REVIEW ARTICLE

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Characteristics of Track Cycling

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Abstract

Track cycling events range from a 200m flying sprint (lasting 10 to 11 seconds) to the 50km points race (lasting ≈1 hour). Unlike road cycling competitions where most racing is undertaken at submaximal power outputs, the shorter track events require the cyclist to tax maximally both the aerobic and anaerobic (oxygen independent) metabolic pathways. Elite track cyclists possess key physical and physiological attributes which are matched to the specific requirements of their events: these cyclists must have the appropriate genetic predisposition which is then maximised through effective training interventions. With advances in technology it is now possible to accurately measure both power supply and demand variables under competitive conditions. This information provides better resolution of factors that are important for training programme design and skill development.

Increased cycling performance can be achieved by decreasing the various sources of resistance and/or increasing the power output of the rider. The speed a cyclist moves is determined by the power supply available for skeletal muscle contraction from physiological sources [i.e. an individual's aerobic and anaerobic (oxygen independent) power and capacity] and the power demand required to overcome resistance (e.g. riding position, body mass, rolling resistance, air resistance, and gradient). Optimal performance occurs when the power supply from all available energy sources is efficiently harnessed to maximise speed over the race distance.[1] The aim of this review is to examine some of the physiological attributes required for successful, high performance track cycling and to discuss how modification of these can effect performance. Data on the physiology and bioenergetics of world class track cyclists during training and competition will also be reviewed.

1. Track Cycling Events

Track cycling is a generic term for all events that take place indoors and outdoors on a banked, hard surfaced track (wood or cement) which normally has a circumference of 333m or less. Track cycling can be divided into 2 broad categories: sprint (<1000m) and endurance races (>1000m). The principal events range from a 200m flying sprint lasting approximately 10 seconds to the 50km points race lasting approximately 1 hour. In addition, there is the prestigious 1-hour record where cyclists ride alone and cover the greatest distance possible.[2,3] At the recent Sydney 2000 Olympic Games, track cyclists competed in the following events: 200m sprint; Olympic sprint (male); 500m (female) and 1000m individual time trial (male); 3000m (female) and 4000m individual pursuit (male); team pursuit (male); points race; Madison and Keirin (male). A detailed explanation of each event is provided elsewhere,[4-6] with current world record times provided in table I.

1.1 Energetics of Track Events

Unlike road cycling, where most competitive events are performed at submaximal exercise in-

Table I. Current world record times for selected track cycling events, estimations of the contributions from the energy systems and estimated competition work rate (modified from Jeukendrup et al.,[7] with permission)

Event	World record (min:sec)	Contribution from the power systems (%)			Estimated competition work rate[a] (% $\dot{V}O_{2max}$)
		alactic	anaerobic glycolytic	aerobic	
200m sprint					
Male	0:09.865[b]	40	55	5	280
Female	0:10.831	40	55	5	235
Olympic sprint					
1st position	0:44.233[c]	40	55	5	355
2nd position		30	60	10	290
3rd position		20	40	40	245
Time trial					
Male (1000m)	1:00.148[b]	10	40	50	180
Female (500m)	0:34.010	20	45	35	245
Individual pursuit					
Male (4000m)	4:11.114[d]	1	14	85	105
Female (3000m)	3:30.816	1	24	75	110
Team pursuit					
Male (4000m)	4:00.958	1	24	75	125-135[e]
1-hour record (km)					
Male	56.375	<1	4	>95	85-90
Female	48.159	<1	4	>95	85-90

a Based on information from Craig et al.[8] and unpublished power output and $\dot{V}O_{2max}$ data.

b Ridden at altitude.

c World best time.

d Ridden in ‘Superman’ position on the bicycle. This position is now banned by the International Cycling Union (UCI).

e When cycling in lead position.

$\dot{V}O_{2max}$ = maximal oxygen uptake.

tensities and power outputs,[7] the medium duration track cycling events require the rider to tax maximally both the aerobic and anaerobic pathways.[9-11] Whilst the consensus is that to be successful in these events, both the aerobic and anaerobic powers and capacities need to be maximally developed through appropriate training, the optimal training strategies to achieve this outcome are still unclear.[12] The relationships between different track events and the proposed primary energy sources utilised have been outlined by Burke.[13] It should be noted that these estimated contributions are based on the concept that the energy sources for a given activity are time-dependent, assuming maximal effort during that time.[14] There is considerable variability in the estimated energy contributions to track events.[6,9,15,16] However, in the 4000m individual pursuit, a contribution of 70 to 80% of energy from aerobic pathways and 20 to 30% from oxygen-independent sources are typical.[6,9,15-17] For the female 3000m individual pursuit, the contribution of aerobic and anaerobic metabolism has been estimated at 75% aerobic and 25% anaerobic.[6] The most variable estimates of the energy contributions are for track events of <4000m. Both Oehme and Lychatz[6] and Astrand and Rodahl[18] proposed that the aerobic and anaerobic contribution to the 1000m time trial was 30 and 70%, respectively, which contrasts with the 5 and 95% contributions estimated by Burke.[13] Using the methods of Medbo et al.[19] to determine the contribution of aerobic and anaerobic energy release during short term exhausting cycling, the aerobic and anaerobic energy contributions to a 1000m time trial are likely to be closer to a 50 to 50% split.[10,20-23] Table I provides estimates of the aerobic and anaerobic energy contributions to the major track cycling events.

Finally, the oxygen uptake ($\dot{V}O_2$) kinetics respond much quicker than originally thought during short term exhaustive exercise.[10] As uptake kinetics are a trainable process[24] and as kinetic rise time has been reported to be a significant predictor of success of distances of <4000m,[9,10] this has significant implications for sport scientists and coaches when constructing training programmes for track cyclists. For example, shorter duration (30- to 90-second) intervals at supramaximal intensities may invoke improvements in $\dot{V}O_2$ kinetics.[10]

2. Physical and Physiological Characteristics of Track Cyclists

There have been relatively few studies to identify the key physiological variables associated with elite track cyclists. An examination of longitudinal data collected from the Australian Institute of Sports' track cycling laboratory (unpublished observations), in conjunction with previously published modelling data[1,9,10] provide insight into the major factors impacting on success in international track cycling.

2.1 Body Shape, Size and Composition

Cycle racing is one of the few sports where performance is determined by physical output in direct interaction with a mechanical device. Consequently, anthropometric parameters need to be considered in relationship to the bicycle set-up and rider's position during competition. McLean and Parker[25] described the relationship between selected anthropometric characteristics of 35 elite male Australian track cyclists to performance. Sprint cyclists were significantly heavier and stronger, and had larger chest, arm, thigh and calf girths than the endurance cyclists. However, no significant relationship was found between any anthropometric parameter and performance in an individual event. Figure 1 illustrates the body size profiles for all male and female cyclists competing at the Sydney Olympics across a number of track events.[27] A higher mesomorphy is important in the shorter events and this progressively decreases as the event distance increases. Sprint cyclists are generally shorter than other track cyclists. Time trialists and pursuiters are the tallest and most ectomorphic who also have longer leg–to–height ratios compared with other groups.[28] This reduces aerodynamic drag of the upper body and allows pursuiters to use much higher gear ratios than any of the other groups, probably because they can use longer crank arms (e.g. 170 *vs* 165mm).[29]

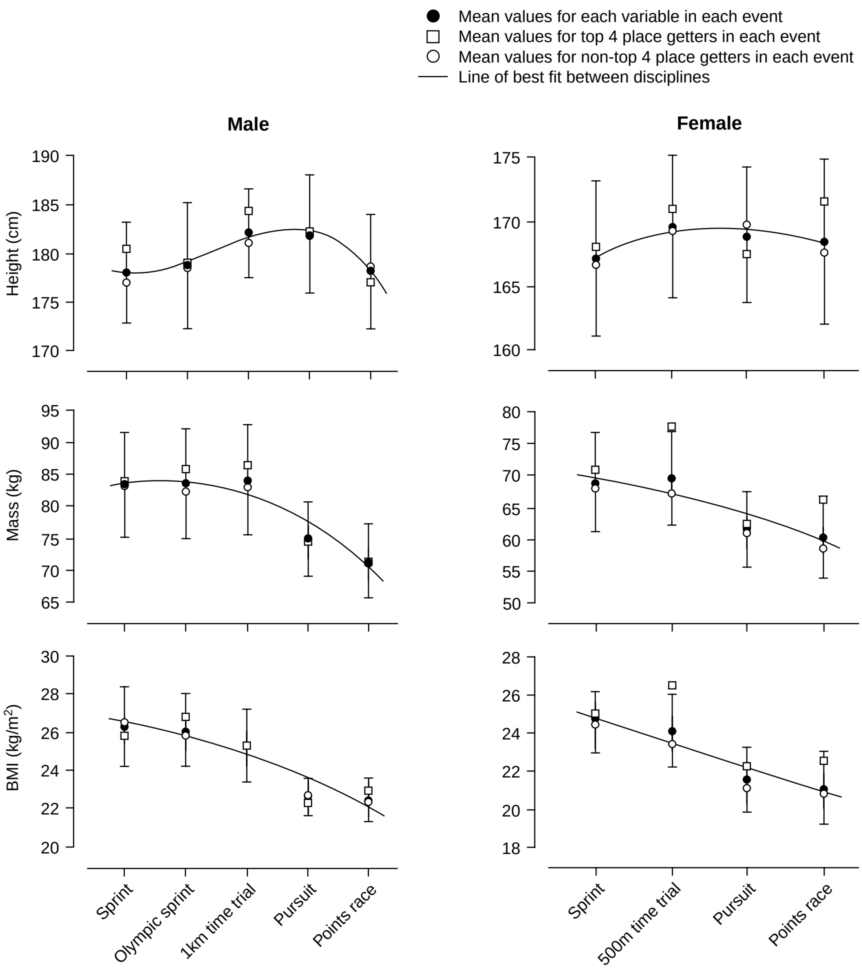

Fig. 1. The body size profiles [height, mass and body mass index (BMI)] for all track cyclists competing at the Sydney 2000 Olympics. The males (**left**) are from 5 track events (sprint, n = 19; Olympic sprint, n = 37; time trial, n = 16; pursuit, n = 57, points race, n = 23). The females (**right**) are from 4 track events (sprint, n = 12; 500m time trial, n = 17; pursuit, n = 11; points race, n = 18). The error bars indicate ± 1 standard deviation. Data are from www.Olympics.com.[26]

Also shown are the mean values for the top 4 place getters and the mean for all others in each of the events. For each event there is an optimal body shape and the winners tend to be bigger versions of this shape in events of 4000m or less.

It is generally accepted that a low relative body fat is desirable for successful performance in almost any sport, as additional body fat adds to the mass of the body without contributing to its force or energy contributing capabilities.[30] With respect to track cycling, increased nonfunctional mass has a triple effect of decreasing performance since it increases the energy cost of acceleration, rolling resistance and the projected frontal surface area of the cyclist.[31] As expected, both male and female elite track cyclists average among the lowest levels of body fat of any sport.[9,10,25,30,32-37] This is not surprising since Australia's elite track cyclists ride in excess of 35 000km per year. From a practical point of view, Olds et al.[1,38] estimated that an increased body fat mass of 2kg would increase a 4000m individual pursuit cycling performance time by about 1.5 seconds, which equates to a distance of approximately 20m. Kyle[39] estimated a 3.5% increase in nonfunctional mass would increase the cyclist's time over 1000m by 0.15 seconds.

2.2 Maximal Oxygen Consumption

A consideration of the relative contributions of the aerobic and anaerobic metabolic energy systems to track cycling events (table I) highlights the importance of a high aerobic capacity for success in most track cycling events. The ability to rapidly reach and thereafter sustain a high maximal oxygen uptake ($\dot{V}O_{2max}$), enables a large, rapid and sustained aerobic energy release that reduces premature reliance upon a large proportion of the finite oxygen deficit. $\dot{V}O_{2max}$ values >90 ml/kg/min have been measured in 2 male pursuit cyclists (world champions, world record holders and Olympic medallists). Both of these cyclists exhibited significant arterial O_2 desaturation (%S_aO_2 ≈90%) during simulated 4000m individual pursuit.[40] Interestingly, when the fraction of inspired oxygen (F_IO_2) was raised to 0.3, S_aO_2 was also elevated to full saturation. During the hyperoxic condition at a constant supramaximal work rate (115% $\dot{V}O_{2max}$), there was a significant reduction in blood lactate, ventilation, adrenaline and noradrenaline levels. Although it was not possible to measure $\dot{V}O_2$ during these hyperoxic performances it was estimated that $\dot{V}O_2$ was approaching 100 ml/kg/min in these athletes.[41]

As high aerobic power is strongly associated with track cycling success,[9] peak values in excess of 80 ml/kg/min for males and 70 ml/kg/min for females are considered prerequisites for successful world class athletes.[8] As $\dot{V}O_{2max}$ and its response to training are under strong genetic control[42] then obviously a high aerobic power base is mandatory for successful track cycling performance. This is highlighted by a male track cyclist reported by Jeukendrup et al.[7] who, in the off-season with little training, recorded a value of 74.3 ml/kg/min. In preparation for the National Championships 6 months later, this value rose to 84.8 ml/kg/min.

In comparison to road cyclists, there is a distinct lack of $\dot{V}O_{2max}$ descriptive data for elite track cyclists.[9,33,34,43-46] Recently, aerobic power data for elite male and female track cyclists, including the training phase, were reported.[8] $\dot{V}O_{2max}$ showed significant variation throughout the training year as a result of alterations in the amount of training volume and intensity. Sjogaard et al.[45] reported changes of up to 22% in the relative $\dot{V}O_{2max}$ of a Danish track cyclist over a 12-month period while Jeukendrup et al.[7] reported longitudinal changes in aerobic indices over a 6-year period for an elite male 4000m team pursuit cyclist. In terms of cycling performance, Olds et al.[1] predicted that a 15% improvement in $\dot{V}O_{2max}$ (5.14 to 5.91 L/min) would enable the track cyclist to complete a 4000m individual pursuit 15.5 seconds faster.

2.3 Blood Lactate Transition Thresholds

The blood lactate transition thresholds, particularly for the track endurance athletes occur at high absolute and relative work rates.[9,46] Furthermore, a significant correlation has been found between the power output at which the thresholds occurred and performances in a group of national level track cyclists.[9] Studies by Aunola et al.[47] and Ivy et al.[48] have demonstrated that blood lactate transition threshold indices reflect the muscle metabolic status or peripheral component of the oxygen transport system, with $\dot{V}O_{2max}$ closely related to and limited by central mechanisms.[49] Both the peripheral and central components of aerobic metabolism have been reported to relate to track cycling performance.[9] Such a finding has implications for training: the optimal way to train these 2 components may not necessarily be the same.[49]

2.4 Anaerobic Capacity

The existence of a significant anaerobic energy contribution during a cycling event is often indicated by a high post-competition blood lactate level.[50] In track cycling events, under competition conditions, post-competition blood lactate

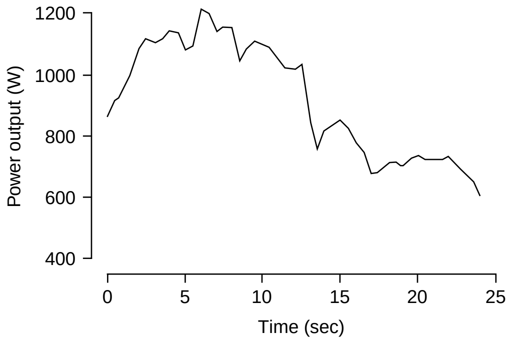

Fig. 2. Power output profile of a female 200m flying sprint.

levels of 11.6 to 22.0 mmol/L have been reported.[6,9,11,33,34,51] These values are not surprising when the racing profile of each track event is considered. For example, de Koning et al.[52] have proposed the best result at the 1000m time trial is obtained when cyclists have the highest anaerobic peak power output and use an 'all-out' pacing strategy. On the other hand, the fastest time in the 4000m individual pursuit is achieved with an 'all-out' start at a high level of initial power, followed by a constant anaerobic power output after the first 12 seconds. After instantaneous power outputs of >1000W at the start, there are power output fluctuations of between 600 to 650W while riding in the lead position during a 4000m team pursuit.[7,53] Craig et al.[9] reported a significant correlation between accumulated oxygen deficit and 4000m individual pursuit performance. Sprint cyclists had a significantly greater anaerobic capacity (66.9 ± 2.2 ml/kg) compared with endurance track cyclists (57.6 ± 6.7 ml/kg).[10] Saltin[54] proposed that a maximal accumulated oxygen deficit (MAOD) value of 100 ml/kg is a likely estimate for a highly trained male 4000m individual pursuit cyclist.

Anaerobic capacity can be improved with appropriate training: Medbo and Burgers[55] reported a 10% increase in MAOD after 6 weeks of high intensity interval training. Such a change in MAOD could, potentially, improve 4000m individual pursuit time by ≈1 second.[1]

3. Competition Power Output

The power output required for successful track cycling performance depends upon variables such as bicycle speed, bicycle design and associated components, cyclist's size and position and environmental factors. Until recently, scientists and coaches have developed and employed mathematical models to estimate the mechanical power requirements of the different track cycling events.[1,3,51,56] While such models have been reasonably accurate, the SRM bicycle crank dynamometer has made it possible to accurately quantify instantaneous power output during track cycling events.[57] In addition to mechanical power, the SRM also measures and stores speed, distance covered, cadence and heart rate. As such, there are now data characterising the demands of elite track cyclists during training and international competition.

3.1 200m Sprint

Figure 2 shows power output data for a female cyclist during a 200m flying qualification sprint at a World Cup event. Peak and average power output during the 200m were 1020 and 752W, respectively. Power output at the end of the 200m was 568W which equates to a 44% drop-off from the peak power. Speed and pedalling cadence peaked at 63.5 km/hour and 150 rpm, respectively, with an average cadence of 142 rpm.

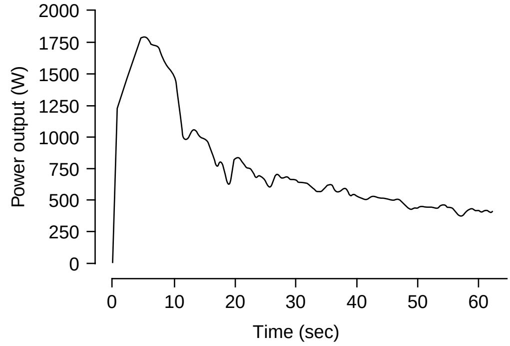

Fig. 3. Power output profile of a 1000m time trial.

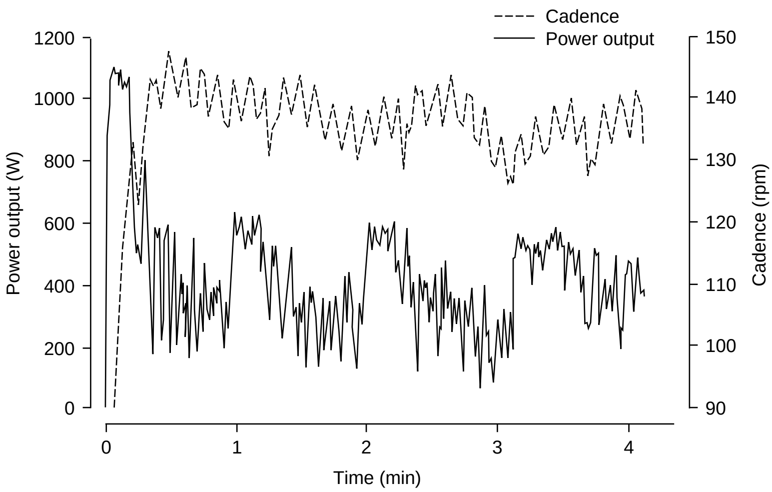

Fig. 4. Power output and cadence profile of a 4000m team pursuit cyclist.

3.2 1000m Time Trial

Figure 3 depicts the power output profile of an elite male cyclist during a 1000m time trial at an international competition. Most notable is the 1799W peak power output at the start and the minimum 399W at the finish, representing a 78% decay in power output. Average power output for the event was 757W at an average cadence of 127 rpm. This profile is typical of that suggested by de Koning et al.[52] who advocates an 'all-out' strategy when riding this event. This pacing strategy may be critical since a significant correlation was found between first lap and final time for the top eight 1000m time trialists at the 1998 World Championship.[52] However, there was no relationship between final lap and finishing time.

3.3 4000m Team Pursuit

Broker et al.[53] were the first to report SRM power output profiles on elite track cyclists during a simulated competition. Recently, Jeukendrup et al.[7] published SRM power output profiles on elite team pursuit cyclists during a World Cup competition. Both researchers reported power output requirements for riders cycling in the lead position. An average power output of 607 ± 45W was reported by Broker et al.[53] which was slightly higher than the 581 ± 43W found for riders under actual competition conditions.[7] This variation could be caused by differences in riding speed, skill, technique, position, body mass, frontal surface area, equipment design, environmental and track conditions. For cyclists riding in positions 2, 3 and 4, Broker et al.[53] reported average power output values of 430 ± 39, 389 ± 32 and 389 ± 33W, respectively. Such values clearly demonstrate the importance and advantage of drafting and the associated high degree of skill required to be a successful team pursuiter. The closer one cyclist follows another, the greater the drag reduction, with the total wind resistance declining from an average of 44% at 1.7m between riders (or zero wheel gap), to only about 27% at 3.7m between riders (or a 2m wheel gap).[58]

Figure 4 presents the power output profile of a single rider during a 4000m team pursuit in a World Cup competition (unpublished observations). Instantaneous power output was approximately 1100W at the start and only dropped to <1000W after the first 10 to 12 seconds of the race. Thereafter, depending on the rider's position in the team, power output fluctuated between 550 to 600W in the lead position and 350 to 400W when following other team members. Despite these power output varia-

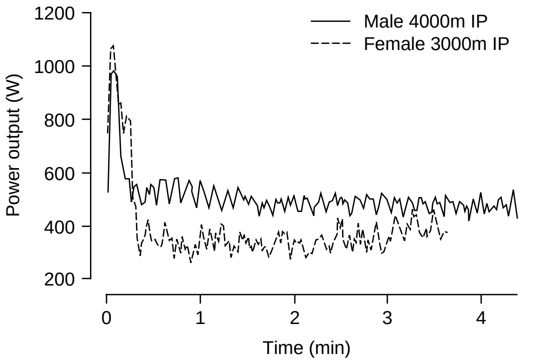

Fig. 5. Power output profiles of a male and female individual pursuit cyclist (from Jeukendrup et al.,[7] with permission). **IP** = individual pursuit.

tions the cadence was held within a narrow range from the lead to the fourth wheel position. This clearly illustrates the stochastic power demands of team pursuit racing and highlights the need to have good riding technique and changing skills.

3.4 4000m Individual Pursuit

In contrast with the large oscillating power requirements of the 4000m team pursuit, the power profile for rider's competing in 4000m individual pursuit races are much more even. Figure 5 displays the power output profiles for an elite male riding a 4000m and an elite female riding a 3000m individual pursuit during World Cup events. The average power output values for the riders were 495 and 381W, respectively, and there was a much narrower range of power outputs required to ride the individual pursuit. Figure 6 illustrates that the power output and speed profiles are still oscillating by up to 100W and 3 km/h with no section being covered uniformly. The power and speed fluctuations are proportional to the cyclist's position on the track, with the power output always lowest in the bends when velocity is at its highest. In contrast, power output is highest and velocity lowest at the beginning and in the middle of the straight (represented as point A in figure 6). The ability to minimise these power output and speed fluctuations by improved pedalling technique is a characteristic seen in the best pursuit cyclists (unpublished observations).

3.5 Madison

For the first time ever, the Madison was included as an Olympic event at the Sydney 2000 Olym-

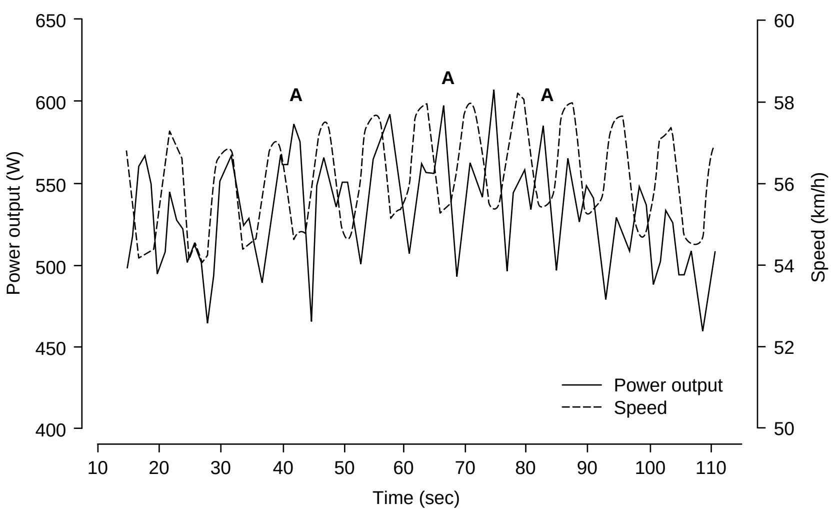

Fig. 6. Power output and speed characteristics during a 4000m individual pursuit. **A** = where power output is highest and velocity lowest (at the beginning and in the middle of the straight).

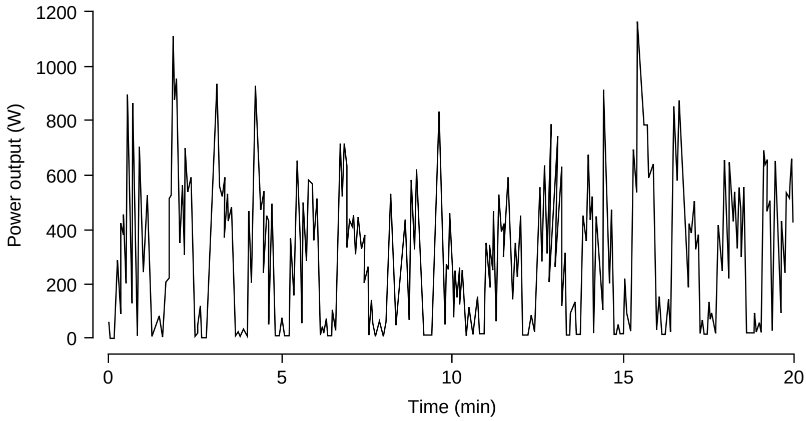

Fig. 7. Power output profile of a Madison track event.

pic Games. It is an event comprising teams of 2 riders, with each rider taking turns in racing and recovery. A 20-minute power output profile of a Madison World Cup competition is presented in figure 7. Typically, work:recovery ratios are in the order of 1 : 1 (35 to 40 seconds duration). When contrasted with the team pursuit, the work : recovery power outputs are more extreme. Figure 8 shows a frequency distribution for the percentage of time spent at various power outputs during an entire Madison event. Even though the peak and average power outputs were 1157 and 287W, respectively, the Madison is clearly a dichotomy of work effort where a large proportion of the competition time is shared by the extremes of power output.

4. Programme Design and Monitoring

Track cycling is a sport with a wide variety of events ranging from very short match sprints of about 10 seconds to a 50km points race or Madison lasting ≈1 hour. The different demands of competition obviously call for implementation of specific training activities. Boulay[59] and Burke[60] have summarised these activities according to the approximate contribution of the aerobic and anaerobic energy sources. In devising an appropriate training programme for an elite track cyclist the selection will be influenced by the experience and knowledge of the coach and cyclist. Each cyclist may respond differently to the same exercise stimulus.

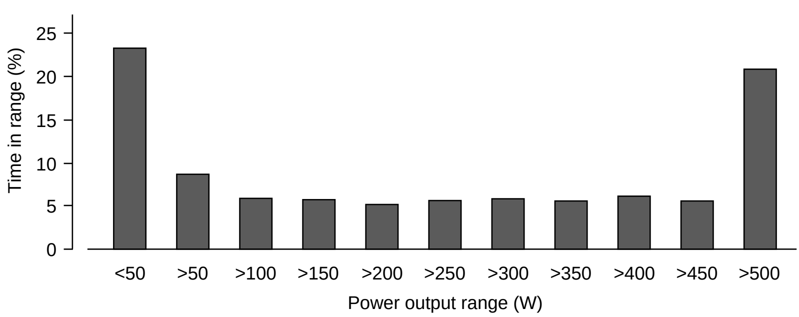

Fig. 8. Frequency distribution for a percentage of time spent at various power output ranges during a Madison track event.

Table II. Monitoring data during a track training session for a 4000m team pursuit cyclist

Interval no.	Rate (km/h)	Gold medal speed (4 min 00 sec) [%]	Average PO (W)	Average PO (W/kg)	Cadence (rpm)	HR (bpm)	$\%HR_{max}$	%IAT	PO in lead position (W)	PO in lead position (W/kg)	PO in lead position %IAT PO	HLa (mmol/L)	pH	HCO_3-1 (mmol/L)	RPE
Pre												2.1	7.391	25	
1 - TP	48.0	80.0	267	3.8	122	162	84	70	359	5.1	94	2.5	7.383	24	3
2 - TP	47.7	79.5	273	3.9	122	167	86	71	361	5.1	94	2.1	7.418	26	3
3 - IP	48.5	80.8	267	3.8	122	164	85	70	IP			2.0	7.462	27	3
4 - IP	48.6	81.0	268	3.8	124	165	85	70	IP			1.9	7.444	27	3
5 - TP	49.8	83.0	284	4.0	128	170	88	74	411	5.8	107	3.4	7.382	22	5
6 - TP	50.1	83.5	300	4.2	128	173	89	78	425	6.0	111	3.6	7.387	23	6
7 - TP	51.1	85.2	318	4.5	131	179	92	83	433	6.1	113	4.9	7.355	21	8
8 - TP	51.4	85.7	333	4.7	131	182	94	87	452	6.4	118	6.2	7.317	18	8
9 - IP	52.7	89.3	326	4.6	134	183	94	85	IP			7.7	7.327	18	7
10 - TP	52.7	89.3	358	5.0	135	181	93	93	482	6.8	126	10.9	7.215	13	9

HLa = blood lactate level; **HR** = heart rate; **IAT** = individual anaerobic threshold power output; **IP** = individual pursuit; **PO** = power output; **RPE** = rating of perception of effort; **TP** = team pursuit.

Examples of general programme designs are provided in the literature.[6,59-62]

By repeated monitoring of selected training sessions, the coach is able to control the quality and quantity of the training, help prevent overtraining and quantify the overall training programme.[59,63-66] Boulay[59] has suggested a variety of physiological variables (i.e. heart rate, lactate, $\dot{V}O_2$) to monitor and quantify training. In the past, the monitoring of these variables would have been difficult, but with the advent of improved technology, many of these variables can be measured accurately and reliably in the field. Table II provides an example of monitoring data during a track training session for a 4000m team pursuit cyclist (unpublished observations). The training session consisted of ten 4km efforts in mainly team pursuit formation at a variety of prescribed speeds. Heart rate, blood lactate, blood pH and bicarbonate, power output, speed and cadence were all monitored for the cyclist. Training power output data were also related to the cyclist's individual anaerobic threshold power output as previously described.[8] The collection of these data provided the coach with an objective assessment of the athlete's level of fatigue and enabled the sport scientist to quantify the session in terms of training volume and intensity.

5. Conclusion

This review outlines the physical and physiological characteristics of high performance cyclists in a range of different track events. Each event has its own set of body type and metabolic requirements in order for the athletes to achieve international success. These specific profiles guide the process of morphological and physiological optimisation of the athletes in each event. This increased degree of specialisation has resulted in improved cycling performances, particularly during the last decade.

The selection of the best juniors through the systematic identification of genetic potential in talent programmes has been in operation in many countries for considerable time. We believe the ability to further develop the physiological attributes of this select pool of talent may be reaching a plateau. It is likely that future improvements in cycling performances will disproportionately come from reductions in the energy demand side of cycling. Currently athletes are dedicating themselves to full-time training. This involves thousands of kilometres of riding which is pushing them to the extremes of training volume and intensity. Even relatively large additions in their physiological attributes, if it were possible, would not necessarily result in corresponding improvements in performance times. This is because a small increment in speed requires a cubic rise in power output. The question now facing coaches, sport scientists and cycling administrators is ‘where do we spend our time and resources – improving the energy supply (i.e. training) or decreasing the energy demand (i.e. equipment modifications and innovations)?’

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