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## Power output during women's World Cup road cycle racing

Accepted: 7 July 2005 / Published online: 6 September 2005  
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**Abstract** Little information exists on the power output demands of competitive women's road cycle racing. The purpose of our investigation was to document the power output generated by elite female road cyclists who achieved success in FLAT and HILLY World Cup races. Power output data were collected from 27 top-20 World Cup finishes (19 FLAT and 8 HILLY) achieved by 15 nationally ranked cyclists (mean  $\pm$  SD; age:  $24.1 \pm 4.0$  - years; body mass:  $57.9 \pm 3.6$  kg; height:  $168.7 \pm 5.6$  cm;  $\dot{V}O_{2\max}$ :  $63.6 \pm 2.4$  mL kg<sup>-1</sup> min<sup>-1</sup>; peak power during graded exercise test (GXT<sub>peak power</sub>):  $310 \pm 25$  W). The GXT determined GXT<sub>peak power</sub>,  $\dot{V}O_{2\text{peak}}$ , lactate threshold (LT) and anaerobic threshold (AT). Bicycles were fitted with SRM powermeters, which recorded power (W), cadence (rpm), distance (km) and speed (km h<sup>-1</sup>). Racing data were analysed to establish time in power output and metabolic threshold bands and maximal mean power (MMP) over different durations. When compared to HILLY, FLAT were raced at a similar cadence ( $75 \pm 8$  vs.  $75 \pm 4$  rpm,  $P=0.93$ ) but higher speed ( $37.6 \pm 2.6$  vs.  $33.9 \pm 2.7$  km h<sup>-1</sup>,  $P=0.008$ ) and power output ( $192 \pm 21$  vs.  $169 \pm 17$  W,  $P=0.04$ ;  $3.3 \pm 0.3$  vs.  $3.0 \pm 0.4$  W kg<sup>-1</sup>,  $P=0.04$ ). During FLAT races, riders spent significantly more time above 500 W, while greater race time was spent between 100 and 300 W (LT-AT) for HILLY races, with

higher MMPs for 180–300 s. Racing terrain influenced the power output profiles of our internationally competitive female road cyclists. These data are the first to define the unique power output requirements associated with placing well in both flat and hilly women's World Cup cycling events.

**Keywords** Competition analysis · Maximal mean power · SRM powermeter

### Introduction

World Cup races are single-day mass-start races, which form part of the official Union Cycliste Internationale (UCI) racing calendar. Riders are awarded points based on finishing place and the World Cup winner is the cyclist with the highest aggregate at the end of the season. Both men and women compete in a World Cup series in addition to the well-known tours such as the Tour de France for men and the Giro d'Italia—Internazionale Femminile for women. Recently, information has become available on the exercise intensity and load (TRIMPS) sustained by male cyclists during mass-start road races (Fernández-García et al. 2000; Lucía et al. 1999; Padilla et al. 2001) and off-road cycling (Impellizzeri et al. 2002) using heart rate (HR) monitoring. However, such competition data investigating HR and power output demands have not been published for professional female cyclists. The only competition data available for female road cyclists are those by Pfeiffer et al. (1993), where finishing time was correlated with maximal aerobic power ( $\dot{V}O_{2\max}$ ), and some preliminary power output data on Australian National Team female cyclists who competed in World Cups (Martin et al. 2001). Competition data are important for identifying the unique characteristics associated with successful performances. These data can then be used by coaches to refine training programmes, modify tactics and perhaps even influence talent identification efforts.

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While research on elite cyclists has concentrated on the demands of racing using telemetered HR (Lucía et al. 1999, 2000; Padilla et al. 2001; Rodríguez-Marroyo et al. 2003), this variable can be influenced by changes in body position, cardiac drift, environmental conditions and the athlete's physical state (i.e. fatigue/overtraining: Jeukendrup and Van Diemen 1998). With the introduction of commercially available cycling power-monitoring equipment such as the SRM powermeter (Schoeberer Resistance Measurement, Jülich, Germany), Power Tap (CycleOps, Madison, WI, USA), Polar Power (Polar Electro, Kempele, Finland) and Ergomo (Ergomo, FL, USA), power output can now be measured during racing and training. Researchers have compared a number of these devices both with each other and to stationary ergometers such as the Monark and Kingcycle and have reported good comparability between the laboratory and field (Balmer et al. 2000; Martin et al. 1998; Millet et al. 2003). Smith et al. (2001) also reported the reliability of power output during a 40-km time trial measured with an SRM powermeter to be 2.1%, which is similar to the 2.5% instrument error reported by the manufacturers. The measuring device of choice for our study was the SRM powermeter, given its proven reliability and accuracy (Gardner et al. 2004) in monitoring power output during cycling.

The aims of this study were to characterise the demands of women's World Cup racing over flat and hilly terrain, determine if terrain influences the power output profile of a race and establish fitness standards for females competing in international races.

## Methods

### Subjects

Race data were collected during the UCI World Cup races from 1999 to 2004, when 3–7 Australian National Team cyclists participated per race for a total of 81 monitored races. Of the 81 races, top-20 finishes were attained 27 times, and this subset represents the data used in this study. The top-20 finishes were achieved by 15 athletes (mean  $\pm$  SD; age:  $24.1 \pm 4.0$  years; body mass:  $57.9 \pm 3.6$  kg; height:  $168.7 \pm 5.6$  cm;  $\dot{V}O_{2\text{peak}}$ :  $63.6 \pm 2.4$  mL  $\text{kg}^{-1}$   $\text{min}^{-1}$ ; peak power from a graded exercise test ( $\text{GXT}_{\text{peak power}}$ ):  $310 \pm 25$  W). In 1999 and 2004, members of this group won the World Cup Series. The project was approved by the Australian Institute of Sport Ethics Committee and athletes provided written informed consent.

### Laboratory data collection

Cyclists performed a GXT in the laboratory within a month (before or after) of the race under analysis. An electronically braked stationary cycle ergometer (Lode Excalibur, Groninger, The Netherlands) was used. The

test started at 125 W and increased by 25 W every 3 min until volitional exhaustion. The cyclists self-selected a cadence and were required to maintain this for the entire test. HR (Polar S710®, Polar Electro, Kempele, Finland) was recorded in the final 30 s of each workload, and oxygen consumption was measured throughout the test using a customised gas analysis system (Australian Institute of Sport, Canberra, Australia).  $\dot{V}O_{2\text{peak}}$  was determined as the two highest consecutive 30 s samples. Peak power output from the GXT was calculated as follows (Kuipers et al. 1985):

$$\text{GXT}_{\text{peak power}}(\text{W}) = W_L + [(t/3) \times 25]$$

where  $W_L$  was the power output of the last complete workload (W),  $t$  was the time (min) for the final incomplete workload, 3 was the workload time increment (min) and 25 was the power output increment (W).

A capillary blood sample (100  $\mu\text{L}$ ) was collected in the last 30 s of each workload to establish the relationship between blood lactate (Radiometer ABL 700 Series, Radiometer, Copenhagen, Denmark) and power output. The exercise intensities corresponding to lactate threshold (LT) and anaerobic threshold (AT) were calculated using specifically designed software (ADAPT Version 3.8, Australian Institute of Sport, Canberra, Australia). LT was defined as the workload preceding a  $<0.4$  mmol  $\text{L}^{-1}$  rise in blood lactate above baseline (ADAPT Version 3.8, Australian Institute of Sport, Canberra, Australia) and AT was defined using the method outlined by Cheng et al. (1992).

### Race data collection

Race data were collected using the professional version of the SRM powermeter. Prior to racing, the cyclists were given instructions on how to use the SRM powermeter. The SRM powermeter is an instrumented device with four strain gauge strips, which determine power via deformation of the powermeter assembly during pedaling. This deformation is proportional to the torque applied, and power is calculated from the product of angular velocity (cadence) and torque. This information is then transmitted to the Powercontrol which is mounted on the handlebar, thereby providing a visual display while storing the data every second.

Each SRM powermeter was calibrated using a dynamic calibration rig fabricated by the Australian Institute of Sport. The calibration confirmed the relationship between the torque (Nm) and frequency of the SRM in hertz (Hz), which was established by the manufacturers. This determines the slope of the relationship, which is unique for each SRM unit, and it must be entered into the Powercontrol for the reading of power to be valid. Following a self-selected warm-up, the SRM was zeroed and the set button pressed to indicate the start of the race. Data were collected at 1 Hz. At the conclusion of the race, the set button was again pressed

and the data were downloaded from the Powercontrol using a serial port cable and commercially available software (SRM Training System, Jülich, Germany; Version 6.32.08). Final placing was recorded and the races were also categorised as either FLAT ( $N=19$ ) or HILLY ( $N=8$ ). The latter races were characterised by three or more hills of longer than 1 km and/or a hill-top finish.

### Race data analyses

Similar to Stapelfeldt et al. (2004), the percentage of total race time was divided into four zones based on results from the graded exercise test in the laboratory: (1) below LT power output, (2) between LT and AT power output, (3) between AT and  $GXT_{\text{peak power}}$  and (4) above  $GXT_{\text{peak power}}$ . Further race analyses were conducted using a specially designed software program to determine average power, cadence and speed, time in power bands and maximal mean power (MMP) for time periods of 5, 15, 30, 60, 120, 180, 240, 300 and 1800 s. The power bands chosen represented: (1) low intensity cycling ( $< 100$  W or  $2$  W  $\text{kg}^{-1}$ ), (2) below  $GXT_{\text{peak power}}$  ( $100\text{--}300$  W or  $2\text{--}5$  W  $\text{kg}^{-1}$ ), (3) high intensity efforts ( $300\text{--}500$  W or  $5\text{--}8$  W  $\text{kg}^{-1}$ ) and sprints ( $> 500$  W or  $8$  W  $\text{kg}^{-1}$ ). Times for cadence (0, 0–60, 60–80, 80–100,  $> 100$  rpm) and power bands were determined for all races.

### Statistics

Data are reported as mean  $\pm$  SD unless otherwise specified. Linear mixed models, which allow some cyclists to participate in multiple races, were used to compare differences in body mass, average race characteristics (e.g. power, cadence and speed), time spent in different power and intensity bands and MMP for varying time periods between FLAT and HILLY terrain. The models consisted of random and fixed effects, allowed for missing data and varying collection time points and dealt with repeated measures (Ugrinowitsch et al. 2004). In our models, the cyclists were the random factor as they contributed a varying number of races to the dataset and FLAT versus HILLY was the fixed factor. Models were fitted using the R Statistical Package Version 2.0.0 (The R Development Core 2004) and statistical significance was set at  $P \leq 0.05$ .

## Results

Table 1 outlines the general characteristics of successful performers (i.e. top-20 finishers) racing over FLAT and HILLY terrain. For the FLAT and HILLY races, the riders finished, on average, in tenth and ninth place, respectively. Figure 1 compares the percentage of race time spent in the exercise intensity zones as determined from the laboratory test, while Fig. 2a and b compare

the percentage of total racing time spent during FLAT and HILLY races in absolute (W) and relative (W  $\text{kg}^{-1}$ ) power bands.

The distinguishing differences between FLAT and HILLY World Cup races were: (1) more time spent between LT and AT ( $P=0.02$ ),  $100\text{--}300$  W and  $2\text{--}5$  W  $\text{kg}^{-1}$  ( $P=0.04$ ) during HILLY races ( $P=0.02$ ); (2) more time accumulated between  $300\text{--}500$ ,  $> 500$  W and above  $GXT_{\text{peak power}}$  for FLAT races (Figs. 1, 2a) and (3) a higher MMP (W) for shorter time periods (5–15 s) during FLAT races and longer times (180–300 s) for HILLY races (Fig. 3). There was also a larger standard deviation for power output during FLAT races compared to HILLY races ( $P < 0.0001$ ), with a reversal of this trend for speed ( $P=0.002$ ). This highlights the stochastic nature of road cycling, especially the surges in power output during FLAT races and the slow ascents but fast descents in HILLY races.

Figure 4 outlines the cadence-power output relationships for FLAT and HILLY races. During HILLY races, there was a trend for more time to be spent at cadences between 60 and 80 rpm compared to FLAT races where more time was spent  $> 100$  rpm.

## Discussion

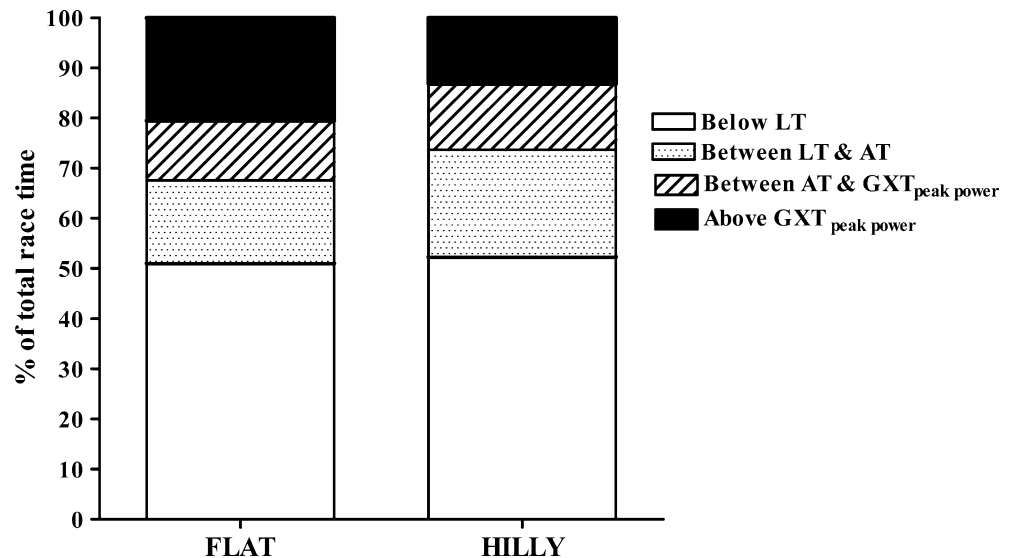
Our data are the first extensive analyses of women's World Cup cycle racing over varying terrain (FLAT versus HILLY) using power output as the measure of intensity. Previous work by our laboratory (Martin et al. 2001) has briefly outlined the demands of women's road racing. A recent study in mountain biking (Stapelfeldt et al. 2004) also outlined the demands of racing using SRM powermeters, but there are no other data on a large sample ( $N=27$  races) of successful performances (only top-20 performers were used in the analyses) from World-class female cyclists. Our data include the 1999 and 2004 World Cup winners and also, at times, the number one UCI ranked cycling nation in the world, thereby providing an insight into the power demands of some of the best contemporary female cyclists. The calibre of our riders ( $\dot{V}O_{2\text{peak}} = 63.8 \pm 2.4$  mL  $\text{kg}^{-1} \text{min}^{-1}$ ) is reinforced by comparable values for the US National Team ( $63.8 \pm 4.2$  mL  $\text{kg}^{-1} \text{min}^{-1}$ ; Wilber et al. 1997) and women competing in the Tour of Idaho ( $64.2 \pm 3.9$  mL  $\text{kg}^{-1} \text{min}^{-1}$ ; Pfeiffer et al. 1993), but are higher than data reported for an earlier US National Team ( $57.4 \pm 6.6$  mL  $\text{kg}^{-1} \text{min}^{-1}$ ; Burke 1980) and trained female cyclists ( $47.4 \pm 7.2$  mL  $\text{kg}^{-1} \text{min}^{-1}$ ; Bishop 1997). Previous investigations have estimated racing power output based on the HR-power output relationship established in the laboratory (Padilla et al. 2001). In addition to this research, many have quantified racing intensity by monitoring HR in male road cyclists (Fernández-García et al. 2000; Lucía et al. 1999; Mujika and Padilla 2001; Rodríguez-Marroyo et al. 2003). Our data are therefore unique in that they provide: timely

**Table 1** Comparison between FLAT and HILLY World Cup female cycling races

	FLAT	HILLY
<i>N</i>	19	8
Average race time (min)	172.5 ± 87.1	187.0 ± 18.6
Average power (W)	192 ± 21	169 ± 17*
Average power:mass (W kg <sup>-1</sup> )	3.3 ± 0.3	3.0 ± 0.4*
Average speed (km h <sup>-1</sup> )	37.6 ± 2.6	33.9 ± 2.7*
Average cadence (rpm)	75 ± 8	75 ± 4
Standard deviation power (W)	153 ± 14	127 ± 12*
Standard deviation speed (km h <sup>-1</sup> )	11.3 ± 2.2	7.7 ± 1.6*
Peak power (W)	797 ± 107	829 ± 112
Peak power:mass (W kg <sup>-1</sup> )	13.6 ± 1.8	14.7 ± 2.3
Time below 100 W (min)	54.1 ± 11.9	61.6 ± 9.1
Time above 7.5 W kg <sup>-1</sup> (min)	12.4 ± 4.9	5.3 ± 2.7*

\* Significantly different from FLAT,  $P \leq 0.05$

**Fig. 1** Percentage of race time in exercise intensity zones as determined from a graded exercise test in the laboratory. *LT* Lactate Threshold, *AT* Anaerobic Threshold, *GXT<sub>peak power</sub>* highest power achieved in graded exercise test



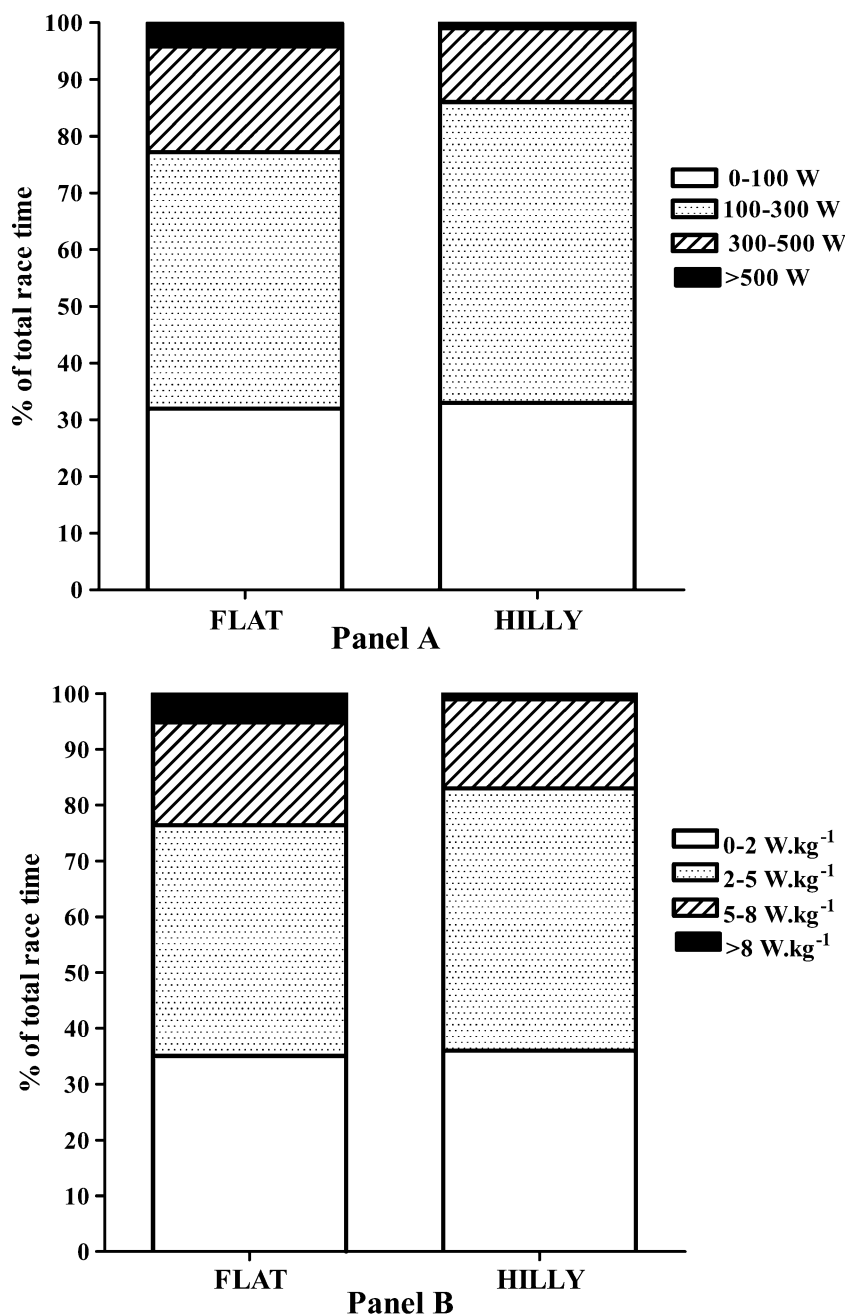
information on the demands of women's road racing over varying terrain determined by using instrumented powermeters, an insight into the fitness standards (e.g. MMP output) required to be competitive in women's international racing and highlight the requirements of placing well in World Cup races.

The average power outputs of women's World Cup racing over FLAT and HILLY terrain were 192 W (3.3 W kg<sup>-1</sup>) and 169 W (3.0 W kg<sup>-1</sup>), respectively. Martin et al. (2001) provide a preliminary report using a subset of our data and observed average power outputs (189.7 W and 3.3 W kg<sup>-1</sup>) during World Cup racing comparable to our FLAT terrain races. In mountain biking, Stapelfeldt et al. (2004) reported an average power output of 193 ± 1 W (3.1 W kg<sup>-1</sup>) for two female mountain bikers when data were collected using SRM powermeters. This is similar to our average power output for FLAT races. Mountain bike races are shorter (< 2 h) in comparison to female road cycle racing (2.5–3.5 h), and they also occur over varying surfaces (road, dirt and gravel). A unique aspect of our study is that powermeters were used to collect data on a large sample of females during international road cycling

competitions. These data are a subset of a larger sample ( $N=81$  races), which includes individuals placing outside the top 20. We chose to include only those who placed well in the World Cup races to determine the requirements for successful performance in FLAT and HILLY World Cup races. A comparison between those who finished in the top 20 and riders who did not revealed the differences that exist between members of these two categories, but it is beyond the scope of this paper.

To the best of our knowledge, there are no directly measured power output data on males during road cycling competitions. All published data have been predicted from the HR-power output relationship determined in the laboratory (Padilla et al. 2001). The average power output of mass-start races in professional male road cycling is estimated to be 192, 234 and 246 W for flat, semi-mountainous and high-mountain stages, respectively (Padilla et al. 2001). In our study, races were categorised as either FLAT or HILLY. In contrast with Padilla et al. (2001), female professional races exhibited higher average power outputs for those classified as FLAT compared to HILLY. Possible reasons for this

**Fig. 2** Percentage of race time in power (W) and in power/mass ( $W\ kg^{-1}$ ) bands during World Cup female road racing over FLAT and HILLY terrain

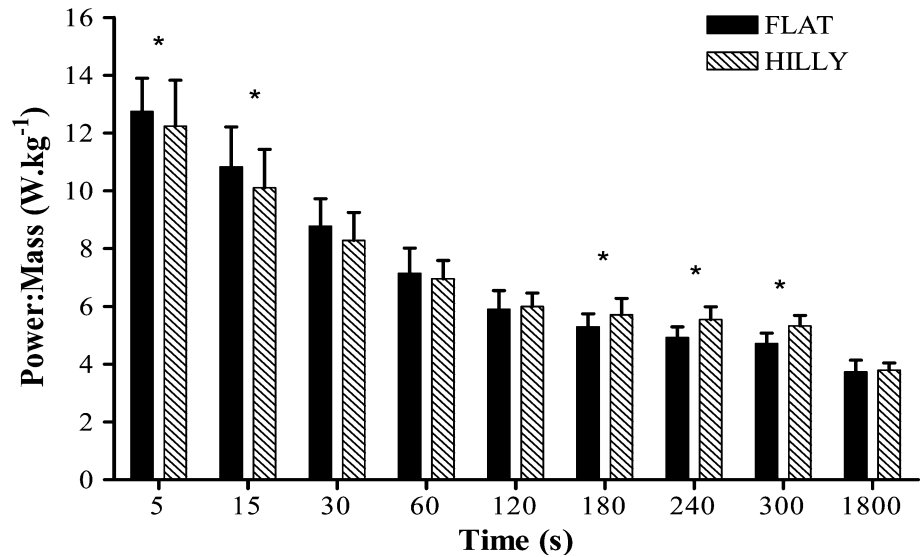


discrepancy may be that male races involve hill-climbs of up to 30 km, while the longest climb for females in the World Cup races was  $\sim 6$  km. The greater climbing distance and number of ascents during male races may have contributed to the higher average power outputs in the hilly races compared to females, because of the sustained medium to high power outputs that are required during hill-climbing. Team tactics can also influence the intensity of a race because the pace in men's races is often controlled by the teams who are in contention to win. This is less obvious in women's racing due to the reduced number of teams. A better comparison between the demands of male and female racing may be possible when body mass is taken into account.

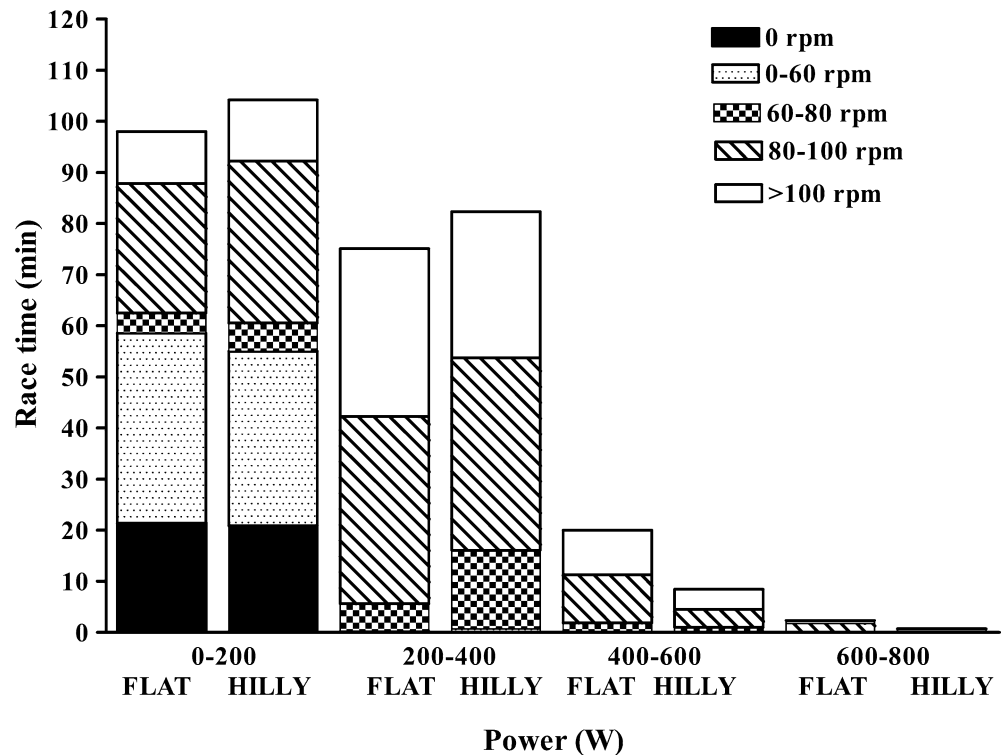
Padilla et al. (2001) did not report  $W\ kg^{-1}$  values in their summary, but using the reported means for their professional male cyclists, the ratios are 2.8, 3.4 and  $3.6\ W\ kg^{-1}$  for flat, semi and high-mountainous terrain, respectively. Our  $3.3$  and  $3.0\ W\ kg^{-1}$  for FLAT and HILLY, respectively, indicate that FLAT races were performed at a higher relative average power output for women, whereas males reported higher values for mountainous races (Padilla et al. 2001).

The type of race terrain significantly influenced the power output profile attained by top-20 finishers in FLAT and HILLY races. Women's World Cup races which were FLAT were conducted at a higher average power output with less total race time in the power

**Fig. 3** Maximal mean power ( $\text{W kg}^{-1}$ ) comparisons between World Cup FLAT and HILLY racing (\*  $P \leq 0.05$ )



**Fig. 4** Time in power-cadence bands for FLAT and HILLY World Cup female cycling races



bands of 100–300 W, but more time above both  $7.5 \text{ W kg}^{-1}$  and  $\text{GXT}_{\text{peak power}}$ . In addition, higher MMPs ( $\text{W}$  and  $\text{W kg}^{-1}$ ) were achieved for shorter time periods (5–15 s) during FLAT races and longer time periods (180–300 s) for HILLY races. FLAT races often involve sprints and surges at a high intensity to maintain position, while HILLY races require the ability to sustain constant submaximal power outputs for extended periods of time when climbing. Rodríguez-Marroyo et al. (2003) reported an estimated power output of 215.3–259.9 W when ascending mountain passes during the Vuelta a España. This agrees with our research on female cyclists who, during HILLY races, spent

significantly more time ( $P < 0.05$ ) at power outputs of 100–300 W and between LT and AT (similar to zone 2: Rodríguez-Marroyo et al. 2003), with higher MMPs for 180–300 s. During HILLY races, riders held higher MMPs of  $5.7 \pm 0.6$ ,  $5.6 \pm 0.4$  and  $5.3 \pm 0.4 \text{ W kg}^{-1}$  for 180, 240 and 300 s, respectively, compared with FLAT races where the MMPs for these time periods were  $5.3 \pm 0.5$ ,  $4.9 \pm 0.4$  and  $4.7 \pm 0.4 \text{ W kg}^{-1}$ , respectively.

To allow comparison with published race data on professional male road cyclists (Padilla et al. 2001) and mountain bikers (Stapelfeldt et al. 2004), we expressed the demands of racing relative to laboratory testing results. In comparison to mountain bike racing, where

power output was measured directly as per our study, in which the riders spent 39, 19, 20 and 22% below LT, LT-AT, AT-GXT<sub>peak power</sub> and above GXT<sub>peak power</sub>, respectively, our riders spent 51, 17, 12 and 20% during FLAT and 52, 22, 13 and 13% of total race time during HILLY races for similar exercise intensity zones as determined from laboratory testing. The greater amount of time spent below LT in road racing compared to mountain bike may be explained by the large groups often seen in road racing compared to single-track riding in mountain biking. Kyle (1979) accordingly reported a 31–33% reduction in external power output when travelling at 32–40 km h<sup>-1</sup> in a group due to a 38% reduction in wind resistance.

Other studies have used HR to determine metabolic thresholds and subsequent racing intensity. Slight variations when describing the metabolic zones are present in the literature; hence, this should be considered when making comparisons. Lucía et al. (1999) investigated the differences in intensity during flat, medium, mountain and high mountain stages of the Tour de France. Similarly, Fernández-García et al. (2000) monitored flat and mountain stages of the Vuelta a España and the Tour de France. Both studies report more time spent in the high intensity zones (i.e. >70%  $\dot{V}O_{2max}$ ) for flat stages and more time at moderate intensity (i.e. 50–70%  $\dot{V}O_{2max}$  or between LT and AT) for mountain stages. This agrees with our findings, where female riders spent more time above GXT<sub>peak power</sub> during FLAT races, whereas a higher percentage of total race time was accumulated between LT and AT during HILLY races. Interestingly, Padilla et al. (2001) found that professional male riders spend more time in the “moderate” (between LT and onset blood lactate accumulation: OBLA) and “hard” (above OBLA) zones during high mountain stages in comparison to flat stages. Despite these differences, which are partly due to methodological issues, a significant amount of time is spent at steady state exercise intensities. This emphasises the need for cyclists to have exceptional aerobic capabilities.

Our data also provide information on the requirements for success at world-class level. These internationally competitive female cyclists accumulated up to 41 and 47% of total race time at 2–5 W kg<sup>-1</sup> during FLAT and HILLY races, respectively. They were also able to produce average power outputs of approximately 12, 7 and 5 W kg<sup>-1</sup> for 5, 60 s and 4 min efforts, respectively. Such data provide an insight into the fitness standards required to be competitive and successful at international level and may offer a screening tool for coaches and sport scientists to identify those athletes with the physiological attributes required to place well in World Cup races.

One interesting observation, although not statistically significant, was that competitors successful in HILLY races were 0.42-kg lighter. It is well known that successful uphill specialists tend to be lighter than flat terrain riders (Mujika and Padilla 2001; Padilla et al. 1999). Being lighter when racing over hilly terrain

affords the advantage of a higher relative maximal oxygen consumption ( $\dot{V}O_{2max}$ : mL kg<sup>-1</sup> min<sup>-1</sup>) and power:mass (W kg<sup>-1</sup>), despite the higher energy cost associated with a larger frontal surface area to body mass ratio exhibited by smaller riders in comparison to larger riders (Swain 1994). The lower body mass of female cyclists who perform well in the hills may therefore be important. We chose a mass exponent of 1 to represent power relative to body mass for both FLAT and HILLY races. Heil (1998) and Padilla et al. (1999) advocate a mass exponent of 1.0 for uphill riding, and we used this value for both uphill and flat terrain cycling, whereas others have found a mass exponent of 0.32 is more appropriate for flat terrain cycling (Padilla et al. 1999; Swain 1994). Body-mass scaling is dependent on the type of performance task and the characteristics of the study population. Our aim was not to predict performance but to better understand the power output requirements for successful women’s road racing; hence, our choice of 1 for the mass exponent.

The average cadence for female World Cup racing over both FLAT and HILLY terrain was ~75 rpm, but this value includes the time when the rider was going downhill at very fast speeds and not pedaling. Further analysis of our data revealed that female cyclists spent the majority of race time between 80 and 100 rpm for power outputs from 100 to 700 W (Fig. 4). This agrees with research conducted on national-level (Foss and Hallén 2005), professional male road cyclists (Lucía et al. 2001), despite the most economical cadences being reported at 50–80 rpm (Coast and Welch 1985). Higher cadences may be adopted by elite road cyclists for reasons such as the higher power outputs they sustain during racing (the most economical cadence increases with increasing power output: Coast and Welch 1985); a reduced rating of perceived exertion (Lucía et al. 2004); more effective skeletal muscle pump resulting in increased muscle blood flow (Gotshall et al. 1996); reduction in crank force application (Patterson and Moreno 1990); reduced neuromuscular fatigue (Takaishi et al. 1996) and/or to minimise glycogen depletion of fast twitch muscle fibres (Ahlquist et al. 1992). Terrain can influence the cadence sustained by professional cyclists. During HILLY races, there was a greater percentage of time spent at 60–80 rpm. This is in accordance with the research on professional male cyclists by Lucía et al. (2001) who reported an average cadence of 71 rpm for high-mountain passes compared to 89 rpm for flat races. Even though there is a slight reduction in the cadence of professional riders when climbing, it is beneficial to adopt higher cadences during ascents as it appears to be more economical (Swain and Wilcox 1992).

In conclusion, the power output profiles exhibited by females during World Cup races vary depending on terrain. During HILLY races, successful performers (top-20 finishers) spent more time in power bands between 100–300 W and 2–5 W kg<sup>-1</sup> and had higher MMPs for 180–300 s compared with FLAT races. But

more time was spent above  $7.5 \text{ W kg}^{-1}$  during FLAT races compared with HILLY races. FLAT races required the ability to repeat short high intensity efforts, while HILLY races were contested at a lower average power output, but required longer periods of time at sustained submaximal intensities. The stochastic nature of cycling, as indicated by the standard deviations for power and the high intensity efforts, highlights the need for road cyclists to possess exceptional aerobic and anaerobic capabilities. These data provide the first extensive insight into women's World Cup racing and the requirements to be competitive in the professional women's cycling circuit over differing terrain. Our data also provide insight into the minimal fitness standards required to be competitive in women's racing. This information could be useful in refining training techniques, assisting in talent identification and replicating the demands of international competition.

**Acknowledgments** The authors acknowledge the Australian Institute of Sport Women's Cycling squad for participating in and supporting the collection of race data. Hamilton Lee and Cassie Trewin are also thanked for assisting with data collection in 1999–2001. Dr Iñigo Mujika is thanked for his constructive manuscript comments. This study would not have been possible without financial support from the Australian Sports Commission, Cycling Australia and Flinders University.

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