Cadence-Power-Relationship during Decisive Mountain Ascents at the Tour de France

Authors S. Vogt[1], K. Roecker[1], Y. O. Schumacher[1], T. Pottgiesser[1], H.-H. Dickhuth[1], A. Schmid[1], L. Heinrich[2]

Affiliations
[1] Department of Preventive and Rehabilitative Sports Medicine, University of Freiburg, Freiburg, Germany
[2] Fachbereich Sportmedizin, Institut für Angewandte Trainingswissenschaft, Leipzig, Germany

Key words
- SRM powermeter
- pedaling rate
- professional cycling
- Grand Tours

Abstract

The aim of the study was to report the relationship between cadence and power developed by professional cyclists during high mountain ascents of the Tour de France. From the 10 cyclists (30 ± 4 years, 178 ± 8 cm, 69 ± 6 kg) involved in the study, 108 ascents were recorded and analyzed using a mobile power measurement device (SRM Training Systems, Jülich, Germany). Based on topographic characteristics, the ascents were categorized into 1st and Hors Category (HC) climbs. During the ascents of the 1st Category climbs, power output averaged 312 ± 43 W (4.5 ± 0.6 W/kg) with a mean cadence of 73 ± 6 rpm and a mean duration of 37 : 41 ± 16 : 16 min. Power output averaged 294 ± 36 W (4.3 ± 0.6 W/kg) at a mean cadence of 70 ± 6 rpm during 57 : 40 ± 10 : 32 min on HC climbs. The maximal mean power for long durations (1800 s) showed a mean power output of 327 W and 346 W for the 1st and HC climbs, respectively. The evaluation of the cadence-power output and the distance per pedaling cycle-power output relationship shows that high power outputs are mainly yielded by higher pedaling cadences and higher gears.

Introduction

The Tour de France is the most famous and prestigious cycling stage race in the world. A broad range of skills is required to be successful in this race. The overall classification of the Tour de France is primarily determined by successfully performing in the individual time trials and on the ascents of the mountain passes in the Alps and Pyrenees. Although heart rate (HR) monitoring has been used to estimate exercise intensity in Grand Tours [7,13,14,24,26], direct quantification of power output during hill climbing is unknown. In recent years, the development of lightweight portable devices measuring direct power output on the bicycle has shed new light on the instantaneous evaluation of performance during cycling competition [6,20,27,30,32].

Many studies have addressed the concept of optimal cadence [1,3,4,11,12,15,17,19,22,25], however, only preliminary data exist describing the cadence used by professional cyclists when cycling uphill [7,15,23,24,26]. Until now, the cadence-power relationship of these decisive moments of a cycling race is unknown. Furthermore, no attempt has been made to describe the power output produced by "successful" and "lesser successful" cyclists on different types of mountain ascents.

Therefore, the purpose of this study was to illustrate direct power output in relation to cadence of professional cyclists during high mountain ascents of the Tour de France using direct power output measurements.

Methods

Subjects

The participating cyclists (n = 10) were members of professional cycling teams and perform a total training and competition workload ranging from 30 000 to 35 000 km per year. Their mean (± SD) age, height and body mass were 30 ± 4 years, 178 ± 8 cm and 69 ± 6 kg, respectively. The weight of the bikes used, including 2 water bottles (500 ml) and bottlecages, was approximately 7.4 – 8.2 kg. To calculate the relative power output the bicycle mass has not been taken into account. The athletes gave their written informed consent to participate in the study, which was approved by the scientific committee of our de-

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Correspondence
Dr. Stefan Vogt, MD
Department of Preventive and Rehabilitative Sports Medicine
University of Freiburg
Hugstetter Strasse 55
79106 Freiburg
Germany
Phone: + 49 76 12 70 74 55
Fax: + 49 76 12 70 74 70
stefan.vogt@uniklinik-freiburg.de

partment. The studied riders were not contending for a high overall ranking (40 – 150 on General Classification; 40 – 120th place for most stages) but represented a broad range of skills from mountain specialists (required to perform maximally in mountain stages) to team domestiques (required to work for the team in the majority of stages, but usually not required to perform maximally in mountain stages).

SRM measurements

A total of 108 recordings of mountain ascents of 10 professional cyclists at the 2005 Tour de France were specifically selected. Recordings of ascents, where the riders were within 9 % of the stage winning time on that day, were referred to as "climber" files (n = 47) and were required to perform maximally during the ascents. Recordings of riders over 9 % to the winning time were marked as "helpers" (n = 61). The helpers usually work for the team in the majority of the stages, but do not have to perform maximally during the ascents.

The terminology of the mountain categories used by the race organizers was adopted. Mountain ascents were classified based on the following criteria: the climbs are divided into categories from 1 (most difficult) to 4 (least difficult) based on their difficulty, measured as a function of their gradient and altitude difference. A fifth category, called *Hors Category* (outside category), is represented by mountains even more difficult than those of the 1st Category (1st). Climbs of the 1st Category had a difference in altitude of at least 600 m, with an average gradient of > 6.5 % or with an altitude difference > 800 m. HC climbs had at least an altitude difference of 1500 m or an average gradient of > 7.5 % at an altitude difference of > 850 m. For the purpose of the study, only mountain ascents of the 1st and HC were selected representing the most famous mountain passes of the Alps (e.g., Col de la Madeleine, Col du Telegraphe, Col du Galibier) and the Pyrenees (e.g., Col d'Aubisque, Col de Peyresourde).

The recordings of these 10 riders were analyzed using a mobile power measurement device (SRM road version Professional, SRM Training Systems, Schoberer Rad Messtechnik, Jülich, Germany). The accuracy of these systems has been tested and validated [9] and used in many other scientific studies [6, 20, 30, 31]. The SRM system registers continuously power output (W) and cadence (rpm). The SRM system is a crank-based device that measures the mechanical power output to the bike through multiplication of the torque applied to the cranks and the speed at which they turn. The crankset experiences a tiny deformation when torque is applied. The SRM system measures this deformation using strain gauges attached to components inside the crank. The system weighs 300 grams, comparable to a conventional bicycle crank and should thereby not influence performance. The sample frequency was in intervals of 2, 3 and 4 seconds. Due to technical reasons (e.g., bike change within the stage or sensor contact problems), not all ascents could be recorded. Most of the 108 ascents were recorded in the 2- and 3-second recording interval (31 and 63 recordings, respectively) of the SRM system. The end of the ascent was identified through changes in speed, cadence and power output in the SRM file. According to the topographical information (length of the climb) of the race organizers, the beginning of the ascents could be determined from that point on.

The measured torque and cadence values were digitized inside the crank and converted to a high frequency, pulse-width modulated electrical signal. The data were transmitted to a registration unit on the handlebar of the bicycle, where the torque was averaged over each complete pedal revolution and multiplied by the cadence to calculate the power output.

The slope for each SRM crank powermeter was calculated dynamically at the SRM laboratory. Because of a possible drift of the zero offset frequency, the device was zeroed daily by one of the investigators prior to each stage. After each stage, the data was transmitted from the registration unit to a personal computer for further processing.

Methodical limitations

It is well known that despite calibration, SRM cranks might show a variation larger than 2.5 % during prolonged use. As no standardized static or dynamic calibration was performed prior to the investigated race, it cannot be excluded that this issue might influence the present data set. However, Gardner et al. [9] demonstrated that once adjusted, the calibration of SRM cranks is stable throughout an 11-month racing season. The SRM systems used in this study underwent calibration by the manufacturer before regular use during racing. Furthermore, a potential drift in zero offset during the race through, e.g., temperature changes or different altitudes can occur and might have influenced the data as well, as zero offset was checked before, but not after the race. It can be speculated that a potential zero offset drift would occur in both directions, causing in some cases false higher or lower power readings. In average, these errors would contribute to a slightly larger variability in the data, but probably not significantly influence the averages displayed in this study. Nevertheless, these methodical limitations have to be considered when interpreting the data.

Race characteristics

The study took place during the "2005 Tour de France", an international stage race for elite cyclists. This 21-day stage race covered 3698 km in 18 mass start stages (7 flat stages, 5 semi-mountainous stages, 6 mountain stages), 2 individual time trials and one team time trial. The overall winner covered this distance in 86 h 15 min at an average speed of 41.65 km/h.

During the mountain stages (stages 9, 10, 11, 14, 15, 16), the riders had to overcome 10 climbs of the 1st and 5 climbs of the HC.

Race data analyses

The PC stored competition data were processed with the software provided with the SRM System. Raw data analysis was conducted using a specially designed software program (JMP software; SAS Institute, Cary, NC, USA) to determine overall averages for power output, cadence and speed during the different mountain categories. As described by Ebert et al. [6], maximal mean power (MMP) for time periods of 15, 30, 60, 120, 180, 240, 300 and 1800 seconds were determined during each entire ascent for each rider. After combining all files for a given type of category, the averages of all MMPs were calculated.

For further analysis of the mean cadence at different power outputs, power output data were grouped into packages of 50 W. In addition, the distance per pedaling cycle in meter per crank revolution (m/cr) was calculated through the recorded speed and cadence measurements.

In order to reflect the real athletes' choice of cadence, the non-pedaling time was excluded when calculating the mean cadences during different ascents.

Table 1 Topographic characteristics of the ascents

	n	Mean length (km)	Mean gradient (%)	Mean altitude difference (m)
1st Category	10	14.3 ± 6.0	6.9 ± 0.9	951 ± 306
Hors Category	5	17.8 ± 4.7*	7.2 ± 0.8*	1245 ± 203*

Mean ± SD; * significant difference from 1st Category (p < 0.01); n = number of climbs

Statistical analysis

Descriptive statistics were used and all data were expressed as mean ± standard deviation (SD) unless otherwise specified. A Kolmogorov-Smirnov-Lillifors test was applied to ensure a Gaussian distribution of all results. Significant differences between the mean values of power output, cadence and speed during the different mountain categories were determined using 2-way ANOVA (type of cyclist [climber, helper]; type of ascent [1st, HC]) followed by the Tukey-Kramer HSD (honestly significant difference) test, which protects the significance tests of all combinations of pairs. One-way ANOVA followed by Tukey-Kramer HSD test was used to determine significant differences between the mean power output and pedaling rate at different ascents. Statistical significance was set at a p value < 0.01 unless otherwise specified.

Results

The topographic characteristics of the 1st and HC climbs are displayed in **Table 1**. HC ascents were significantly longer and steeper and had a significantly greater mean altitude difference. **Table 2** presents the average power output, cadence and speed of "climbers" and "helpers" during the different hill climbs. At the 1st and HC ascents, the climbers produced a significantly higher power output with a higher cadence compared to the helpers. On the other hand, intragroup analysis of climbers and helpers did not reveal significant differences in power output, cadence and speed between 1st and HC climbs.

Table 3 shows the physical efforts over different periods of time the riders have to endure during the ascents. No significant differences exist between the 1st and HC climbs concerning the average MMP. **Table 4** presents the average power output, cadence, duration and the topographic characteristics for each climb. The table shows a daily decline of power output in the consecutive climbs of each mountain stage. During the subsequent mountain stages 9 to 11 and 14 to 16, no significant changes in power output and cadence could be observed.

Fig. 1 shows the distribution of the mean pedaling rate and the power output during the climbs. High power outputs are mainly maintained with significantly higher pedaling cadences. Furthermore, **Fig. 2** displays the relation between the mean distance per pedaling cycle and the power output. A significant and continuous increase in the mean distance per pedaling cycle could be observed at a power output higher than 200 W. At lower power output (below 200 W), the distance per pedaling cycle was higher than at a power output above 200 W.

Fig. 3 shows exemplarily the mean relative power outputs of climbers compared to helpers on the 22-km ascent to Courchevel. During the entire ascent, the climbers sustain a higher relative power output than the helpers.

Table 2 Average power output, cadence and speed at the different mountain categories of climbers (within 9% of winning time) and helpers (> 9% of winning time)

			1st Category	Hors Category
Climbers	power output	(W)	321 ± 87* [229 – 422]	311 ± 65 [244 – 391]
	rel. power output	(W/kg)	4.7 ± 1.1* [3.5 – 6.1]	4.5 ± 0.9 [3.5 – 5.9]
	cadence	(rpm)	75 ± 10* [62 – 89]	71 ± 10 [60 – 84]
	speed	(km/h)	20.1 ± 4.2 [15.0 – 28.1]	18.0 ± 5.4 [12.8 – 24.8]
	duration	(h:m:s)	0:38:17 ± 0:16:26*	0:55:26 ± 0:05:37
Helpers	power output	(W)	292 ± 75* [221 – 382]	287 ± 77 [210 – 374]
	rel. power output	(W/kg)	4.1 ± 1.1 [3.1 – 5.4]	4.1 ± 1.2 [3.0 – 5.4]
	cadence	(rpm)	71 ± 9* [60 – 83]	69 ± 10 [58 – 83]
	speed	(km/h)	17.7 ± 5.0* [12.9 – 22.9]	16.2 ± 5.2 [12.2 – 21.8]
	duration	(h:m:s)	0:39:33 ± 0:16:20*	0:59:26 ± 0:13:05

Mean ± SD and range [minimum – maximum]; * significant difference from climbs of the Hors Category (p < 0.01)

Discussion

The purpose of the present study was to determine the direct power output and to describe the relationship between power output and cadence during decisive uphill segments of the Tour de France. Previous reports investigated the exercise intensity during uphill cycling in professional cyclists via telemetered HR recordings [15,26]. By using this parameter, physical performance can be estimated. The most accurate description of performance in cycling is the mechanical power output that is produced by the cyclist to propel the bike [5]. This parameter can be measured directly and precisely on the bicycle using a mobile SRM crank powermeter [9]. Gardner et al. [9] assessed a mean accuracy of the SRM system of 2.3% and determined stable results during an 11-month racing season (– 0.8 ± 1.7%).

Our study is the first extensive analysis of a large sample of 1st and HC ascents of the Tour de France (n = 108) involving world-class cyclists using direct power output measurement.

The climbs of the 1st and Hors Category represent uphill cycling periods of 20 – 80 min at high submaximal intensities [14,23] where the cyclist must mainly overcome the force of gravity [28].

In the current study, the cyclists produced a significantly higher mean power output (312 ± 43 W [4.5 ± 0.6 W/kg] vs. 294 ± 36 W [4.3 ± 0.6 W/kg]) at significantly higher cadences (73 ± 6 rpm vs. 70 ± 6 rpm) during the 1st Category climbs compared to HC climbs. This might be due to the fact that the 1st Category climbs had a lesser severity of slopes and a shorter duration of ascents, where the cyclists can likely use higher gears.

Table 3 Average maximal mean power (MMP) for 15, 30, 60, 120, 180, 240, 300 and 1800 seconds during the different mountain ascents (in W)

		MMP 15	MMP 30	MMP 60	MMP 120	MMP 180	MMP 240	MMP 300	MMP 1800
1st Category	(W)	598	492	453	431	420	411	404	327
	(W)	[482 – 751]	[387 – 549]	[363 – 527]	[340 – 506]	[330 – 489]	[329 – 475]	[324 – 464]	[272 – 427]
	(W/kg)	9.2	7.3	6.5	6.3	6.2	6.0	5.9	4.8
	(W/kg)	[6.7 – 11.7]	[5.8 – 8.4]	[5.5 – 7.6]	[4.9 – 7.3]	[4.8 – 7.2]	[4.8 – 7.1]	[4.7 – 7.0]	[4.2 – 5.5]
Hors Category	(W)	556	495	450	423	405	396	389	346
	(W)	[440 – 683]	[397 – 605]	[346 – 550]	[340 – 501]	[338 – 488]	[337 – 467]	[336 – 455]	[307 – 400]
	(W/kg)	8.4	7.4	6.7	6.2	6.0	5.9	5.8	5.0
	(W/kg)	[6.6 – 10.7]	[6.0 – 8.9]	[5.7 – 8.2]	[4.9 – 7.6]	[4.8 – 7.5]	[4.8 – 7.3]	[4.7 – 7.2]	[4.3 – 6.0]

Mean and range [minimum – maximum]

Table 4 Mean power output, cadence, length, gradient, altitude difference and duration of the high mountain ascents

Stage	Mountain	Cat.	n	Mean power output (W)	Mean rel. power output (W/kg)	Mean cadence (rpm)	Length (km)	Gradient (%)	Altitude difference (m)	Duration (h : m : s)
9	Ballon d'Alsace	1	7	355 ± 48	5.2 ± 0.7	79 ± 5	9.1	6.8	619	24 : 03 ± 2 : 47
10	Roselend	1	8	331 ± 52	4.7 ± 0.6	78 ± 6	20.1	6.0	1206	56 : 05 ± 5 : 35
10	Courchevel	1	8	283 ± 32*	4.0 ± 0.3*	71 ± 3*	22.2	6.2	1376	1 : 11 : 29 ± 5 : 23
11	Madeleine	HC	6	328 ± 27	4.7 ± 0.5	76 ± 4	25.4	6.1	1550	1 : 11 : 03 ± 3 : 27
11	Telegraphe	1	6	282 ± 25*	4.0 ± 0.4*	71 ± 4*	12.0	6.7	804	43 : 18 ± 1 : 20
11	Galibier	HC	6	267 ± 20*	3.8 ± 0.4*	67 ± 2*	17.5	6.9	1208	1 : 03 : 29 ± 2 : 36
14	Port de Palíheres	HC	8	279 ± 25	4.1 ± 0.4	66 ± 4	15.1	8.1	1223	1 : 01 : 52 ± 4 : 22
14	Ax-3-Domaines	1	8	282 ± 19	4.1 ± 0.3	66 ± 3	7.9	8.3	656	31 : 18 ± 1 : 32
15	Col de Mente	1	8	335 ± 17	4.9 ± 0.4	75 ± 3	7.0	8.6	602	22 : 30 ± 1 : 32
15	Col de Portillon	1	8	337 ± 29	4.9 ± 0.5	79 ± 4*	8.4	7.3	613	23 : 24 ± 1 : 45
15	Col de Peyresourde	1	7	281 ± 19	4.1 ± 0.3	69 ± 2*	13.0	7.0	910	45 : 59 ± 0 : 55
15	Col de Val-Louron-Azet	1	6	274 ± 17*	4.0 ± 0.3*	67 ± 1*	7.4	8.3	614	29 : 51 ± 0 : 42
15	Saint-Lary-Soulan	HC	6	276 ± 21	4.0 ± 0.3	64 ± 1*	10.3	8.3	855	41 : 20 ± 2 : 21
16	Col de la Marie-Blanque	1	8	363 ± 35	5.3 ± 0.5	74 ± 2	9.3	7.7	716	27 : 41 ± 2 : 02
16	Col d'Aubisque	HC	8	333 ± 35*	4.8 ± 0.4*	75 ± 3*	16.5	7.0	1155	51 : 20 ± 3 : 09

Mean ± SD and range; Cat. 1: 1st Category; HC: Hors Category; n = number of riders per climb (total n = 108). * significant difference from the previous ascent on that stage ($p < 0.05$)

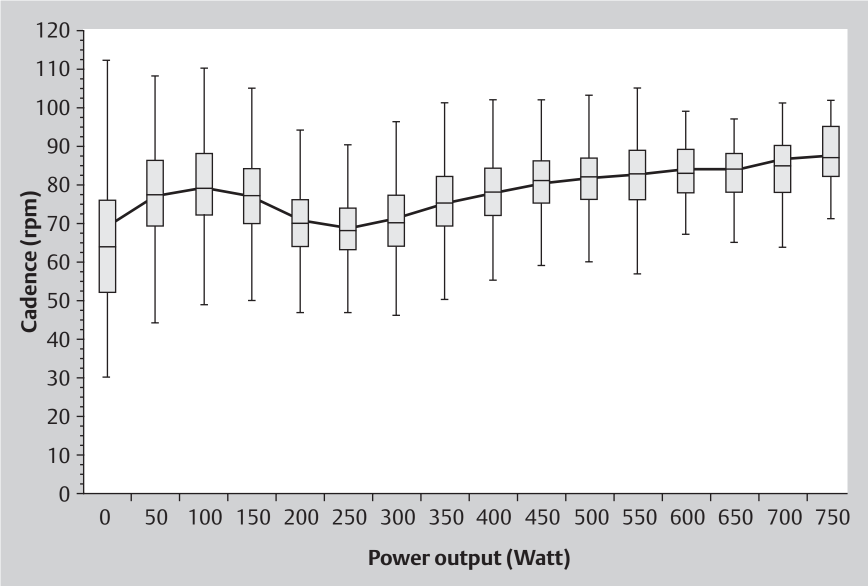

Fig. 1 Plot of cadence vs. power output. Box plots with SD and connected means (solid line). The box plot illustrates the mean, the 25% and 75% quartiles and the range within + and – 1.5 × the interquartile range (whiskers) of the cadence at the related power output. The subsequent values from 0 – 550 W are significantly different from each other ($p < 0.01$).

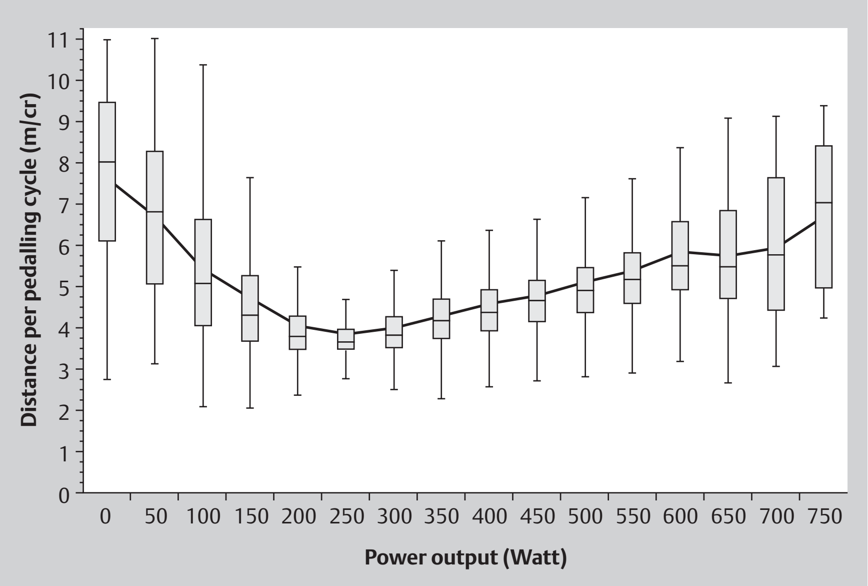

Fig. 2 Plot of the distance per pedaling cycle vs. power output. Box plots with SD and connected means (solid line). The box plot illustrates the mean, the 25 % and 75 % quartiles and the range within + and – 1.5 × the interquartile range (whiskers) of the propulsion at the related power output. The subsequent values from 0 – 600 W are significantly different from each other (p < 0.01).

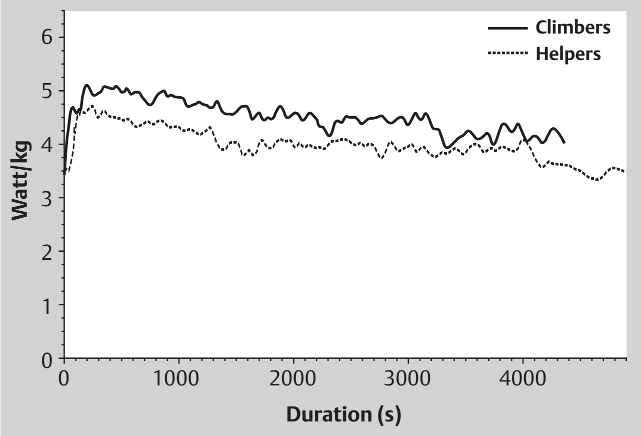

Fig. 3 Mean relative power output of climbers and helpers at the ascent to Courchevel. Climbers: solid line; helpers: dashed line.

Rodriguez-Marroyo et al. [26] estimated the mean power output of mountain ascents during the Vuelta a Espagna through the multiplication of body mass, gravity acceleration and vertical velocity and calculated a notable lower mean power output for the climbs of the 1st and HC (251 ± 10 W and 215 ± 7 W, respectively) in comparison to our directly measured results. Although the topographic characteristics of the climbs and the velocity of the cyclists were comparable between the two studies, the data give reason to assume that the calculation of power output by body mass, gravity acceleration and vertical velocity might be imprecise. The power output might be underestimated when using this method because factors like, e.g., wind velocity, rolling resistance and chain friction were disregarded.

In a former study of our workgroup [30], the power output during an uphill time trial of a professional stage race was examined. There, the directly measured power output was higher than during the mountain ascents in the present study (392 ± 60 W [5.5 ± 0.4 W/kg]). This can be explained by the fact that in the present study the mountain ascents were approached within mass-start stages with a mean length of 193 km and were therefore longer than the above-mentioned 13 km-uphill time trial.

Analysis of power output and cadence shows that climbers produced a significantly higher mean power output at a higher pedaling rate than helpers (▶ **Table 2**). ▶ **Fig. 3** shows exemplarily the mean relative power outputs of climbers compared to helpers on the 22-km ascent to Courchevel. In the course of the 2005 Tour de France, this stage was the first mountain stage with a high altitude arrival in Courchevel. During the entire ascent, climbers sustain a higher relative power output than helpers. This could be explained by the particular physiological and performance characteristics of top-level climbers as described by Lucia et al. [16]. In laboratory tests, they determined for climbers a higher maximal oxygen consumption normalized by body mass and a greater buffer capacity compared to riders who perform better in flat time trials. These facts might explain the actual cycling performance of the climbers: they are known for their ability to rapidly switch from an already demanding pace to higher speeds during mountain stages. Such interval type of exercise likely demands a great adaptation on anaerobic and buffer systems. Probably to avoid breakaways, the power output in ▶ **Fig. 3** was higher in the first approximately 10 minutes of the ascent than at the end. It can be assumed that cyclists contending for a successful final placing have to yield power outputs higher than 6.0 W/kg over longer periods when climbing and even tolerate repeated bouts of high intensity efforts in the final section of the ascent.

In addition to the mean power output data, the performance profile of the cyclists during the ascents was determined (▶ **Table 3**). These data demonstrate the considerable physical efforts the cyclists have to sustain during the 1st and HC climbs. Compared to the MMPs during flat stages at the same Tour de France [32], the MMPs for shorter durations (15 s) were higher during the flat stages (895 W vs. 556 W) while the MMPs for longer durations (1800 s) were comparable (342 W vs. 346 W). This shows that the ascents were cycled with a constantly high submaximal power output for extended periods of time without maximal power output bursts over short time periods (15 s).

Though not unexpected, another interesting finding of the study was the significant decline of the mean climbing power output and cadence on consecutive climbs at mountain stages 10, 11, 15 and 16 (**Table 4**). This can be interpreted as a sign of fatigue because the riders cannot hold up the power output. Otherwise, as the studied cyclists were team helpers and none of them were contending for a high overall finish, it has to be considered that they have accomplished their duties for their team on the early climbs and may reduce their speed voluntarily. Then, the remaining stage is cycled at moderate power output to save energy for the next day. As no significant changes in power output and cadence could be observed during the subsequent mountain stages 9 to 11 and 14 to 16, this could support the concept that the riders tried to cycle economically to avoid physical fatigue.

A publication of Tour de France data [32] showed significantly lower total pedaling rates during mountain stages compared to flat stages (81 ± 15 rpm vs. 87 ± 14 rpm). In the present study, cyclists obtain a mean pedaling rate of 73 ± 6 rpm during the 1st Category climbs and 70 ± 6 rpm during the HC climbs. These findings agree with other field studies of highly trained cyclists [15,23] where the cyclists also spontaneously adopt cadences of 80 – 100 rpm in flat stages and lower cadences during climbs (around 70 rpm).

As the several long climbs belong to the exhausting elements of a race, cyclists try to perform as efficiently as possible, that is, to produce a high power output at an energy cost as low as possible. Laboratory studies [2,4,17,18,22,25] showed that during a constant-power ergometer test, pedaling at low rates (50 – 60 rpm) results in a lower oxygen uptake, blood lactate concentration, ventilation, HR and lower rates of perceived exertion than pedaling at 90 – 100 rpm.

Other studies [2,4,8] reported an increase in the most economical cadence from 50 to 80 rpm as power output increased from 100 to 300 W. However, these laboratory studies describing the cadence-power output relationship were conducted on non-cyclists or amateur cyclists with lower workloads than during decisive phases of a race. A transformation of these findings into professional cycling is difficult, as our studied elite cyclists have to sustain higher workloads over longer periods of time than the amateur individuals (see **Table 3**).

Fig. 1 demonstrates the relationship between the pedaling rate and the power output during 1st and Hors Category climbs. The figure shows that higher power outputs were predominantly achieved through higher pedaling rates. The mean pedaling rate increased significantly with workload (from 69 rpm at 250 W to 83 rpm at 550 W). This increase in cadence and workload is comparable to the findings of the laboratory studies of amateur cyclists [2,4,8] but at higher power output levels.

Reasons for this voluntary increase of pedaling rate may be an improvement of hemodynamics by an improved skeletal muscle pump and an increased muscle blood flow and venous return when pedaling at higher rates [10]. Takaishi et al. [29] reported that cyclists undergo, especially at high power outputs, a marked occlusion in their micro-vessels of the knee extensors during the down-stroke phase of the crank cycle. Therefore, higher cadences may also be selected to minimize the local intramuscular pressure because the time of muscle contraction is shorter when spinning quickly [21].

Another interesting finding is that higher power outputs are not only achieved through higher cadences but also by using higher gears as shown by the significant increase of the mean distance per pedaling cycle from 250 W up to 600 W (**Fig. 2**). Interestingly, the distance per pedaling cycle below 250 W is greater than in the section from 250 to 700 W. In the low-power section, the riders cycled with a higher gear and thus greater distance per pedal revolution.

Conclusions

Our study presents analyses of a large sample of mountain ascents of the 1st and Hors Category at the 2005 Tour de France (n = 108) involving world-class cyclists using a mobile crank powermeter (SRM system). The results provide the first insight into the power output requirements and the cadence-power output relationship during these decisive segments of a multistage race and demonstrate the considerable physical efforts the cyclists have to accomplish during the ascents. Over a period of at least 30 minutes, they have to sustain a mean direct power output of 350 – 400 W during the ascents. According to their team duties, the mountain specialists produce an even higher relative power output than the team helpers. The cadence-power output relationship shows that high power outputs are mainly accomplished by both significantly higher pedaling rates and higher gears.

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