_2$) at first (VT) and second (RCT) ventilatory thresholds were measured in the laboratory, and correlated with race time during a cross country circuit race.**Results:** The only physiological indices of aerobic fitness correlated with off road cycling performance were PO and $\dot{V}O_2$ at RCT when normalised to body mass ($r = -0.63$ and $r = -0.66$, respectively; $p < 0.05$). VT, $\dot{V}O_{2max}$, and PPO were not correlated to performance in this homogeneous group of high level mountain bikers.**Conclusions:** The results of this study suggest that submaximal indices of aerobic fitness such as PO and $\dot{V}O_2$ at RCT are more important determinants of off road cycling performance than maximal indices such as PPO and $\dot{V}O_{2max}$. This study confirms the importance of body mass for mountain biking performance. As aerobic fitness explained only 40% of the variance, other physiological and technical factors should be investigated, as they may be important determinants of cross country performance among elite mountain bikers.

Mountain biking is a popular recreational and competitive sport, and one of its most popular events (cross country circuit racing) was included as an official Olympic sport in the 1996 Atlanta Summer Games. Despite the growing interest in it, few studies have investigated the physiological aspects of this sport.^{1–6} Overall, the available studies show that cross country circuit races are carried out at very high exercise intensity, with average competition heart rate close to 90% of maximum for races lasting up to two hours,^{1,2} and with power output (PO) values reaching 250 to 500 W during uphill cycling.³ Furthermore, more recent investigation has shown that high maximum oxygen uptake ($\dot{V}O_{2max}$) and the capacity to maintain high submaximal aerobic work (lactate thresholds) are important determinants of off road performance.⁶ Some studies have also demonstrated that body mass should be taken into account when evaluating the physiological characteristics of mountain bikers and their relation to off road cycling performance.^{4,6}

To date, the relations between physiological indices of aerobic fitness and performance have been investigated only in a heterogeneous group of off road cyclists with large race time differences between the first and last cyclists within the group (26 minutes).⁶ However, when applied to more homogeneous samples, some physiological variables were found to be poor discriminators of performance differences.⁷ In fact, previous studies in road cycling suggest that some physiological predictors of time trial performance in a group of cyclists of different performance levels^{8–11} might not be associated with performance in a more homogeneous group of top level professional cyclists.¹²

The aim of this study was therefore to examine whether physiological indices of aerobic fitness similar to those found to be correlated with cross country race performance in a heterogeneous group of mountain bikers by Impellizzeri *et al*⁶ are also associated with performance in a more homogeneous group of elite off road cyclists (race time difference of six minutes).

METHODS

Subjects

Fifteen male high level off road cyclists were recruited for the study (mean (SD) age 25.5 (3.8) years, height 175.9 (6.4) cm, body mass 66.2 (5.4) kg, maximum oxygen uptake ($\dot{V}O_{2max}$) 75.9 (5.3) ml/kg/min, peak power output (PPO) 428 (39) W, off road cycling experience 9.9 (2.9) years). These mountain bikers were internationally competitive cyclists and eight of them had been classified at least once in the first 10 positions of the most important international competitions (World Cup, European Cup, World Championship, or Olympic Games). The other seven mountain bikers won several international events included in the UCI calendar. After being informed of the aims and procedures of the study and prior to commencement of testing, all subjects gave their written consent in accordance with the Declaration of Helsinki. The study was approved by the institutional review board.

Laboratory tests

During the tapering week before a cross country competition, cyclists carried out an incremental maximal exercise test on an electromagnetically braked ergometer (SRM Ergometer, Welldorf, Germany) equipped with an SRM Powermeter incorporating 20 strain gauges (SRM Science, Welldorf, Germany). The ergometer were regularly checked for accuracy and reliability using a calibration rig (model 17810, Vacumed, Ventura, California, USA). The ergometer settings were individually adjusted to allow each cyclist to replicate the position he assumes on his own bicycle.

Subjects were instructed not to eat for at least three hours before testing, not to drink coffee or beverages containing

Abbreviations: HR_{max}, maximum heart rate; PO, power output; PPO, peak power output; RCT, respiratory compensation threshold; $\dot{V}O_2$, oxygen uptake; $\dot{V}O_{2max}$, maximum oxygen uptake; VT, ventilatory threshold

caffeine for at least eight hours before testing, and to avoid intense exercise for 48 hours before testing. The test started at 100 W and resistance increased by 25 W/min until volitional exhaustion. The subjects were instructed to maintain a cadence between 90 and 95 rev/min throughout the test. The choice of this arbitrary cadence was based on our previous experience with mountain bikers, who prefer a high rather than a low cadence. This is in agreement with the results of Takaishi *et al.*¹³ who showed that well trained cyclists prefer a higher pedalling rate to minimise neuromuscular fatigue. Furthermore, in previous investigations on off road cyclists, a similar cadence range (90–100 rpm) was used.^{1,3,6} During the test, athletes were encouraged verbally by the laboratory technicians as well as by their team coach.

If the last workload was not completed, the PPO was calculated using the formula of Kuipers *et al.*¹⁴

$$\text{PPO} = W_f + (t/60.25)$$

Where W_f is the last completed workload in watts, t is the time in seconds of the uncompleted step, and 25 is the difference in watts between consecutive workloads.

Maximum oxygen uptake was measured using a breath by breath automated gas analysis system (VMAX29, Sormedics, Yorba Linda, California, USA). Before each test, flow and volume were calibrated using a three litre capacity syringe (Sormedics), while gas analysers were calibrated using two tanks of known concentrations of oxygen uptake (O_2) and carbon dioxide (CO_2) (16% O_2 and 4% CO_2 , 26% O_2 and 0% CO_2 , respectively; Sormedics). Achievement of $\dot{V}\text{O}_{2\text{max}}$ was assumed on attainment of at least two of the following three criteria: a plateau in $\dot{V}\text{O}_2$ with increasing speeds; a respiratory exchange ratio above 1.10; a heart rate within ± 10 beats/min of age predicted maximum heart rate ($220 - \text{age}$).¹⁵

Ventilatory threshold (VT) and respiratory compensation threshold (RCT) were assessed by combining three common methods for the determination of gas exchange thresholds according to Gaskill *et al.*¹⁶ (1) the ventilatory equivalent of O_2 and CO_2 ($\dot{V}\text{e}/\dot{V}\text{O}_2$ and $\dot{V}\text{e}/\dot{V}\text{CO}_2$, respectively); (2) excess CO_2 ; (3) the V-slope method. Thus, VT was visually detected as the intensity corresponding to (1) an increase in $\dot{V}\text{e}/\dot{V}\text{O}_2$ with no increase in $\dot{V}\text{e}/\dot{V}\text{CO}_2$, (2) the first sustained rise in excess CO_2 , and (3) the first increase in the slope of the $\dot{V}\text{CO}_2$ v $\dot{V}\text{O}_2$ plot. RCT was determined as the intensity corresponding to (1) an increase in both $\dot{V}\text{e}/\dot{V}\text{O}_2$ and $\dot{V}\text{e}/\dot{V}\text{CO}_2$; (2) the second sustained rise in excess CO_2 ; and (3) the second increase in the slope of the $\dot{V}\text{CO}_2$ v $\dot{V}\text{O}_2$ plot. VT and RCT were detected by two independent experienced investigators. If the $\dot{V}\text{O}_2$ at VT and RCT determined by the two investigators was within 3%, the mean value of the two investigators was used. When the difference exceed 3% a third investigator was asked to determine VT and RCT. The combination of these three methods of gas exchange threshold detection has been shown to improve the accuracy and reliability of VT identification.¹⁶

Cross country competition

The cross country circuit competition of international level was run in March (six laps, total distance of 33.6 km and total altitude climbed 1362 m; data supplied by the race organisation). The day before the race, the participants were allowed to practise the competition course cycling at an intensity $< 85\%$ of maximum heart rate (HR_{max}). Before the race, they carried out a warm up for one hour at intensities of $< 80\%$ of HR_{max} and high cadence (> 90 rev/min) on the road or using a cyclo-simulator. All athletes started the race with 500 ml of an electrolyte solution and they were free to take a 500 ml bottle of carbohydrate–electrolyte beverage or a

maltodextrin gel (30 ml) or both at each lap. Time taken to complete the race was used as the performance index (individual competition times were supplied by the race organisation). Athletes were instructed to complete the race in the fastest possible time. Only mountain bikers who completed the competition without mechanical problems were included. We used actual race performance as the dependent variable to examine the influence of the selected physiological predictors on real cross country performance and thus to increase the ecological validity of this study. However, the use of a single race performance has the limitation that correlations could be influenced by the degree of technical ability required by the specific race course.

Statistical analysis

Data are reported as means (SD). Before using parametric tests, the assumption of normality was verified using the Shapiro–Wilk W test. Pearson's product-moment correlations were used to examine the relations between the aerobic fitness indices (expressed in absolute terms and normalised by body mass values) as measured during the laboratory tests ($\dot{V}\text{O}_{2\text{max}}$, PPO, PO, and $\dot{V}\text{O}_2$ at VT and RCT), and time taken to complete the race. In off road cycling, a particular factor that could influence final race time is the starting position. The cross country discipline is a massed start event and the starting grid is defined according to the UCI points or the national points system, or both, for the national events. This allows the best cyclists to start in front of the group to avoid being slowed down by lower standard riders. A different starting position could influenced competition time and, consequently, its relation to laboratory variables. For this reason, in a previous similar study, Impellizzeri *et al.*⁶ also applied the Spearman's rank correlation. In the present study, all the athletes started in the first two lines and so their starting positions could not have influenced the correlations. The level of statistical significance was set at $p < 0.05$. Statistical analyses were undertaken using the

Table 1 Characteristics of off road cyclists who completed the race and were included in the final statistical analysis ($n = 12$)

	Mean (SD)	Min	Max
Age (years)	24.9 (2.9)	23.0	32.0
Weight (kg)	66.4 (5.7)	54.0	75.0
Height (cm)	176 (7)	165.0	188.0
$\dot{V}\text{O}_{2\text{max}}$ (litres/min)	5.11 (0.46)	4.58	6.11
$\dot{V}\text{O}_{2\text{max}}$ (ml/kg/min)	76.9 (5.3)	70.8	86.1
$\dot{V}\text{O}_{2\text{max}}$ (ml/kg ^{0.75} /min)	185.8 (11.7)	170.0	210.7
$\dot{V}\text{O}_{2\text{RCT}}$ (litres/min)	4.45 (0.36)	4.01	5.32
$\dot{V}\text{O}_{2\text{RCT}}$ (ml/kg/min)	67.3 (4.8)	61.0	75.0
$\dot{V}\text{O}_{2\text{RCT}}$ (ml/kg ^{0.75} /min)	162.1 (10.4)	149.8	183.5
$\dot{V}\text{O}_{2\text{VT}}$ (litres/min)	3.77 (0.43)	3.15	4.79
$\dot{V}\text{O}_{2\text{VT}}$ (ml/kg/min)	56.8 (4.8)	50.8	67.5
$\dot{V}\text{O}_{2\text{VT}}$ (ml/kg ^{0.75} /min)	137.0 (11.5)	121	165
PPO (W)	426 (40)	373	525
PPO (W/kg)	6.4 (0.6)	5.8	7.4
PPO (W/kg ^{0.75})	15.5 (1.2)	14.0	18.1
PO _{RCT} (W)	360 (29)	323	432
PO _{RCT} (W/kg)	5.4 (0.4)	4.9	6.1
PO _{RCT} (W/kg ^{0.75})	13.1 (0.9)	12.0	14.9
PO _{VT} (W)	272 (40)	230	365
PO _{VT} (W/kg)	4.1 (0.6)	3.3	5.2
PO _{VT} (W/kg ^{0.75})	9.9 (1.4)	8.1	12.6
Maximum HR (beats/min)	183 (8)	171	201
HR _{RCT} (beats/min)	168 (7)	155	180
HR _{VT} (beats/min)	148 (10)	132	162
$\dot{V}\text{e}_{\text{max}}$ (litres/min)	179 (12)	160	197
Race time (s)	6826 (101)	6650	6995

HR, heart rate; PO, power output; PPO, peak power output; RCT, respiratory compensation point; $\dot{V}\text{e}$, ventilation; $\dot{V}\text{O}_{2\text{max}}$, maximum oxygen uptake, VT, ventilatory threshold.

Figure 1 Scatterplot of race time v power output at respiratory compensation threshold (RCT), normalised to body mass (BM) raised to the power of 1. SEE, standard error of estimate.

software package STATISTICA (version 6.0, StatSoft, Tulsa, Oklahoma, USA).

RESULTS

Three off road cyclists withdrew from the race owing to mechanical problems. Thus only 12 mountain bikers were included in the final analysis. The characteristics of these subjects are presented in table 1.

Correlation between race time and $\dot{V}O_{2max}$, PPO, PO, and $\dot{V}O_2$ at RCT and VT, expressed in absolute values and normalised by body mass and relative confidence intervals (CI 95%), are presented in table 2. $\dot{V}O_2$ and PO corresponding to RCT normalised to body mass raised to the power of 1 and 0.79 were found to be moderately correlated with race time (figs 1, 2, 3, and 4).

DISCUSSION

The main finding of this study was that $\dot{V}O_{2max}$ and PPO were not correlated with cross country circuit race performance, and that the only predictors of off road cycling performance were PO and $\dot{V}O_2$ at RCT normalised to body mass raised to the power of 1 and 0.79. This is in contrast with our previous findings in a less homogeneous group of off road cyclists, in which $\dot{V}O_{2max}$, PPO, and lactate thresholds were all highly correlated with performance in a cross country circuit race. On the other hand, the results of the present study are similar to those recently reported by Lucia *et al.*,¹² who found that among a group of top professional road cyclists during the Tour de France, PO at VT was the only variable strongly correlated with time trial performance. While in the study of Impellizzeri *et al.*⁶ maximal and submaximal indices of aerobic

Figure 3 Scatterplot of race time v power output at respiratory compensation threshold (RCT), normalised to body mass (BM) raised to the power of 0.79. SEE, standard error of estimate.

fitness explained 80% of the variance in off road performance, in the present study the only variables found to be correlated with cross country circuit race performance (intensity at RCT) explained about 40% of variance. This confirms that the physiological predictors of performance in a heterogeneous group of athletes cannot be applied to high level athletes who are characterised by a more homogeneous performance ability.⁷ The greater heterogeneity of the sample used by Impellizzeri *et al.*⁶ is shown by the difference between the race time of the first and the last riders within the group investigated (~26 minutes), while in the present study this was only six minutes.

The intensity at RCT found in the present study for elite off road cyclists (91.8% of HR_{max} and 87.5% of $\dot{V}O_{2max}$) is similar to that reported for top level professional road cyclists.^{17, 18} According to Lucia *et al.*,¹⁷ the high RCT intensity could reflect the ability to tolerate high exercise intensity during cycling competitions. Indeed, the RCT intensity found in our group of off road cyclists is similar to the relative heart rate and estimated $\dot{V}O_2$ reported for cross country off road cycling races^{1, 2, 6} (91% of HR_{max} and 84% of $\dot{V}O_{2max}$). It is possible that the factors influencing the respiratory pH defence against lactic acid reflected by RCT (chemoreflex feedback provided by P_{CO_2} , hydrogen ion, potassium, catecholamines, and increased body temperature)¹⁹ are important during off road competitions which are characterised by high exercise intensity in which anaerobic energy production probably plays a significant role. As intense exercises cause the production of large amounts of lactic acid, leading to an

Figure 2 Scatterplot of race time v oxygen uptake at respiratory compensation threshold (RCT), normalised to body mass (BM). SEE, standard error of estimate.

Figure 4 Scatterplot of race time v oxygen uptake at respiratory compensation threshold (RCT), normalised to body mass (BM) raised to the power of 0.79. SEE, standard error of estimate.

Table 2 Correlations (Pearson *r*) between race time and physiological variables expressed as absolutes and scaled to body mass values (*n*=12)

	Race time v absolute values		Race time v values/BM ¹		Race time vs values/BM ^{0.79}	
	<i>r</i>	95% CI	<i>r</i>	95% CI	<i>r</i>	95% CI
$\dot{V}O_{2max}$	-0.03	(-0.59 to 0.55)	-0.46	(-0.85 to 0.15)	-0.38	(-0.78 to 0.25)
$\dot{V}O_2$ at RCT	-0.18	(-0.68 to 0.44)	-0.66*	(-0.89 to -0.14)	-0.63*	(-0.88 to -0.06)
$\dot{V}O_2$ at VT	-0.01	(-0.58 to 0.57)	-0.38	(-0.78 to 0.25)	-0.30	(-0.75 to 0.33)
PPO	-0.11	(-0.64 to 0.50)	-0.48	(-0.83 to 0.13)	-0.43	(-0.81 to 0.19)
PO at RCT	-0.22	(-0.70 to 0.41)	-0.63*	(-0.88 to -0.06)	-0.61*	(-0.88 to -0.06)
PO at VT	-0.17	(-0.68 to 0.45)	-0.37	(-0.78 to 0.26)	-0.34	(-0.76 to 0.29)

BM, body mass; CI, confidence interval; PO, power output; PPO, peak power output; RCT, respiratory compensation point; $\dot{V}O_{2max}$, maximum oxygen uptake, VT, ventilatory threshold.

**p*<0.05.

increase in hydrogen ion activity, the hyperventilation response acts as a rapid way of maintaining pH stability.^{20, 21} The importance of the aerobic-anaerobic transition (that is, lactate thresholds and VTs) at a high workload, other than a high $\dot{V}O_{2max}$, has also been suggested and reported for cross country skiing competitions which are usually performed at exercise intensities of between 85% and 90% of $\dot{V}O_{2max}$,^{22, 23} similar to off road cycling races.

Like Impellizzeri *et al*,⁶ we found that body mass should be taken into account when investigating the physiological determinants of off road cycling performance. In fact, PO and $\dot{V}O_2$ at RCT were significantly associated with cross country circuit race performance only when normalised to body mass. In the study by Impellizzeri *et al*,⁶ the best correlations (*r*>0.90) between a cross country race and $\dot{V}O_{2max}$, PPO, and PO at lactate threshold were found when these variables were normalised to body mass. This further confirms the conclusions of Lee *et al*⁴ that power to weight characteristics are important for success in off road events. Lee *et al* compared top level Australian mountain bikers and professional road cyclists and found no significant differences between groups in $\dot{V}O_{2peak}$, PPO, lactate threshold, or average power output during a 30 minute laboratory time trial, expressed in absolute values. However, when these physiological variables were scaled to body mass, significantly higher values were found in off road cyclists compared with road cyclists. Moreover, Lee *et al*⁴ reported that the off road cycling world champions from 1997 to 2000 had an average body weight of about 60 kg, a value similar to that reported in high level climber road cyclists.^{17, 24} The body mass found in the present investigation and in Lee's study are only slightly higher than the 64.3 and 62.4 kg reported, respectively, by Lucia *et al*¹⁷ and Padilla *et al*²⁴ for climbers.

The average $\dot{V}O_{2max}$ measured in the off road cyclists involved in the present study are similar to those reported by Lee *et al* for Australian elite mountain bikers,⁴ and to the $\dot{V}O_{2max}$ measured by Lucia *et al* (78.6 ml/kg/min)¹⁷ and estimated by Padilla *et al* (80.9 ml/kg/min)²⁴ for top level climber road cyclists. Overall, the mountain bikers' physiological characteristics given in previous reports and in the

present investigation (table 3) indicated that a high $\dot{V}O_{2max}$ (>70 ml/kg/min) is a prerequisite for competing at high level in off road events.

The unexplained 60% of variance in off road cycling performance found in the present study could be related to other physiological or technical factors. Cross country circuit races are undertaken at very high exercise intensity^{1, 2} with peak PO, directly measured using mobile crank dynamometers, ranging between 250 to 500 W during uphill cycling.² Owing to the high PO required during steep climbing at the start of the race and when sprinting to pass slower riders, several investigators^{1, 2, 5} have suggested that high anaerobic power or capacity, or both, rather than high aerobic fitness, are important for meeting the physiological demands of off road cycling competitions. Baron⁵ compared maximal aerobic and anaerobic power of a group of elite mountain bikers with sport science students. He showed that national and international level off road cyclists have higher $\dot{V}O_{2max}$, PPO, and PO at the 4 mmol/l fixed lactate threshold compared with sport science students, and they also showed higher anaerobic power measured during 10 second isokinetic cycling tests at cadence ranging from 50 to 140 rev/min. According to Baron, anaerobic characteristics should routinely be evaluated in cyclists in addition to physiological indices of aerobic fitness. As factors such as anaerobic power and non-respiratory buffering capacity (bicarbonate and non-bicarbonate) could account for part of the unexplained variance of the present study, further studies are necessary to investigate the contribution of anaerobic energy system to off road performance. Moreover, the ability to recover during the descents following the several climbs should be also investigated because it could account for an important portion of the unexplained variance.

Another determinant of off road performance could be technical ability. Off road competitions are characterised by repeated climbs and descents. While prowess at hill climbing requires a high power to weight ratio for top performance, descents carried out over different terrain conditions (dirt and gravel roads) necessitate a high degree of technical ability. Thus it is possible that among a homogeneous group

Table 3 Maximum oxygen uptake ($\dot{V}O_{2max}$) of off road cyclists in published reports

Study	Cycling level	n	Height (cm)	Mass (kg)	$\dot{V}O_{2max}$ (ml/kg/min)
Wilber <i>et al</i> (1997) ³	Int	10 male	176 (7)	72 (8)	70.0 (3.7)
Baron (2001) ⁵	NAT and INT	25 male	179 (5)	69 (7)	68.4 (3.8)
Lee <i>et al</i> (2002) ⁴	Int	7 male	178 (7)	65 (7)	78.3 (4.4)
Impellizzeri <i>et al</i> (2002) ¹	Int	5 male	175 (3)	64 (5)	75.9 (5.0)
Stapelfeldt <i>et al</i> (2004) ²	Int	9 male	180 (6)	69 (5)	66.5 (2.6)
Impellizzeri <i>et al</i> (2005) ⁶	NAT and INT	13 male	177 (8)	65 (6)	72.1 (7.4)
Present study	Int	15 male	176 (7)	66 (6)	75.9 (5.3)

Int, international level off road cyclists; Nat, national level off-road cyclists; $\dot{V}O_{2max}$, maximum oxygen uptake.

What is already known

A previous study conducted on a heterogeneous group of mountain bikers showed high correlations between maximal and submaximal indices of aerobic fitness ($\dot{V}O_{2\max}$, PPO, and lactate thresholds normalised to BM) and a cross country race. About 80% of variance in performance was explained by aerobic fitness.

What this study adds

In a homogeneous group of elite off road cyclists with high $\dot{V}O_{2\max}$, the ability to sustain high intensity submaximal aerobic work (RCT/BM) was the only variable correlated with cross country performance. As only 40% of variance was explained, other physiological or technical factors may be important for elite performance in cross country events.

of high level off road cyclists technical ability may play a more important role than in a heterogeneous group of mountain bikers.

In conclusion, our results suggest that PO and $\dot{V}O_2$ at RCT are more important determinants of off road cycling performance than $\dot{V}O_{2\max}$ and PPO in high level off road cyclists. As a result, training strategies in elite mountain bikers with high $\dot{V}O_2$ should focus on improving the capacity to maintain a high level of submaximal aerobic work (that is, RCT intensity). However, as significant correlation does not imply causality,⁷ experimental studies are needed to determine whether training aimed at improving lactate thresholds or VTs results in enhanced off road cycling performance.²⁵ Furthermore, as the correlations we found explained only 40% of the variance in cross country performance, further studies should also investigate other technical and physiological factors associated with off road cycling performance in high level mountain bikers, using not only actual race performance but also laboratory race simulations.

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