Power Output During a Professional Men’s Road-Cycling Tour

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Purpose: To quantify the power-output demands of men’s road-cycling stage racing using a direct measure of power output. Methods: Power-output data were collected from 207 races over 6 competition years on 31 Australian national male road cyclists. Subjects performed a maximal graded exercise test in the laboratory to determine maximum aerobic-power output, and bicycles were fitted with SRM power meters. Races were described as flat, hilly, or criterium, and linear mixed modeling was used to compare the races. Results: Criterium was the shortest race and displayed the highest mean power output (criterium 262 ± 30 v hilly 203 ± 32 v flat 188 ± 30 W), percentage total race time above 7.5 W/kg (criterium 15.5% ± 4.1% v hilly 3.8% ± 1.7% v flat 3.5% ± 1.4%) and SD in power output (criterium 250 v hilly 165 v flat 169 W). Approximately 67%, 80%, and 85% of total race time was spent below 5 W/kg for criterium, hilly and flat races, respectively. About 70, 40, and 20 sprints above maximum aerobic-power output occurred during criterium, hilly, and flat races, respectively, with most sprints being 6 to 10 s. Conclusions: These data extend previous research documenting the demands of men’s road cycling. Despite the relatively low mean power output, races were characterized by multiple high-intensity surges above maximum aerobic-power output. These data can be used to develop sport-specific interval-training programs that replicate the demands of competition.

Key Words: SRM power meter, terrain, criterium

It has been suggested that the most remarkable tests of human endurance are multiple-week cycling tours (stage races), notably the Tour de France, Giro d’Italia, and Vuelta a España. These races involve cycling 72 to 90 hours over 3 weeks, covering thousands of kilometers (Tour de France ≈4352 km and Vuelta a España ≈3358 km) with minimal recovery time between stages (≈18 hours) and only 1 to 2 days of complete rest.¹ There are also shorter tour races (6 to 8 days) such as the Tour of Switzerland and the Tour Down Under (Australia). Tours
involve individual and team time trials, circuit racing (criteriums), and road stages over varying terrain (i.e., flat and hilly). Each team has a designated leader, who is surrounded by domestiques and is required to maintain a high placing on general classification. Overall position in a tour is based on the accumulated finishing time of the highest-placed rider, and it is not uncommon to see the winner finish in front by only 200–400 seconds. As highlighted by Jeukendrup et al., this margin equates to only 0.07% to 0.13% of the total race time.

Research has been conducted to determine the demands of the major tours using heart rate (HR) as the measure of intensity and examining the time spent in designated HR zones that have been determined from a graded exercise test in the laboratory and have been shown to be stable throughout a competitive year. The use of HR as a measure of intensity can be affected, however, by “cardiac drift,” whereby HR shows a continued rise despite the maintenance of the same power output, possibly as a result of dehydration and elevated core temperature. Nikolopoulos et al. report differences in power output between repeated time trials (19°C, 45% to 55% relative humidity) but little difference in HR, suggesting that HR might not fully reflect muscle activity. There might also be a problem in assuming that the HR–power-output relationships determined using progressively increasing “steady-state” loads in the laboratory to predict power output also apply to the more stochastic exercise dynamics of road racing. This is because there is a lag between the responses of a cyclist’s HR to the power-output demands. It is therefore possible for the same average HRs to be recorded for a steady-state effort and one involving multiple short-duration intervals with short recovery periods.

Despite the popularity of road cycling and the large interest generated during the grand tours, very few data are available on the power-output requirements (measured with power meters) during a tour. The recent advance in power-output monitoring has allowed the physiological and biomechanical responses to training and competition to be measured or monitored with greater accuracy than previously, when only speed was available. Speed can be influenced by factors such as wind, course topography, and race dynamics and therefore might not provide an accurate representation of absolute intensity when compared with power output. The purpose of this study was to determine the power-output demands of stage racing, using power meters, in a large group of nationally ranked cyclists. We also compared the different types of stages in a tour, namely, flat and hilly road stages and circuit racing (also called criteriums).

**Methods**

Race data were collected during the 6-day Tour Down Under stage race (UCI category 2.HC) held in Adelaide, Australia, each January from 1999 to 2004. Six to eight Australian Institute of Sport under-23 road cyclists participated per tour, for a total of 207 monitored races. Before each tour, the cyclists were weighed using calibrated digital scales (AND UC 300 scales, A&D Co, Tokyo, Japan) and undertook a maximal graded exercise test in the laboratory to determine maximum aerobic-power output (MAP) and peak oxygen consumption (VO2peak). Subjects provided written informed consent to participate in the data collection.
Maximal Graded Exercise Test

This test was performed on an SRM ergometer (Schoberer Rad Messtechnik, Jülich, Germany) that had a flywheel and was equipped with masses to simulate actual in-field cycling conditions. The athletes commenced cycling at 100 W with a cadence of 96 rpm for ≈15 minutes. The power output was thereafter increased by 25 W/min until volitional exhaustion or the cadence dropped below 70 rpm. Oxygen consumption was measured using a customized gas-analysis system (South Australian Sports Institute, South Australia, Australia) consisting of an S-3A/I oxygen analyzer and CD-3A CO₂ analyzer (AEI Technologies, Pittsburgh, Pa). The analyzers were calibrated before and after each test using alpha-grade calibration gases (BOC Limited, Wetherill Park, NSW, Australia). The system incorporated a respiratory valve (Hans Rudolf 2700, Kansas City, Mo) attached to a unidirectional turbine volume transducer (PK Morgan, Chatham, Kent, UK). Oxygen consumption was measured every 30 seconds.

Race Data

All race data were collected using dynamically calibrated SRM power meters (SRM Training System, Schoberer Rad Messtechnik). The operation and calibration of this device have been described elsewhere. Before each race, each cyclist undertook a self-selected warm-up. The SRM power meter was then zeroed, and data were collected from the power meter every second. The data were downloaded using a serial-port cable and analyzed with commercially available software (SRM Training System, version 6.32.08, Schoberer Rad Messtechnik).

The road stages (stages 2, 3, 4, and 5) were described as either flat or hilly, with the latter races characterized by hill climbs of longer than 1 km and/or a hilltop finish. Stages 1 and 6 were criterium-style races involving laps around a 2- and 4.5-km course, respectively. The stage time was recorded, and the percentage back from the winning time was calculated. Races in which the rider finished within 2.5% of the winning time (n = 142 races) were used in the power-output analyses. All races (N = 207) were included for the determination of maximal mean power output (MMP), which was the highest mean power the cyclist held for the given time period (e.g., 5-second or 30-minute periods) during a race.

Data Analyses

The following variables were calculated using a specially designed computer program (AISCycle, version 2.5.45, Kinetic Performance Technology, Canberra, Australia) to outline the demands of competition: (1) distance covered and race time; (2) mean and peak power, power-to-mass ratio, speed, cadence, and HR; (3) percentage of total race time spent in power bands of 0 to 100, 101 to 300, 301 to 500, 501 to 700, and >700 W; (4) percentage of total race time spent in relative power bands of 0 to 1.9, 2.0 to 4.9, 5.0 to 7.9, and >8.0 W/kg; (5) time spent below 100 W and above 7.5 W/kg; (6) MMP (W and W/kg) for 5, 15, 30, 60, 120, 180, 240, 300, and 1800 seconds; (7) high-intensity-effort number and duration (mean power for sprint greater than MAP; durations were grouped together: <6, 6 to 10, 11 to 15, 16 to 20, 21 to 25, and 26 to 30 seconds); and (8) time spent in
different cadence bands (0, 0 to 60, 61 to 80, 81 to 100, and >100 rpm) for each 200-W band in power output.

Statistics

Linear mixed models,16 which allowed for the fact that some cyclists participated in multiple races, were used to compare differences in mean race characteristics (eg, power, cadence, speed); time spent in different power output bands; MMP for various time periods; the number of sprints for flat, hilly, and criterium; and finishing position. These models consist of random and fixed effects, allow for missing data and various collection time points, and deal with repeated measures.17 The cyclists were the random factor in these models because they each contributed a different number of races to the data set, and flat versus hilly versus criterium was the fixed factor. Models were fitted using the R Statistical Package Version 2.0.0,16 and statistical significance was set at \( P \leq 0.05 \). Unless otherwise specified, all data are expressed as mean ± SD.

Results

Thirty-one cyclists participated over 6 years of competition (mean ± SD; age 20.9 ± 0.4 years, body mass 69.8 ± 2.8 kg, height 177 ± 4 cm, VO\(_{\text{peak}}\) 74.0 ± 2.4 mL · kg\(^{-1}\) · min\(^{-1}\), MAP 455 ± 6 W). Table 1 outlines the general race characteristics for flat, hilly, and criterium racing. The main differences occurred between the criterium and the road stages (flat and hilly). A greater percentage of total race time was spent between 2.0 and 4.9 W/kg \( (P < .0001) \) and less time above 8 W/kg \( (P < .0001) \) for the road stages (flat and hilly) than for the criterium (Figure 1). When comparing the road stages, a higher mean power output was achieved for the hilly races than for the flat races (≈15 W or 0.2 W/kg, \( P < .001 \)) because of more time spent between 2.0 and 7.9 W/kg and less time below 2 W/kg \( (P = .0004) \).

The mean cadences for criterium and flat and hilly stages were 77, 67, and 71 rpm, respectively. There were significant differences between the 3 types of races for these cadences, which include the time that riders were not pedaling (ie, cadence = 0 rpm), with cadences for criterium > hilly > flat. To provide a better understanding of the cadence requirements of racing, a power–cadence profile was developed for each race type. Figure 2 accordingly highlights the large percentage of total race time for all race types spent between 80 and 100 rpm.

The number of sprints performed above MAP was determined for those who had completed the laboratory graded exercise test before the tour \( (n = 90 \text{ races}) \). Figure 3 depicts the number of sprints and duration for criterium, flat, and hilly races. There were more sprints under 30 seconds during criterium than during flat and hilly, with significantly more of the sprints during criterium being less than 10 seconds in duration. In all race types, most of the sprints were between 6 and 10 seconds.

The 207 races were analyzed to determine the MMPs for each style of racing, highlighting the mean but also the minimum and maximum (Figure 4). The MMP (W/kg) for time periods of ≤15 seconds were significantly lower \( (P < .05) \) for the road races (flat and hilly) than for the criterium, but they were higher for ≥60
Table 1  Characteristics (mean ± SD) of the Different Types of Stages in the Tour Down Under

<table>
<thead>
<tr>
<th></th>
<th>Criterium</th>
<th>Flat</th>
<th>Hilly</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>67</td>
<td>38</td>
<td>37</td>
</tr>
<tr>
<td>Distance (km)</td>
<td>68.2 ± 24.7*†</td>
<td>146.9 ± 9.8</td>
<td>156.8 ± 12.6</td>
</tr>
<tr>
<td>Mean race time (min/s)</td>
<td>89.3 ± 34.7*†</td>
<td>224.7 ± 17.6</td>
<td>237.8 ± 27.6‡</td>
</tr>
<tr>
<td>Mean power (W)</td>
<td>262 ± 30*†</td>
<td>188 ± 30</td>
<td>203 ± 32‡</td>
</tr>
<tr>
<td>Mean power to mass (W/kg)</td>
<td>3.8 ± 0.4*†</td>
<td>2.7 ± 0.4</td>
<td>2.9 ± 0.4‡</td>
</tr>
<tr>
<td>Mean cadence (rpm)</td>
<td>77 ± 6*†</td>
<td>67 ± 6</td>
<td>71 ± 6‡</td>
</tr>
<tr>
<td>Mean speed (km/h)</td>
<td>44.9 ± 1.2*†</td>
<td>38.0 ± 2.2</td>
<td>38.4 ± 2.2</td>
</tr>
<tr>
<td>Peak power (W)</td>
<td>1209 ± 173*</td>
<td>1119 ± 187</td>
<td>1108 ± 184</td>
</tr>
<tr>
<td>Peak power to mass (W/kg)</td>
<td>17.4 ± 2.5*</td>
<td>16.1 ± 2.7</td>
<td>16.1 ± 2.5</td>
</tr>
<tr>
<td>Time below 100 W (min)</td>
<td>30.4 ± 9.8*†</td>
<td>85.9 ± 15.8</td>
<td>81.8 ± 23.6</td>
</tr>
<tr>
<td>Total race time below 100 W (%)</td>
<td>35.2 ± 5.2</td>
<td>37.6 ± 5.6</td>
<td>33.1 ± 6.4‡</td>
</tr>
<tr>
<td>Time above 7.5 W/kg (min)</td>
<td>12.8 ± 3.0*†</td>
<td>8.1 ± 3.2</td>
<td>9.1 ± 3.6</td>
</tr>
<tr>
<td>Total race time above 7.5 W/kg (%)</td>
<td>15.5 ± 4.1*†</td>
<td>3.5 ± 1.4</td>
<td>3.8 ± 1.7</td>
</tr>
</tbody>
</table>

*Hilly significantly different (P ≤ .05) from criterium.
†Flat significantly different (P ≤ .05) from criterium.
‡Hilly significantly different (P ≤ .05) from flat.

Figure 1 — Percentage of total race time spent in different power-output bands (W/kg) for criteriums (CRIT) and flat (FLAT) and hilly (HILLY) stages of the Tour Down Under.
Figure 2 — Percentage of total race time in power-cadence bands for criteriums (CRIT) and flat (FLAT) and hilly (HILLY) stages of the Tour Down Under.

Figure 3 — Duration and number of sprints above maximum aerobic power output for criteriums (CRIT) and flat (FLAT) and hilly (HILLY) stages of the Tour Down Under. *CRIT > FLAT; #CRIT > HILLY; ^HILLY > FLAT; all $P \leq .05$. 
Figure 4 — Maximum mean power output (W/kg: mean, minimum, and maximum) for criteriums (CRIT), flat (FLAT), and hilly (HILLY) stages of the Tour Down Under (N = 207 races).
seconds. The only significant difference between the road races was a higher 5-second MMP for flat races than for hilly races ($P = .02$).

**Discussion**

Our data are unique, as the demands of competition were investigated by directly measuring power output during actual competition (professional stage racing) with a very large sample of nationally ranked riders ($N = 207$ races) over consecutive years. Before this study, only limited data were available on professional-category male road cyclists, in whom power output had been measured directly using instrumented power meters.\(^1\)\(^\text{10-13,18}\) These data were derived from small samples during 1 race or tour only. When comparing road races it is important to have an understanding of the race distance, terrain, and type of cyclist monitored. Golich and Broker\(^1\)\(^\text{10}\) monitored 4 road riders during a stage of the 1994 Tour duPont but only reported limited data on 1 subject. Lim and colleagues\(^1\)\(^\text{11}\) collected data on 8 men during a 6-day stage race. Weber et al\(^1\)\(^\text{13}\) monitored 4 “top level” professional cyclists during 1-day and stage races, and Heinrich et al\(^1\)\(^\text{18}\) studied 6 professional male road cyclists during a 5-day tour. These reports provide a preliminary description of the demands of professional road cycle racing. Recently, Vogt et al\(^1\)\(^\text{12}\) conducted a more extensive analysis of stage racing and outlined competition demands relative to laboratory testing. They monitored 6 professional road cyclists during an international stage race (UCI category 2.3) and reported a mean power output of 220 ± 22 W, with a large percentage of time spent near lactate threshold. They contrasted stage races with an uphill time trial but made no attempt to compare the mass-start stages. Our study investigated the differences in race characteristics between mass-start stage types, namely, flat and hilly stages and circuit races. Previous work has explored different mass-start stages but measured intensity via HR,\(^3\)\(^\text{6,19}\) which might provide an indication of the metabolic stress endured during competition, but it does not precisely reflect the power output sustained.\(^1\)\(^\text{11,20,21}\)

The current study monitored 207 races over 6 years of the Tour Down Under. Races were categorized as criteriums (short circuit races) or flat or hilly road stages. From these races, a subset of those who finished within 2.5% of the winning time ($n = 142$ races) was used to compare the power-output demands for the 3 race types. Criteriums were raced at significantly higher power outputs and speeds than were flat and hilly races, but they were shorter in distance. In the current study, there was a mean power output of 268 W for the short circuit criterium races. This was similar to that during the criterium stage monitored by Lim et al\(^1\)\(^\text{11}\) (279 W). Higher power outputs during races have been reported for events such as the time trial and prologue. Padilla et al\(^3\) report predicted power outputs of 362, 347, and 342 W for short, long, and uphill time trials, respectively, for professional male cyclists, and Lim et al\(^1\)\(^\text{11}\) measured a mean power output of 410 W for a prologue (North American professional team). Vogt et al\(^1\)\(^\text{12}\) reported a power output of 392 ± 55 W (5.5 ± 0.6 W/kg) for a 13-km uphill time trial, and Heinrich et al\(^1\)\(^\text{18}\) a power output of 5.48 W/kg for a 13-km time trial for professional male road cyclists. These data highlight the varying power-output demands of road racing over different terrain and distances.

For the longer Tour Down Under road stages, the mean power outputs for the flat races (188 W or 2.7 W/kg) were similar to those estimated by Padilla
et al\textsuperscript{6} for flat races (flat = 192 W, and hilly = 246 W), but lower power outputs were recorded for our hilly races (208 W or 2.9 W/kg). The professional cyclists monitored by Weber et al\textsuperscript{13} produced average power outputs of 234 ± 30 (4.8 ± 0.7 hours) and 256 ± 35 W (4.7 ± 0.5 hours) for a stage of a tour and 1-day race, respectively. Heinrich et al\textsuperscript{18} provided data relative to body mass with a range of 2.7 to 3.2 W/kg for road races between 160 and 168 km, but they did not distinguish the type of terrain. Padilla et al\textsuperscript{6} estimate power outputs of 192, 234, and 246 W for flat, semimountainous, and high-mountainous races, respectively. Jeukendrup and van Diemen\textsuperscript{14} estimated a mean power output of 240 W for a mountainous stage during the Tour de France. The differences in power output for hilly stages observed by Padilla et al\textsuperscript{6} and Jeukendrup and van Diemen\textsuperscript{14} when compared with our data might be related to the distance and number of climbs in the races they analyzed. Typically, mountainous stages in the Tour de France are 170 to 220 km and include 4 to 6 mountain passes of up to 25 km with gradients of 4% to 8%. The average distance of the hilly stages of the Tour Down Under was 157 km, with 1 or 2 mountain passes of no more than 10 km. It is also important to note that the Tour Down Under is held in the Australian summer, when the temperatures can be very high; this might also be a factor in the lower power output observed in the current study. Many of the competitors race during the Australian summer as preparation for the European season (Australian winter), which might also influence the power-output profiles obtained in the current study when compared with those obtained during the grand tours.

We also investigated the time spent in different power-output bands during the different race types (Figure 1). As expected, a greater percentage of race time was spent above 8 W/kg for the criterium than for the flat and hilly stages. This reflects the high power-output requirements when accelerating out of corners and also the faster race speeds. During hilly races, slightly less time was spent in the 0- to 1.9-W/kg power-output band than in the flat races. This might represent the sustained nature of hill climbing and the reduced impact of drafting during hill climbing, which would otherwise lower the power-output requirement for a given speed. Vogt et al\textsuperscript{12} also explored the time spent in different zones derived from laboratory testing. Their zones were as follows: zone 1 < 3.5 W/kg, zone 2 = 3.5 to 4.6 W/kg, and zone 3 > 4.6 W/kg. A comparison between studies can be made for the percentage of total race time above ≈5 W/kg. Our data for the flat and hilly stages indicate that approximately 20% of race time is spent above 5 W/kg, whereas the cyclists in the study of Vogt et al\textsuperscript{12} spent 20% to 35% above this power output. This difference might be attributed to reasons outlined previously regarding race distance and terrain.

Monitoring power output as opposed to HR highlights the variable nature of road cycling, and mean power output does not provide a true reflection of the stochastic nature of road cycling. In the current study, the SDs for power output during criterium, flat, and hilly races were 250, 165, and 169 W, respectively. The power-output ranges were 0 to 1665, 0 to 1510, and 0 to 1419 W for the criterium, flat, and hilly races, respectively. The variable nature of road cycling provides a challenge for both athlete and coach to train appropriately. Palmer et al\textsuperscript{20} compared the metabolic responses to steady-state and variable exercise. Variable exercise resulted in a higher lactate concentration and a smaller reduction in total muscle glycogen but greater glucose oxidation. Fewer type I and more type II fibers were
glycogen depleted after the variable exercise. This type of exercise mode occurs during mass-start road races, as indicated by the large SDs for power output, because of the dynamics of the peloton. It is therefore important for cyclists to have good drafting and positioning skills to allow for recovery between surges.

Cycling involves multiple high-intensity efforts of varying duration. The highest or maximum MMP a rider produces for a defined time period was therefore determined from the race data (Figure 4). There were higher MMPs for the shorter time periods (≤15 seconds) for the criterium, which would be expected because a criterium involves numerous accelerations out of corners and often a number of attacks. The minimum MMP seen for 5 seconds during the criterium (12.3 W/kg) was higher than that for the flat (10.2 W/kg) and hilly races (9.8 W/kg). For the 4-minute effort, the opposite was observed (criterium = 4.2 W/kg, and both flat and hilly = 4.7 W/kg). This observation would also be expected given the tight circuit of the criterium and the inability to hold a high power output for a long period of time before a corner presents. These data might provide minimal power-output requirements for racing over varying terrain and closed circuit events.

In conjunction with determining the highest power output a rider held for a certain time period, we established the number of sprints above their MAP. During criteriums, cyclists produced nearly 70 sprints per race lasting 3 to 30 seconds, which was equivalent to 1 sprint nearly every minute of the race (Figure 3: criterium race time ≈ 89 minutes). This was significantly higher than the number of sprints during flat and hilly races, which was expected because of the many turns and tactics involved in criterium racing, in which riders have to continually accelerate out of corners. During flat and hilly races, sprints are often confined to breakaway attempts, sprint bonuses during a race, and a sprint finish. Our data highlight the very different power-output demands of criterium and road cycling races and provide a framework for constructing competition-specific training programs that, in the case of criterium racing, should focus more on anaerobic-fitness traits.

The mean cadences were 77, 67, and 71 rpm for criterium, flat, and hilly, respectively, but these values include the time when the rider was going downhill at very fast speeds and not pedaling. Further analysis of the data revealed that cyclists spent the majority of race time between 81 and 100 rpm at power outputs of 100 to 700 W. This agrees with research conducted on national-level and professional male road cyclists, despite the most economical cadences being reported as 50 to 80 rpm. Higher cadences selected to produce 200 to 400 W might be used by elite road cyclists for a number of reasons including improved pedaling technique from years of high-volume training, decrease in crank-force application, reduced neuromuscular fatigue, or to minimize glycogen depletion of fast-twitch muscle fibers.

In summary, for men’s stage racing, criteriums were performed at a high intensity with a significant number of accelerations above the rider’s MAP output when compared with flat and hilly road stages. This may be partly because of their short duration and circuit format. These data are unique because they are based on the direct measurement of power output during professional road racing, a technique only recently used by the scientific community, when compared with HR monitoring. This study also presents data highlighting the mean power-output requirements for particular race types but further extends the analysis of the demands of road racing by providing the time spent in various power-output bands, maximal mean
power outputs, and high-intensity sprints. This extensive investigation allows for a greater understanding of the demands of competition in different styles of racing and might assist in training prescription.

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References