Physical Demands of Sprinting in Professional Road Cycling

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Key words
- physiology
- exercise
- physical fitness
- athletic performance
- maximal
- elite

Abstract

The aim of this study was to quantify the demands of road competitions ending with sprints in male professional cycling. 17 races finished with top-5 results from 6 male road professional cyclists (age, 27.0 ± 3.8 years; height, 1.76 ± 0.03 m; weight, 71.7 ± 1.1 kg) were analysed. SRM power meters were used to monitor power output, cadence and speed. Data were averaged over the entire race, different durations prior to the sprint (60, 10, 5 and 1 min) and during the actual sprint. Variations in power during the final 10 min of the race were quantified using exposure variation analysis. This observational study was conducted in the field to maximize the ecological validity of the results. Power, cadence and speed were statistically different between various phases of the race ($p < 0.001$), increasing from 316 ± 43 W, 95 ± 4 rpm and 50.5 ± 3.3 $km \cdot h^{-1}$ in the last 10 min, to 487 ± 58 W, 102 ± 6 rpm and 55.4 ± 4.7 $km \cdot h^{-1}$ in the last min prior to the sprint. Peak power during the sprint was 17.4 ± 1.7 $W \cdot kg^{-1}$. Exposure variation analysis revealed a significantly greater number of short-duration high-intensity efforts in the final 5 min of the race, compared with the penultimate 5 min ($p = 0.010$). These findings quantify the power output requirements associated with high-level sprinting in men's professional road cycling and highlight the need for both aerobic and anaerobic fitness.

Introduction

Sprints are a key feature in road cycling with approximately one third of grand tour stages (i.e., Tour de France, Giro d'Italia, and Vuelta a España) being specifically designed for sprinters [6,10]. Furthermore, several prestigious one-day races typically end with a bunch sprint. Sprints are described as the acceleration which occurs toward the end of competitions in order to reach the finish line in front of other competitors. Despite the high number of sprint finishes in road cycling and their importance for the competitions' results, the number of sprint specialists is limited [10,14]. In fact, typically there are only 1 or 2 specialised sprinters per cycling team. Padilla and colleagues described the characteristics of the different cycling specialists [14] however, despite listing 5 different categories (i.e., uphill riders, flat terrain riders, all terrain riders, time trial specialists and sprinters), their study only examined 4 categories as there were no sprinters specialists in their sample. In a similar study Sallet and colleagues analysed a sample of 71 cyclists belonging to different specialty groups, but only 4 cyclists were sprinters [18]. The limited number of sprinters considerably reduces the possibility to study this relevant aspect of cycling. As a direct consequence, research related to specialised professional road sprinters is extremely limited. Likewise, the current literature describing the demands of competitions ending with a sprint is limited to only 2 studies presenting data from single cyclists [8,12].

The majority of research that has examined the physiological characteristics and demands of road cycling competitions has focused on uphill and time trial performances [7,13,14]. Of these studies, performance has largely been explored and quantified by reporting data averaged over entire stages or large sections of a race [17,21,22]. A contemporary modelling approach used to evaluate the stochastic nature of physical activities is exposure variation analysis (EVA) [20]. This method of analysis has been used to describe variation in power output during cycling in a variety of cycling events [2] and under various environmental conditions [16]. EVA may be useful to provide insights into the demands of road sprinting whereby power output continually

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changes prior to the final sprint due to several technical and tactical factors. Indeed, the lead-up to the sprint (i.e., the final 10 min prior to the sprint) could be considered the most crucial part of sprint competitions. In this phase the race intensity may dramatically increase while cyclists attempt to find the best position within the peloton [9,12]. During the lead-up phase, team support is considered an important factor because it enables efficient positioning in the bunch [10], possibly also decreasing both the intensity and number of efforts ridden prior to the sprint finish. However, to the best of our knowledge, there are no studies describing the variability in power output in the final part of male professional road races. An important aspect that is likely to influence the variability in power output during cycling as well as the ability of a cyclist to reach the finish line with the majority of competitors is the change in elevation throughout the race. Indeed, total elevation gain (TEG) throughout a race is believed to be an important variable relevant to road cycling sprint performances [10]. However this research is limited to a case study on single cyclist and thus the importance of elevation gain on sprint cycling is currently not clear. Therefore, the aim of this study was to describe the physical characteristics (e.g., power, speed, TEG, power output variability) of male professional road races ending with a sprint, with particular focus on the lead-up phase and the final sprint.

Materials & Methods

Race data from 6 male professional road sprint cyclists (age, 27.0 ± 3.8 years; height, 1.76 ± 0.03 m; weight, 71.7 ± 1.1 kg) were collected during 2 entire cycling seasons. Cyclists were classified as sprinters when their best performances were achieved in relatively flat competitions finishing at high speed and against a relatively large number of competitors [10]. As a selection criterion, only races in which the participants finished in the top 5 were included in this study. At the time of the study, all participants were specialised sprinters, competing for a UCI WorldTour professional team. During the 2 monitored cycling seasons, 17 competitions finishing with a bunch sprint met the selection criteria. The analysed races consisted of 4 first, 4 s, 4 third, 4 fourth and 1 fifth places. The analysed sprints were performed in World Tour (n = 7), Hors Category (n = 6) and Category 1 (n = 4) competitions. This research was conducted ethically according to international standards and as required by the International Journal of Sports Medicine [5]. The participants provided written informed consent to participate in this study, which was approved by Edith Cowan University's Human Research Ethics Committee, in the spirit of the Helsinki Declaration.

Power output, cadence, speed and TEG (i.e., sum of every gain in elevation, or vertical distance) were recorded at 1 Hz using SRM PowerMeters mounted on the participants' bikes (PC7, SRM Training System, Jülich, Germany). The "automatic zero" setting was selected on the SRM PC7 according to the manufacturer recommendation. The SRM calculates TEG based on barometric altimeters. The accuracy and consistency of power and elevation gain data recorded with SRM devices have been previously reported [1,11]. Race files were uploaded online with the web-based service TrainingPeaks, then downloaded and analysed using WKO + 3.0 software (Peaksware LLC, Lafayette, CO, USA) or Microsoft Excel (EVA; described below). Power output (W and $W \cdot kg^{-1}$), cadence, speed and total elevation gain (TEG) were averaged over the entire race. Furthermore, in order to gain an understanding of the lead-up phase and overall sprint performance, data were also analyzed in the 60, 10, 5 and 1 min prior to the sprint. The sprint was defined using the SRM data and measured as the continuous time elapsed between the rapid increase in power output (i.e., beginning of the sprint) and the immediate drop of power (i.e., end of the sprint) [12]. The duration and the speed of the sprint were also measured from the SRM race files.

EVA was used to provide a detailed analysis of the variations in power output during the penultimate and final 5 min of the race. EVA is a contemporary modelling approach used to evaluate the stochastic nature of road cycling and it has been previously utilized in road cycling to describe the total time and the "acute" time spent at different intensities [2]. The total time was defined as the overall time spent in a predetermined intensity zone, while the "acute" time referred to the duration for which power output was continuously within a zone. Due to the fact that the aim of the study was to describe road sprint finishes and the physical demands of competitions, not the subjective intensity for the participants to this investigation, the intensity zones were arbitrarily determined and defined as power to body mass ratio ($W \cdot kg^{-1}$) instead of being related to individual intensities (e.g., anaerobic threshold). Increments of 3.33 $W \cdot kg^{-1}$ were used to define intensity zones, resulting in a total of 5 zones (▶ **Fig. 1**). Finally, to correspond to previous research, the length of time of the acute bands was split into the following zones: from 0 to 1.875, 1.875–3.75, 3.75–7.5, 7.5–15 and > 15 s [2,15]. EVA results are expressed as a tri-dimensional distribution. The standard deviation of the EVA matrix was determined to provide an indication of variability in power output [2,16].

Results are presented as average ± standard deviation (range). Dependent variables (power, cadence, speed, TEG) were compared between different competition phases (race, 60, 10, 5 and 1 min prior to the sprint) using a one-way analysis of variance (ANOVA). The standard deviations of the average EVA matrix were calculated and compared using a paired T-test (penultimate 5 min vs. last 5 min) in order to evaluate the variation in power output in the final part of the race before the sprint. A greater standard deviation indicates higher variability with intensity. The time spent at high-intensity (> 6.6 $W \cdot kg^{-1}$) for short period of time (< 3.8 s) was also compared using a paired T-test. Significance was set at $p \leq 0.05$.

Results

Power output, cadence, speed and TEG over the entire race and in the final 60 min are summarized in ▶ **Table 1**. Power, cadence, speed and TEG were statistically different among different race phases ($p < 0.001$).

▶ **Fig. 1** shows the average EVA plots, ▶ **Fig. 1a** represents the penultimate 5 min while ▶ **Fig. 1b** represents the last 5 min before the final sprint. The EVA SD was not statistically different between the penultimate 5 min and last 5 min of competitions (15.3 and 13.6, respectively). The time spent at high-intensity (> 6.6 $W \cdot kg^{-1}$) for short period of time (< 3.8 s) was different between the penultimate and last 5 min, with 36 ± 17 (11–70) and 70 ± 14 (41–88) s, respectively ($p = 0.010$) (▶ **Fig. 1**, black bars).

Average and peak values recorded during the sprints are reported in ▶ **Table 2**. Sprint duration was 13.2 ± 2.3 s (9.0–17.0 s).

Discussion

The aim of this study was to examine the characteristics of the sprint finish in professional road cycling competitions, thus describing the physical demands of successful road sprints. The main findings of this study were: i) when the cyclists approached the finish line, the intensity gradually increased, with an average power output of 487 W and cadence of 102 rpm in the last minute prior to the sprint; ii) the last 10 min of racing was stochastic in nature with about twice as many short, high-intensity efforts in the last 5 min when compared with the penultimate 5 min and; iii) during the final sprint the peak power was 17.4 W · kg^{-1}, with a peak cadence of 114 rpm and a peak speed of 66 km · h^{-1}.

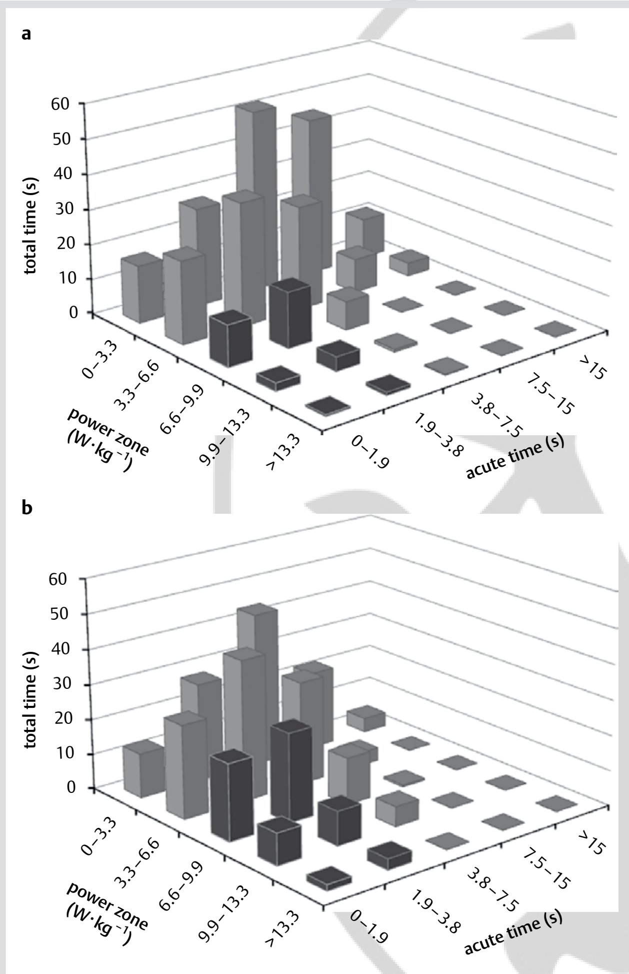

Fig. 1 Exposure variation analysis of the penultimate 5 min **a**, and last 5 min **b** of competition prior to the sprint. Black columns represent the time spent in short-duration and high-intensity efforts (i. e., > 6.6 W · kg^{-1} and < 3.8 s).

Within the present study the race intensity was approx. 15 % higher in the last 60 min of the race when compared with the intensity over the entire race. The intensity continued to increase reaching a power output in the final 10 min of race similar to the intensity previously reported in a pilot study examining professional road sprint competitions (316 and 332 W, respectively) [12]. Interestingly, the highest 5 min power to mass ratio observed in this study was 6.1 W · kg^{-1}, which is only 8 % lower than the estimated 6.6 W · kg^{-1} required for a 4 min (20 % shorter) world level team pursuit event (computed using the power output predicted by Broker et al. [3] and the world-record team's average body weight reported by Schumacher et al. [19]). These results highlight the high intensities at which professional road sprinters were required to ride in the final kilometers of races in order to be in contention for the sprint finish.

Associated with the very high power outputs and speeds observed in the final kilometres of the race is the variability in intensity, which is likely to be as relevant to sprint performance. Indeed, many important tactical and technical factors are likely to influence the variability in power output, including team support, position within the peloton, cornering and the need to rapidly accelerate. Furthermore, it has been previously shown that team support during the last minute of the lead-up to the sprint is an important factor in road sprint performance [10]. It was suggested that team support allows sprinters to be protected from the wind and sudden changes in speed, allowing them to conserve energies. However, it was not possible to verify it as power output was not monitored in the study [10]. Within the present study EVA was used to quantify the variability in power output in the final 10 min of the races. While examination of the entire EVA matrix did not highlight significant differences between the penultimate and final 5 min of the race, closer analysis indicated that twice as many high-intensity and short-duration efforts (i. e., > 6.6 W · kg^{-1} and < 3.8 s) were evident in the last 5 min, compared with the penultimate 5 min (**Fig. 1**, black bars). Unfortunately, it is unclear from the present study whether this increase in the variability of power output was associated with technical and tactical factors, such as a decrease in number of team-members supporting the sprinter, changes in the race profile (i. e., corners) or the slight increase in speed (50.5 km · h^{-1} to 52.1 km · h^{-1}). Regardless, these findings are important in understanding the physical demands of professional road sprinting and will potentially assist in selecting cyclists and developing training programs for athletes who specialise in sprinting.

Results of the present study indicate that the cyclists produce high power outputs during the sprint finish. The average and peak power observed during the sprint in the present study (1 020 W and 1 248 W, respectively) are similar to those previously published within case studies on professional sprinters recorded during road sprints (e. g., average, 926 and 1 120 W; peak 1 097 W and 1 370 W) [8, 12]. Furthermore, the peak power

Table 1 Characteristics of professional sprint races; mean ± SD (range).

	Entire Race	60 min before sprint	10 min before sprint	5 min before sprint	1 min before sprint
Power (W) [a]	200 ± 27 (155–256)	233 ± 33 (180–287)	316 ± 43 (231–424)	363 ± 38 (273–438)	487 ± 58 (409–593)
Cadence (rpm) [a]	87 ± 4 (80–91)	89 ± 4 (82–96)	95 ± 4 (84–104)	96 ± 5 (84–105)	102 ± 6 (91–113)
TEG (m) [a]	1 101 ± 725 (144–2 397)	218 ± 192 (0–581)	27 ± 37 (0–152)	15 ± 19 (0–59)	3 ± 6 (0–25)
Speed (km · h^{-1}) # [a]	41.0 ± 2.2 (37.1–45.4)	45.4 ± 2.9 (41.2–50.1)	50.5 ± 3.3 (46.1–56.4)	52.1 ± 4.1 (44.1–60.3)	55.4 ± 4.7 (45.7–61.9)

TEG: total elevation gain

[a] Significantly different among competition's phases ($p < 0.001$)

n = 15 races

Table 2 Characteristics of road sprints in professional competitions; mean ± SD (range).

	Whole sprint	Peak data
Power (W)	1 020 ± 77 (865–1 140)	1 248 ± 122 (989–1 443)
Power ($W \cdot kg^{-1}$)	14.2 ± 1.1 (12.2–15.8)	17.4 ± 1.7 (13.9–20.0)
Cadence (rpm)	110 ± 5 (100–117)	114 ± 5 (102–121)
Speed ($km \cdot h^{-1}$) #	63.9 ± 3.8 (53.7–69.1)	66.1 ± 3.4 (57.1–70.6)

n = 15 races

data recorded in this study were similar to the 1279 ± 74 W recorded in laboratory conditions in elite road sprinters [18]. Likewise, the peak speed observed in this study (66.1 $km \cdot h^{-1}$) is similar to the speed observed by Martin et al. (65 $km \cdot h^{-1}$) [8].

Despite the high power outputs observed here, the maximal sprint capacity of these athletes is considerably lower than that previously reported in track cycling sprinters (i.e., approx. 21 $W \cdot kg^{-1}$) [4]. However, the difference is reasonable given the vastly different characteristics of road and track sprint races. Indeed, prior to the sprint, road sprint cyclists are required to cycle for prolonged periods at moderate intensities. Within the present study, the average power output over the entire race was 2.8 $W \cdot kg^{-1}$, which is higher than that previously reported in flat races (2.0 ± 0.4 $W \cdot kg^{-1}$) [22], but slightly lower than the intensity reported in a different stage race (3.1 ± 0.2 $W \cdot kg^{-1}$) [21]. A major factor influencing the average power output throughout the stage is the total elevation change. A large range in the TEG was observed in the races analyzed in this study (i.e., 144–2397 m), with the average (i.e., 1 100 m) being considerably higher than that previously reported in a case study of an extremely successful professional sprinter (~600 m) [10]. Clearly, the climbing ability of different sprinters could be diverse and, as such, the elevation change throughout a race is likely to have considerable influences on sprint performance. It is noteworthy to consider that the distribution of the elevation gain along the race course is likely to be of great importance to the race outcomes. As a matter of fact, in this study no sprints occurred when the total elevation gain was higher than 2 400 m, or when the elevation gain was above 580 m in the last 60 min. Such data is important as it gives an indication of the climbing ability that could be required by sprinters in order to reach the finish line and be in contention to sprint. From a practical point of view, these data could contribute to highlight the importance of aerobic fitness (e.g., climbing ability) in road sprint cycling and could have significant influences on training prescription and/or the selection of sprinters for particular races.

Despite the small number of successful professional road sprinters [10] and the limited data published on this topic (i.e., 2 case studies) [8,12], a relatively high number of road sprints from high-level professional cyclists were examined in this investigation. The results of the present study indicate that the physical demands of road sprint cycling are unique. In fact, in order to be in contention for the sprint cyclists are required to ride for prolonged periods (approx. 4 h) at moderate intensities (2.8 $W \cdot kg^{-1}$) with varying elevation gain (up to 580 $m \cdot h^{-1}$ of vertical ascension rate in the 60 min prior to the sprint). The final 5 min of the race could be extremely demanding due to the combination of very high intensity and significant variability in power output. Indeed, the final 5 min of the race contained about twice as many short-duration, high-intensity efforts as the penultimate 5 min. Top 5 finishers observed in this study produced average power outputs of 14.2 $W \cdot kg^{-1}$ for 13 s during the sprints, reaching peak powers of 17.4 $W \cdot kg^{-1}$. It would be possible to speculate that a sprinter who produces such power output without top 5 race results should consider to improve his tactic (e.g., position in the bunch), instead of his sprint power. These data provide important information regarding the physical demands of professional road sprinting and thus may aid in the identification of talent, in training prescription, and in the selection of teams or athletes for specific road races.

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Conflict of interest: The authors have no conflict of interest to declare.

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