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Physiological and Performance Characteristics of Male Professional Road Cyclists

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Contents

Abstract

Male professional road cycling competitions last between 1 hour (e.g. the time trial in the World Championships) and 100 hours (e.g. the Tour de France). Although the final overall standings of a race are individual, it is undoubtedly a team sport. Professional road cyclists present with variable anthropometric values, but display impressive aerobic capacities [maximal power output 370 to 570W, maximal oxygen uptake 4.4 to 6.4 L/min and power output at the onset of blood lactate accumulation (OBLA) 300 to 500W]. Because of the variable anthropometric characteristics, 'specialists' have evolved within teams whose job is to perform in different terrain and racing conditions. In this respect, power outputs relative to mass exponents of 0.32 and 1 seem to be the best predictors of level ground and uphill cycling ability, respectively. However, time trial specialists have been shown to meet requirements to be top competitors in all terrain (level and uphill) and cycling conditions (individually and in a group). Based on competition heart rate measurements, time trials are raced under steady-state conditions, the shorter time trials being raced at average intensities close to OBLA (≈400 to 420W), with the longer ones close to the individual lactate threshold

(LT, ≈370 to 390W). Mass-start stages, on the other hand, are raced at low mean intensities (≈210W for the flat stages, ≈270W for the high mountain stages), but are characterised by their intermittent nature, with cyclists spending on average 30 to 100 minutes at, and above LT, and 5 to 20 minutes at, and above OBLA.

Male professional road cycling competition is composed of 1-day, 4- to 10-day and 3-week races. Among these, it is probably the 3-week stage races (Tour de France, Giro d'Italia and Vuelta a España) that best represent the sport and draw the highest levels of attention from sponsors, media and the general public. From a historic perspective, during the 1930s and 1940s cyclists participated in the 3-week races on an individual basis. Subsequently, in the 1950s and 1960s, cyclists took part in these events as members of their national teams. However, during the late 1970s when sponsorship and television became involved in the sport, riders were grouped as professionals in sponsored trade teams, which is currently the prevailing format not only in the 3-week stage races, but in most other competition events as well. The only exceptions to this participation format are the World Championships and the Olympic Games, in which cyclists race as members of their respective national teams (table I).

1. Structure of the Sport and the Racing Calendar

In addition to the cyclists themselves and their respective trade teams, other basic components of the professional cycling structure and governing bodies include the Union Cycliste Internationale (UCI), the International Olympic Committee, each country's own cycling federation and the race organisers. This amalgam of organising structures has resulted in professional cycling having an undeniable image of dispersal, heterogeneity and diversity of criteria. For instance, participation of some trade teams in the most important race of the calendar, the Tour de France, relies exclusively on the criterion of the race organisers. However, during the last decade, the UCI has made a great effort in assuming a leading role as the major governing body regulating, among other aspects of professional cycling, participation in races as well as the competition calendar.

Table I. Union Cycliste Internationale (UCI) competition calendar and scores

Competition modality	Duration	Participation format	Examples	Racing format	Points to winner
Major tour races	21-22 days	Trade team	Tour de France	Mass-start	500
			Giro d'Italia	Individual TT	
			Vuelta a España	Team TT[a]	
Stage races	4-10 days	Trade team	Paris-Nice	Mass-start	200
			Tirreno-Adriatico	Individual TT	
			Vuelta al País Vasco	Team TT[a]	
World Cup classics	1 day	Trade team	Paris-Roubaix	Mass-start	280
			Milano-San Remo		
			Clásica San Sebastián		
World Championships	2 days[b]	National team		Mass-start[b]	400
				Individual TT[b]	240
Olympic Games	2 days[b]	National team		Mass-start[b]	400
				Individual TT[b]	240
Other 1-day races	1 day	Trade team	Subida a Montjuic	Mass-start	175

a The team time trial (TT) is not necessarily included in these races.

b The mass-start race and the time trial are independent of each other.

As shown in table I, the UCI competition calendar includes several races with different competition modalities, including the major 3-week stage tours, some 4- to 10-day stage races, the World Cup 1-day classic races, the World Championships and each country's National Championships including a time trial race and a 1-day mass-start race, the Olympic Games, and a series of other 1-day races. In all these races, the UCI grants a certain amount of points to the individual cyclists. For example, the overall winner of the Tour de France is awarded 500 points, whereas the winner of each stage and the race leader receive 70 points each. In addition, 15 points are awarded to all tour finishers. The winners of the mass-start race and the time trial at the World Championships or the Olympic Games receive 400 and 240 points, respectively (table I), [for additional information on the UCI scoring system readers are referred to http://www.uci.ch].[1] Each cyclist is ranked according to his individual score, and trade teams are ranked by adding up the scores of its riders. However, it is worth noting that the athletic, financial and even the social impact of a victory in any of these races is in general much higher than the UCI ranking itself. Moreover, this ranking should be considered an index of performance regularity, rather than an index of athletic ability, because there is no relationship between the amount of points granted and the physiological and performance demands of each race of the calendar.

2. Teams, Countries and the Cyclists

According to the above mentioned UCI, in October 8, 2000 there were 22 professional cycling teams classified as Category I, 46 as Category II and 23 as Category III. The average yearly budget of a Category I team composed of 22 to 24 riders is about $US8 to 10 million. Of the 22 Category I trade teams, 8 were Italian, 4 Spanish, 4 French, 2 were from The Netherlands and the remaining 4 were from Germany, USA, Belgium and Denmark. However, only Italy with 4, Spain with 3, Germany, The Netherlands and France with 1 team each were represented in the top 10 trade team rankings. Of the 71 countries ranked by the UCI at that same time, the top 5 were Italy, Spain, Germany, Belgium and France.

The individual rankings of the UCI listed 1938 male cyclists in October 8, 2000, but only 200 of them are allowed to take part in any given race of the international competition calendar. The 10 most represented countries in the top 100 ranking were Italy (22 cyclists), Spain (18), Belgium (12), France (7), The Netherlands (7), Germany (5), Denmark (4), Russia (4), USA (4) and Switzerland (4). The countries represented in the top 10 individual ranking were Italy (2), Spain (2), Germany (2), USA, Latvia, Belgium and France, with 1 cyclist each.

3. Laboratory-Based Characteristics of Male Professional Road Cyclists

Professional road cyclists are often tested in the laboratory to assess their physiological capabilities. Even though elite cyclists often express their preference for sport-specific field tests performed with equipment with which they are most familiar, laboratory testing on adapted cycle ergometers has been shown to be a valid means to evaluate a cyclist's physiological and performance potential.[2] Indeed, the response to exercise does not depend on the type of resistance the cyclist must overcome (i.e. friction force exerted by the cycle ergometer *vs* air resistance and rolling resistance when cycling in the field). Nevertheless, it has been shown that when elite cyclists are tested under laboratory conditions, physiological values expressed relative to anthropometric characteristics predict performance in the field more accurately than absolute values.[2]

3.1 Physical Characteristics

Male professional road cyclists show a wide range of values in their physical characteristics (table II). The average age of the members of a typical professional cycling team (n = 24) is about 26 years, ranging between 20 years for the neoprofessionals and 33 years for the most experienced cyclists. Given the fact that anthropometric characteristics play a major role on performance in different cycling conditions (see section 4), there is also a great variability in the values for height (mean 180cm, range 160

Table II. Physical, maximal and submaximal physiological characteristics of male professional road cyclists (n = 24)[3,4]

Characteristic	Mean	Range	
		min	max
Age (y)	26	20	33
Height (cm)	180	160	190
Body mass (kg)	69	53	80
Body surface area (m^2)	1.87	1.54	2.08
Frontal area (m^2)	0.35	0.28	0.38
W_{max} (W)[a]	439	349	525
W_{max} (W/kg)[a]	6.4	5.7	6.8
$\dot{V}O_{2max}$ (L/min)	5.4	4.4	6.4
$\dot{V}O_{2max}$ (ml/kg/min)	78.8	69.7	84.8
HR_{max} (beats/min)	194	187	204
$[La]_{peak}$ (mmol/L)	9.9	6.9	13.7
W_{LT} (W)[a]	334	202	417
W_{LT} (% W_{max})	76	58	83
$\dot{V}O_{2LT}$ (% $\dot{V}O_{2max}$)	77	74	83
HR_{LT} (beats/min)	163	146	174
W_{OBLA} (W)[a]	386	275	478
W_{OBLA} (% W_{max})	87	76	94
$\dot{V}O_{2OBLA}$ (% $\dot{V}O_{2max}$)	86	81	91
HR_{OBLA} (beats/min)	178	168	191

a To compare power output values with those measured on electromagnetically braked ergometers, 9% should be added to values in the table because of the friction in the transmission system of Monark ergometers.[5]

HR_{max} = maximal heart rate; **$[La]_{peak}$** = peak blood lactate level; **LT** = lactate threshold; **OBLA** = onset of blood lactate accumulation; **$\dot{V}O_{2max}$** = maximal oxygen uptake; **W_{max}** = maximal power output.

to 190cm), body mass (BM, mean 68.8kg, range 53 to 80kg), body surface area (BSA, mean 1.87m^2, range 1.54 to 2.08m^2) and frontal area (FA, mean 0.35m^2, range 0.28 to 0.38m^2).[3,4] Percentage body fat has been reported to be about 8%, ranging between 6.5 and 11.3%.[6,7]

3.2 Maximal Physiological Characteristics

Professional road cyclists typically cycle 25 000 to 35 000km in a season, adding up training and competition distances. One of their most outstanding characteristics is their high aerobic capacity, as shown by the maximal power output (W_{max}) and maximal oxygen uptake ($\dot{V}O_{2max}$) values consistently reported in the literature.[3,4,6-8] Testing the cyclists on a mechanically braked cycle ergometer using 4-minute increments, W_{max} values ranging between 349 and 525W (5.7 and 6.8 W/kg) have been reported.[3,4] The same individuals presented with $\dot{V}O_{2max}$ values of 4.4 to 6.4 L/min (69.7 to 84.8 ml/kg/min), maximal heart rate (HR_{max}) of 187 to 204 beats/min, and peak blood lactate level at the end of the above mentioned incremental testing protocol of 6.9 to 13.7 mmol/L (table II).[3,4] However, it should be taken into consideration that to compare workloads with those obtained on electromagnetically braked ergometers, 9% should be added to account for the friction in the transmission system of the Monark ergometer.[5]

3.3 Submaximal Physiological Characteristics

As shown in table II, typical physiological characteristics of professional road cyclists at the individual lactate threshold (LT) include power output of 334W (76% W_{max}), oxygen uptake of 4.0 L/min (77% $\dot{V}O_{2max}$) and heart rate (HR) of 163 beats/min (84% HR_{max}). Typical values corresponding to the onset of blood lactate accumulation (OBLA, i.e. the exercise intensity eliciting a blood lactate level of 4 mmol/L) are 386W (87% W_{max}), 4.5 L/min (86% $\dot{V}O_{2max}$) and 178 beats/min (92% HR_{max}), respectively.[3,4] However, a recent study[9] on the 5-time winner of the Tour de France, reported a power output at OBLA of 505W (after addition of the above mentioned 9% correction), and an oxygen uptake ($\dot{V}O_2$) of 5.65 L/min. Professional road cyclists also present with a mean mechanical efficiency averaged through the entire range of submaximal and maximal cycling intensities of 23% (range 21.5 to 24.5%) [unpublished observations]. Recent studies have reported the individual anaerobic threshold and the second ventilatory threshold [characterised by an increase in both minute ventilation ($\dot{V}E$)/$\dot{V}O_2$ and $\dot{V}E$/carbon dioxide production ($\dot{V}CO_2$)] of professional road cyclists to occur at 87 to 90% $\dot{V}O_{2max}$.[6,7]

4. Comparative Values Among Specialists

Professional road cyclists are required to perform in a great variety of terrain (i.e. level, uphill and downhill roads) and competitive situations (i.e. individually or drafting behind other cyclists). In any of these situations, a cyclist's performance will be determined by his anthropometric characteristics. Indeed, BM has a major influence on uphill cycling performance, as it determines gravity-dependent resistance, whereas FA affects performance when cycling individually in level roads, because of its influence on aerodynamic resistance.[10] Differences in morphological characteristics of cyclists have contributed to the appearance of morphotype-dependent specialists in professional cycling, with clearly differentiated roles during the different phases of a race. These include flat terrain riders whose aim is to control the race on level roads; uphill riders who perform their team work mainly in the hills; all terrain riders performing fairly well in all types of terrain; time trial specialists, who excel in these individually raced events; and sprinters, who mainly race for the win in level road stages. The specific characteristics of the former 4 groups of specialists are described below.[3] Unfortunately, to the best of the authors' knowledge no specific data on the characteristics of sprinters are available in the literature.

4.1 Anthropometric Characteristics

As can be seen in table III, uphill cycling specialists have been reported to be not only significantly shorter than flat terrain riders (175 ± 7 *vs* 186 ± 4cm), but also lighter than all other specialists (62 ± 4, 68 ± 3, 71 ± 6 and 76 ± 3kg for uphill, all terrain, time trial and flat terrain specialists, respectively). In addition, they also have a significantly smaller BSA (1.76 ± 0.10, 1.87 ± 0.04, 1.91 ± 0.11, 2.00 ± 0.06m^2, respectively) and FA (0.33 ± 0.02, 0.35 ± 0.01, 0.35 ± 0.02, 0.37 ± 0.01m^2, respectively).[3] Because the lower velocities when riding in the mountains minimise the influence of aerodynamic resistance on performance, these values seem to give an edge to uphill specialists in this type of terrain. On the other hand, the bigger and heavier cyclists presented with lower BSA/BM × 10^{-3} and FA/BM × 10^{-3} values (table III), which have been associated with lower aerodynamic resistance in relation to BM, therefore lower energy cost per unit of BM and better performance during level terrain cycling.[10] These observations highlight the importance of scaling maximal and submaximal physiological variables in relation to anthropometric values to predict performance in different field conditions.

4.2 Maximal Physiological Values

Flat terrain specialists were the group of cyclists achieving the highest mean absolute W_{max} and $\dot{V}O_{2max}$ values (461 ± 39W, 5.7 ± 0.4 L/min), but the values of time trial specialists were almost identical (457 ± 46W and 5.7 ± 0.5 L/min). However, scaling these values in relation to BM, resulted in uphill specialists showing the highest mean W_{max} and $\dot{V}O_{2max}$ values (6.5 ± 0.3 W/kg and 80.9 ± 3.9 ml/kg/min). These values were closely matched by those of time trial specialists (6.4 ± 0.1 W/kg and 79.2 ± 1.1 ml/kg/min). When W_{max} was expressed relative to mass exponents 0.32 and 0.79 (previously suggested as the best predictors of level cycling and uphill cycling performance, respectively)[11] or relative to FA, top values were also observed in the time trial specialists (table III). It was concluded that time trial specialists had an overall performance advantage over the other groups in all cycling terrains.[3] In this respect, it is worth mentioning that despite their much bigger body size, some of the best time trial specialists of the last decade consistently matched and often surpassed the performances in the mountains of the much smaller and lighter uphill specialists.

4.3 Submaximal Physiological Values

Since most of the racing time during professional road cycling competition is not spent at maximal exercise intensities (see section 5), it is interesting to determine the ability of the various groups of specialists to perform at different submaximal intensity levels. In this respect, time trial specialists have been shown to display very high power outputs at both the individual LT and the OBLA exercise intensities, whether these values were expressed in absolute terms (357 ± 41 and 409 ± 46W, respec-

Table III. Physical, maximal and submaximal physiological characteristics of the specialist rider groups. Values are mean ± SD[3]

Characteristic	Group			
	flat terrain (n = 5)	time trial (n = 4)	all terrain (n = 6)	uphill (n = 9)
Age (y)	27 ± 3	28 ± 5	25 ± 2	25 ± 4
Height (cm)	186 ± 4	181 ± 6	180 ± 2	175 ± 7[a]
BM (kg)	76 ± 3	71 ± 6	68 ± 3[a]	62 ± 4[a,b,c]
BSA (m^2)	2.00 ± 0.06	1.91 ± 0.11	1.87 ± 0.04[a]	1.76 ± 0.10[a,b,c]
FA (m^2)	0.37 ± 0.01	0.35 ± 0.02	0.35 ± 0.01[a]	0.33 ± 0.02[a,b,c]
BSA/BM × 10^{-3}	26.3 ± 0.5	26.8 ± 0.7	27.4 ± 0.5[a]	28.3 ± 0.5[a,b,c]
FA/BM × 10^{-3}	4.9 ± 0.1	5.0 ± 0.1	5.1 ± 0.1[a]	5.2 ± 0.1[a,b]
W_{max} (W)[d]	461 ± 39	457 ± 46	432 ± 27	404 ± 34[a,b]
W_{max} (W/kg)[d]	6.0 ± 0.3	6.4 ± 0.1	6.4 ± 0.2	6.5 ± 0.3[a]
W_{max} (W • $kg^{-0.32}$)[d]	115.0 ± 8.5	116.6 ± 8.6	111.9 ± 5.6	107.6 ± 7.3
W_{max} (W • $kg^{-0.79}$)[d]	15.0 ± 0.8	15.7 ± 0.5	15.4 ± 0.6	15.4 ± 0.8
W_{max} (W/m^2 FA)[d]	1300 ± 62	1293 ± 57	1253 ± 51	1239 ± 66
$\dot{V}O_{2max}$ (L/min)	5.7 ± 0.4	5.7 ± 0.5	5.4 ± 0.3	5.1 ± 0.4[a,b]
$\dot{V}O_{2max}$ (ml/kg/min)	74.4 ± 3.0	79.2 ± 1.1[a]	78.9 ± 1.9[a]	80.9 ± 3.9[a]
W_{LT} (W)[d]	356 ± 31	357 ± 41	322 ± 43	308 ± 46
W_{LT} (W/kg)[d]	4.7 ± 0.3	5.0 ± 0.2	4.7 ± 0.5	4.9 ± 0.5
W_{LT} (W • $kg^{-0.32}$)[d]	89.0 ± 6.7	91.0 ± 8.0	83.4 ± 10.0	81.9 ± 10.8
W_{LT} (W • $kg^{-0.79}$)[d]	11.6 ± 0.7	12.3 ± 0.6	11.5 ± 1.2	11.7 ± 1.3
W_{LT} (W/m^2 FA)[d]	963 ± 59	1010 ± 65	934 ± 110	941 ± 10
W_{LT} (% W_{max})	77 ± 2	78 ± 3	74 ± 7	76 ± 3
W_{OBLA} (W)[d]	417 ± 45	409 ± 46	366 ± 38	356 ± 41[a,b]
W_{OBLA} (W/kg)[d]	5.5 ± 0.4	5.7 ± 0.2	5.4 ± 0.4	5.7 ± 0.5
W_{OBLA} (W • $kg^{-0.32}$)[d]	104.1 ± 10.3	104.3 ± 8.9	94.8 ± 8.7	94.8 ± 9.6
W_{OBLA} (W • $kg^{-0.79}$)[d]	13.6 ± 1.1	14.0 ± 0.7	13.0 ± 1.0	13.6 ± 1.1
W_{OBLA} (W/m^2 FA)[d]	1126 ± 100	1157 ± 70	1061 ± 91	1090 ± 88
W_{OBLA} (% W_{max})	90 ± 3	89 ± 2	84 ± 5	88 ± 5

a Significantly different from flat terrain.

b Significantly different from time trial.

c Significantly different from all terrain.

d To compare power output values with those measured on electromagnetically braked ergometers, 9% should be added to values in the table because of the friction in the transmission system of Monark ergometers.[5]

BM = body mass; **BSA** = body surface area; **FA** = frontal area; **LT** = lactate threshold; **OBLA** = onset of blood lactate accumulation; **SD** = standard deviation; $\dot{V}$**O**$_{2max}$ = maximal oxygen uptake; **W**$_{max}$ = maximal power output.

tively) or relative to BM (5.0 ± 0.2 and 5.7 ± 0.2 W/kg, respectively), BM exponents 0.32 (91.0 ± 8.0 and 104.3 ± 8.9 W • $kg^{-0.32}$, respectively) and 0.79 (12.3 ± 0.6 and 14.0 ± 0.7 W • $kg^{-0.79}$, respectively), FA (1010 ± 65 and 1157 ± 70 W/m^2 FA, respectively) or as a percentage of W_{max} (78 ± 3 and 89 ± 2%, respectively). As expected, the power outputs of flat terrain specialists were similar to the above in absolute values (356 ± 31 and 417 ± 45W, respectively) and relative to BM exponent 0.32 (89.0 ± 6.7 and 104.1 ± 10.3 W • $kg^{-0.32}$, respectively), which were indicative of a similar performance ability in level terrain. Uphill riders, on the other hand, closely matched the submaximal power output values displayed by the time trial specialists at LT and OBLA when these were expressed relative to BM (4.9 ± 0.5 and 5.7 ± 0.5 W/kg, respectively) [table III]. In view of these results, it was concluded that BM exponents 0.32 and 1 should be used to assess level ground and uphill cycling performance. Moreover, the authors of the study suggested that power output at LT and OBLA could be useful tools to predict performance and establish target exercise intensities during the different types of competition time trial and mass-start stages.[3]

5. Characteristics of Male Professional Road Cycling Competitions

Professional road cycling is characterised by 2 possible competition formats, i.e. time trial and mass-start racing. A cyclist's athletic success in 1-day, 1-week or 3-week races is therefore determined by his performance level in either one or both of these competition formats. To optimise training strategies and performance, the physiological demands of professional cycling competition need to be determined. Unfortunately, this has been a difficult task because of the technical difficulties inherent in the determination of $\dot{V}O_{2max}$ and blood lactate levels during competition, which are 2 of the main methods used by exercise scientists to quantify exercise intensity. The advent of accurate portable telemetric HR monitors and power measuring devices, however, has made it possible to assess exercise intensity during cycling competition, by relating individual HR values measured in the field with those previously obtained in a laboratory setting, and by measuring power output during actual racing, respectively.[4,6,7,12-15]

5.1 Time Trials

In a recent investigation,[4] the exercise intensity of different competition time trials was studied in a group of World Class cyclists, by relating their racing HR with maximal (%HR_{max}) and submaximal [HR at LT and at OBLA (HR_{LT} and HR_{OBLA}, respectively)] values previously obtained during progressive laboratory tests to exhaustion. As reported in table IV, this study showed that prologue time trials (7.3 ± 1.1km, level terrain) were raced at the highest relative intensity (89 ± 3% HR_{max}, 114 ± 8% HR_{LT} and 100 ± 3% HR_{OBLA}), followed by short time trial (28.0 ± 8.6km, level terrain, 85 ± 5% HR_{max}, 108 ± 9% HR_{LT} and 95 ± 7% HR_{OBLA}), team time trial (67.0 ± 0.5km, all members of the team riding together, 82 ± 2% HR_{max}, 105 ± 11% HR_{LT} and 92 ± 4% HR_{OBLA}), long time trial (49.2 ± 8.0km, level terrain, 80 ± 5% HR_{max}, 103 ± 8% HR_{LT} and 89 ± 5% HR_{OBLA}) and uphill time trial (40.6 ± 4.8km, over 500m of altitude change, 78 ± 3% HR_{max}, 101 ± 5% HR_{LT} and 87 ± 2% HR_{OBLA}). However, taking into consideration the total time spent at and above the HR_{LT} and HR_{OBLA}, as well as the amount of TRIMP (training impulse, considered as an integrative marker of the exercise load undertaken during competition),[16] it was concluded that team time trials were the 'hardest' of all time trials, followed by uphill time trials, long time trials, short time trials and prologue time trials (table IV). These differences in the demands of the different time trials were not reflected by the average speed achieved in each type of race. In addition, the authors suggested that HR_{LT} and HR_{OBLA} could be valuable indices to determine appropriate competition pace for time trial events lasting respectively longer and less than 30 minutes.[4] However, extremely talented cyclists have been shown to be able to maintain exercise intensities corresponding to, or somewhat higher than, the OBLA for 60 minutes under steady-state conditions.[9]

A recent study[6] reported average HR values of 171 beats/min and 17 minutes of 'anaerobic exercise' during time trial stages of a mean duration of 38 minutes. These values were remarkably similar to those of 172 beats/min and 17 minutes at and above HR_{OBLA} reported for short time trials in table IV. It is important to note, however, that all of the above intensity values were higher for those cyclists riding all out in the competition time trial, and lower for those undertaking a more conservative approach because of team racing strategies.[4]

5.2 Mass-Start Stages

Recent investigations have used a similar approach based on HR monitoring to analyse exercise intensity and load during mass-start cycling competition.[6,7,12] In one of these studies, mass-start stages were classified as flat, semi-mountainous or high mountain depending on the uphill cycling distance and the total altitude change. Again, it was shown that cycling speed is not a fair reflection of the physiological demands of the race, as average speed

Table IV. Characteristics of male professional road cycling competitions. Values are mean ± SD[4,12]

Characteristic	Stage type							
	prologue TT (n = 12)	short TT (n = 18)	long TT (n = 19)	uphill TT (n = 8)	team TT (n = 7)	FLAT	SEMO	HIMO
Distance (km)	7.3 ± 1.1	28.0 ± 8.6[a]	49.2 ± 8.0[a,b]	40.6 ± 4.8[a,b,c]	67.0 ± 0.5[a,b,c,d]	210 ± 35	197 ± 32[e]	190 ± 29[e]
Time (min)	10 ± 2	39 ± 11[a]	66 ± 12[a,b]	75 ± 8[a,b]	75 ± 3[a,b]	312 ± 60	302 ± 57	355 ± 67[e,f]
Speed (km/h)	46.3 ± 2.8	43.1 ± 3.0[a]	44.7 ± 2.0	32.5 ± 2.0[a,b,c]	53.4 ± 1.8[a,b,c,d]	40.7 ± 3.1	39.5 ± 3.1[e]	32.7 ± 3.7[e,f]
Heart rate (beats/min)	177 ± 5	172 ± 9[a]	162 ± 6[a,b]	158 ± 7[a,b]	165 ± 5[a,b]	119 ± 10	130 ± 9[e]	135 ± 9[e,f]
% HR_{max}	89 ± 3	85 ± 5[a]	80 ± 5[a,b]	78 ± 3[a,b]	82 ± 2[a]	51 ± 7	58 ± 6[e]	61 ± 5[e,f]
% HR_{LT}	114 ± 8	108 ± 9[a]	103 ± 8[a]	101 ± 5[a,b]	105 ± 11[a]	65 ± 10	74 ± 11[e]	79 ± 9[e,f]
% HR_{OBLA}	100 ± 3	95 ± 7[a]	89 ± 5[a,b]	87 ± 2[a,b]	92 ± 4[a]	57 ± 8	65 ± 7[e]	69 ± 6[e,f]
Watts[g]	380 ± 62	362 ± 59	347 ± 46	342 ± 32	353 ± 42	192 ± 45	234 ± 43[e]	246 ± 44[e]
% W_{max}	89 ± 6	84 ± 7[a]	79 ± 5[a,b]	77 ± 5[a,b]	80 ± 5[a]	45 ± 9	53 ± 8[e]	57 ± 8[e,f]
Time ≥ LT_{ZONE} (min)	9 ± 2	32 ± 21[a]	48 ± 37[a,b]	52 ± 28[a,b]	57 ± 35[a,b]	32 ± 29	58 ± 50	93 ± 70
Time ≥ $OBLA_{ZONE}$ (min)	8 ± 5	16 ± 19[a]	10 ± 16	2 ± 2[b]	21 ± 12[a,c,d]	6 ± 8	13 ± 16	16 ± 22
TRIMP	21 ± 3	77 ± 23[a]	122 ± 27[a,b]	129 ± 14[a,b]	146 ± 6[a,b,c,d]	156 ± 31	172 ± 31[e]	215 ± 38[e,f]

a Significantly different from prologue.
b Significantly different from short time trial.
c Significantly different from long time trial.
d Significantly different from uphill time trial.
e Significantly different from FLAT.
f Significantly different from SEMO.
g To compare power output values with those measured on electromagnetically braked ergometers, 9% should be added to values in the table because of the friction in the transmission system of Monark ergometers.[7]

FLAT = flat mass-start stage; **HIMO** = high-mountain mass-start stage; **HR** = heart rate; **HR_{max}** = maximal heart rate; **LT** = lactate threshold; **LT_{ZONE}** = HR_{LT} ± 3 beats/min; **OBLA** = onset of blood lactate accumulation; **$OBLA_{ZONE}$** = HR_{OBLA} ± 3 beats/min; **SD** = standard deviation; **SEMO** = semi-mountainous mass-start stage; **TRIMP** = training impulse;[16] **TT** = time trial; **W_{max}** = maximal power output.

was highest in flat (40.7 ± 3.1 km/h) and lowest in high mountain stages (32.7 ± 3.7 km/h), but average HR was lowest in the former (119 ± 10 beats/min) and highest in the latter (135 ± 9 beats/min). Average HRs represented 51 ± 7, 58 ± 6 and 61 ± 5% HR_{max}, 65 ± 10, 74 ± 11, 79 ± 9% HR_{LT} and 57 ± 8, 65 ± 7 and 69 ± 6% HR_{OBLA}, for flat, semi-mountainous and high mountain stages, respectively. Estimated average power outputs were respectively, 192 ± 45, 234 ± 43 and 246 ± 44W (45 ± 9, 53 ± 8 and 57 ± 8% W_{max}) (table IV).[12] Similar HR responses have been reported by other investigators,[6,7] and the estimated average power output for the high mountain stages was almost identical to that of 240W measured with the SRM Training System during a mountain stage of the Tour de France,[14] suggesting that HR is a valuable tool to estimate average power output during road cycling competition. Indeed, this has been proven true, given that these 2 variables are sampled at sufficiently long time intervals.[15]

However, these low average HR and power output values do not reflect the fact that professional road cycling competition is not performed in steady-state conditions. On the contrary, the intermittent nature of road cycling mass-start racing was reflected by the high intensity spurts interspersed with lower intensity recovery periods. Overall, during flat, semi-mountainous and high mountain stages cyclists spent a total time of 32 ± 29, 58 ± 50 and 93 ± 70 minutes, respectively at, or above, the LT intensity, and 6 ± 8, 13 ± 16 and 16 ± 22 minutes at, or above, the OBLA intensity. In addition, there was a remarkable inter-individual variability in these values (table IV), because of the specific role of a cyclist in a given stage, team strategies, race and environmental conditions, etc. High mountain stages were the hardest of all, followed by the semi-mountainous and the flat stages. This was in fact reflected by the amount of TRIMP corresponding to each of these stage types (215 ± 38, 172 ± 31 and 156 ± 31, respectively) (table IV).[12]

6. Conclusion

In conclusion, male professional road cyclists are characterised by very high aerobic capacities, both at maximal and submaximal exercise intensities. Given that anthropometric characteristics play a major role in the resistance a cyclist must overcome to generate movement, laboratory-based physiological measurements should be scaled in relation to body dimensions to assess road cycling performance. Further, time trial specialists seem to have an overall performance advantage over the other groups of cyclists in all types of terrain and riding conditions. Finally, HR monitoring has been shown to be a useful tool to determine exercise intensity and load during time trial and mass-start competition, by relating racing values with laboratory-based maximal and submaximal reference values.

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