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Examining pacing profiles in elite female road cyclists using exposure variation analysis

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ABSTRACT
Objective In this study, the amplitude and time distribution of power output in a variety of competitive cycling events through the use of a new mathematical analysis was examined: exposure variation analysis (EVA).

Design Descriptive field study.

Setting Various professional road cycling events, including: a 5-day–eight-stage tour race, a 1-day World Cup event and the Australian National Individual Time Trial Championships.

Participants 9 elite female cyclists (mean (SD), mass = 57.8 (3.4) kg, height = 167.3 (2.8) cm, \( V_{\text{O}}2\text{peak} = 63.2 (5.2) \text{ml kg}^{-1} \text{min}^{-1} \)).

Interventions None.

Main outcome measurements The variation in power output and the quantification of the total time and acute time spent at various exercise intensities during competitive professional cycling were examined. predefined levels of exercise intensity that elicited first ventilation threshold, second ventilation threshold and maximal aerobic power were determined from a graded exercise test performed before the events and compared with power output during each event.

Results EVA exposed that power output during the time trial was highly variable (EVA_50 = 2.81 (0.33)) but more evenly distributed than the circuit/criterium (4.23 (0.31)) and road race events (4.81 (0.96)).

Conclusion EVA may be useful for illustrating variations in the amplitude and time distribution of power output during cycling events. The specific race format influenced not only the overall time spent in various power bands, but also the acute time spent at these exercise intensities.

Ebert et al. recently documented the percentage of overall performance time spent in various power bands during women’s flat and hilly World Cup professional races. In this study, it was found that the racing terrain may have influenced the power output profiles in these cyclists, as a greater percentage of time was spent above 500 W and between 100 and 300 W during flat and hilly races, respectively. While this analysis provides valuable information regarding the overall power output distribution during such events, comprehensive analysis of the acute time spent in various power bands has not been explored. In addition, the minor fluctuations in power output often observed during cycling are poorly understood. It is believed that these minor fluctuations in power output may be related to a central regulation of exercise intensity. However, the fundamental mathematical techniques used to quantify variation in these studies fail to expose important aspects of variation. For instance, it has previously been found through the use of discrete Fourier transformation that dominant power frequency bands may exist, which may be cycling task specific. However, in these studies, the use of Fourier transformation only quantifies the degree of variation and is not sensitive to changes in amplitude, frequency and time.

Exposure variation analysis (EVA) is an analytical method developed to quantify acute and cumulative physical load exposure in ergonomic research. For example, Straker et al. have recently used EVA to examine musculoskeletal stress in children during various administrative tasks and found that both posture and muscle activity were less variable/more monotonous when working with computers, compared with books, pens and paper. Briefly, EVA is an analytical technique that describes the total duration as well as the intermittent or acute time spent at predefined exercise intensities. An advantage of EVA over previously used analytical techniques is that EVA examines not only the cumulative race time spent at various exercise intensities (ie, >500 W) but also the duration that these exercise intensities were maintained for. It is therefore possible that EVA may provide a more comprehensive indication of the variation in power output and the work-to-rest ratios experienced during cycle racing.

The purposes of this study were to (1) examine the amplitude and time distribution of power output of elite-level female road cyclists performing in a variety of competitive cycling events through the use of EVA and (2) examine the relationship between physiological variables measured during a graded exercise test and field-based elite cycling performance.

METHODS
Subjects
Race data were collected from a total of nine elite female cyclists (mean (SD), mass = 57.8 (3.4) kg, height = 167.3 (2.8) cm, \( V_{\text{O}}2\text{peak} = 63.2 (5.2) \text{ml kg}^{-1} \text{min}^{-1} \)) performing in a 5-day–eight-stage tour race, a 1-day World Cup event and the Australian National Individual Time Trial Championship (described below). Subjects were classified as “elite” based upon their physiological characteristics, training status and previous race performance. Before the events, subjects provided written informed consent in accordance with the Human Research Ethical Committee of the Australia Sports Commission.

Laboratory data collection
Before competing in the events, each subject performed a graded maximal exercise test on an
VT2 (4.5%) and MAP (3.0%). These power output ranges were determined via previously described methods. The calculation of the ventilation threshold (VT1 and VT2, respectively) were determined via previously described methods. The ventilation threshold (VT1, VT2 and VO2peak (MAP)) was calculated via the following equation:

$$\text{MAP} = (W_l + t(3) \times 25) / 9$$

where $W_l$ refers to the power output (W) of the last stage completed, and t is the amount of time (min) that was competed in the incomplete workload. The workloads (W) corresponding to the first and second ventilation threshold (VT1 and VT2, respectively) were determined via previously described methods. The calculation of the power output corresponding to VT1, VT2 and VO2peak (MAP) allowed the determination of four levels of exercise intensity; these include phase I (<VT1), II (VT1 to VT2), III (VT2 to MAP) and IV (>MAP). Further three levels were determined based upon the SE of measurement in power output at VT1 (6.9%), VT2 (4.5%) and MAP (3.0%). These power output ranges were then compared with power outputs recorded during each field event (described below).

Field data collection

Before each event, the subject’s bicycle was fitted with a professional model SRM power metre (Schoberer Rad Mebtechnik, Julich, Germany), which recorded power output, cadence and speed every second. Overall performance times of all cyclists were retrieved from the official race timing results following each event. The environmental conditions of each race were retrieved from the Bureau of Meteorology following each event.

5-Day–eight-stage road race (Tour de Snowy)

The 2001 Tour de Snowy was an eight-stage road race (449.4 km) held in the Snowy Mountains of New South Wales, Australia, performed over five consecutive days (3–7 March 2001). During this event, cyclists participated in three short-circuit/criterium events (~30 km) and five short-distance to mid-distance road races (35–110 km). The race involved a total of five mountain passes, four of which were classified as category 2 and one of which was classified as a category 1. In total, 71 cyclists from 15 teams started the event, and 61 cyclists completed the race. Data were collected from six cyclists who competed in two separate teams. At commencement of the race, ambient air temperature was 18°C, relative humidity was 76% and wind speed was 7.6 km h⁻¹.

Individual road time trial

The women’s Australian National Road Time Trial Championship was conducted in Canberra, Australia on 11 March 2001 and involved a 24.2-km individual cycle time trial performed over two flat (<10-m elevation), equal distance laps (12.1 km). Data were collected on six cyclists. Upon commencement of the event, ambient air temperature was 18°C, relative humidity was 46% and wind speed was 15 km h⁻¹.

Exposure variation analysis

The quantification of the total time and acute time spent at various exercise intensities during all events was expressed using EVA and analysed using customised software written in Labview (National Instruments Corporation, Austin, Texas, USA). The EVA program developed for this study expresses power output during the various events as a tridimensional distribution. In short, EVA was used to separate field-based cycling power output into both time and amplitude domains. As with previous research, EVA quantified the percentage of overall race time (ie, cumulative time) that was spent within predefined levels of exercise intensity (ie, phase I to phase IV). In addition to this, EVA was also used to quantify the duration or length of time for which power output was maintained within each predefined level of exercise intensity (ie, acute time), without changing to another power band/level. For the purpose of this study, the overall time spent in each power band has been referred to as the “cumulative” or percentage of overall race time. The period for which power output was maintained in each power band, without changing to another power band, has been referred to as the “acute” time. To correspond with previous research, the levels of exercise intensity used in this study (ie, x axis; fig 1B) were based upon the power output corresponding to VT1, VT2 and MAP (table 1). The percentage of overall race time (z axis; fig 1B) and the acute time (y axis; fig 1B) spent at these exercise intensities were determined. The duration of each acute time band was determined based upon the hyperbolic relationship between power output and time to exhaustion. Briefly, the duration of each acute time band was increased by a factor of two (ie, 1.875, 3.75, 7.5, 15 and 30 s). The duration of the longest acute time band (30 s) was chosen to be similar to the duration of a typical cycling anaerobic test. Average EVA plots were then calculated by grouping data into an individual time trial (Australian National Time Trial), circuit/criterium events (total of four stages/events) and short-to-middle distance road races (total of five stages).

Statistical analyses

Data are reported as means (SDs) unless otherwise specified. Average power output and planned comparisons of particular intensity/duration bands during the various events were compared using a one-way repeated measure ANOVA. To statistically assess the variations in power output during the various events, the SD of the EVA matrix (EVA_SD) was calculated and compared using a one-way repeated measure ANOVA. A greater EVA_SD indicates that more time is spent within particular intensity/duration band, which therefore reflects greater monotony or less-even dispersion of power output.
circuit/criterium and road race events (p < 0.05), but no differences were found between the circuit/criterium or road race events (p = 0.009; fig 3A). The percentage of race time spent within set power bands for greater than 15 s was significantly different among the time trial, circuit/criterium and road race events (p < 0.05; fig 3B). The percentage of race time spent within set power bands for 3.75 to 7.5 s was significantly less during the road race, compared with the time trial and circuit/criterium events (p < 0.05; fig 3B).

The absolute power output (W) corresponding to Vo2peak (MAP) and VT2 was significantly correlated with average power output during the time trial (r = 0.96; p = 0.011; 95% CL = 0.67 to 1.00, and r = 0.93; p = 0.024; 95% CL = 0.48 to 0.99, respectively) and the circuit/criterium events (r = 0.92; p = 0.009; 95% CL = 0.43 to 0.99, and r = 0.93; p = 0.007; 95% CL = 0.48 to 0.99, respectively). No other physiological variables measured during the graded exercise test were significantly correlated with average absolute power output during the time trial, circuit/criterium and road race events. Average power output during the road race was significantly correlated with the percentage of overall race time spent at MAP (r = 0.89; p = 0.019; 95% CL = 0.25 to 0.99) and negatively correlated with the percentage of race time spent at VT1 (r = −0.33; p = 0.41; 95% CL = −0.98 to −0.06). Average power output during the time trial was significantly correlated with the percentage of overall race time spent at phase II (r = 0.86; p = 0.026; 95% CL = 0.16 to 0.98) and negatively correlated with the percentage of race time spent in the acute time band of 0–1.875 s (r = −0.95; p = 0.007; 95% CL = −0.99 to −0.48).

DISCUSSION

The purposes of the present study were to (1) investigate the power output distribution of elite-level female road cyclists performing in a variety of competitive cycling events through the use of EVA and (2) examine relationships between laboratory-based physiological variables and performance during competitive elite female cycling. The major finding from this study was that the specific race format influenced not only the overall time spent in various power bands but also the acute time spent at these exercise intensities.

The overall distribution of exercise intensity during the circuit/criterium events and road race events observed in this study (fig 3A) are comparable to that previously reported in...
mountainous/hilly stages of both male and female cycling events. Similarly, the average power output during the circuit/criterium and road race events (~170 W; table 2) is similar to that previously observed during a Women's UCI World Cup road cycling event that was performed over hilly terrain (169 (17) W). However, during the time trial, the distribution of power output relative to the subject's individual physiological variables (ie, VT1, VT2 and MAP) was considerably lower than that which has previously been reported in professional male cyclists. Lucia et al found that during the Tour de France, professional male cyclists perform more than 50% of their individual time trials at intensities above the second ventilation threshold (> phase III). In the present study, however, subjects only held intensities above second ventilation threshold for ~20% to 40% of the total time trial duration. Differences observed between these two studies may be due to differences in the methodologies used to assess exercise intensity. Indeed, Lucia et al examined the heart rate response of their elite cyclists during competition and compared this with heart rates obtained from an incremental exercise test. While the use of heart rate may provide detailed information regarding the overall physiological stress experienced during such events, it is possible that factors such as a delayed heart rate response to rapid changes in exercise intensity coupled with cardiovascular drift could result in an overestimation of the exercise intensity found in the Lucia et al study.

In the present study, power output during the various events was found to be highly variable. Indeed, the acute time spent in the moderate-to-high exercise intensity power bands (ie, > VT1) was extremely short (<15 s), irrespective of the racing format (fig 2). It is likely that such variable power outputs observed during the various events of the present study are a reflection of the variable external “field” conditions, such as wind, terrain and race dynamics. Increasing power output uphill and into headwinds and reducing power output during downhill and tailwinds sections may improve overall performance times during endurance cycling events. Thus, the variations in power output observed during the time trial event in the present study may have occurred in response to varying external conditions. During the circuit/criterium and road race events, however, race dynamics would have likely become increasingly more influential on the variability of pace observed during the event. During circuit/criterium and road race events, very little time was spent at exercise intensities between VT1 and MAP.
In conclusion, results of the present study have indicated that performance time during road race events was significantly correlated with the power output corresponding to VT1 and MAP during circuit/criterium events. Indeed, overall performance during the circuit/criterium events (table 2) was significantly correlated with the power output corresponding to VO2peak (ie, MAP) determined from the graded exercise tests. While overall performance during the road race events was correlated with the percentage of race time spent at MAP, average power output during the road race events was also negatively correlated with the percentage of race time spent in the acute time band of 0 to 1.875 s. Therefore, it seems that performance during road race events is not necessarily dictated by the ability to rapidly produce power, but may instead be influenced by the percentage of overall race time spent at high power outputs (ie, >MAP). The ability to produce high power outputs for prolonged periods was of increasing importance to overall road race performance in this particular case.

In conclusion, results of the present study have indicated that power output during competitive cycling may be highly variable and dependent on the specific racing terrain. Further, previous research using discrete Fourier transformation has found that dominant power frequencies bands may exist and be cycling task specific, although Fourier transformation is limited and not sensitive to changes in amplitude, frequency and time.

What this study adds

- Exposure variant analysis may be a useful tool for quantifying variations in the amplitude and time distribution of power output during cycling.
- The use of such research may enhance our understanding of the physiological demands of competitive cycling events and thus assist in the development of training programs, sport-specific testing and talent identification for cycling.
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Competing interests None.

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