Journal of Sports Sciences, 1998, **16**, S91–S99

Heart rate monitoring during training and competition in cyclists

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To obtain optimal training effects and avoid overtraining, it is necessary to monitor the intensity of training. In cycling, speed is not an accurate indicator of exercise intensity, and therefore alternatives have to be found to monitor exercise intensity during training and competition. Power output may be the most direct indicator, but heart rate is easier to monitor and measure. There are, however, limitations that have to be taken into account when using a heart rate monitor. For example, the position on the bicycle may change heart rate at a given exercise intensity. More important, however, is the increase in heart rate over time, a phenomenon described as 'cardiac drift'. Cardiac drift can change the heart rate–power output relationship drastically, especially in hot environments or at altitude. It is important to determine whether one is interested in monitoring exercise intensity *per se* or measuring whole-body stress. Power output may be a better indicator of the former and heart rate may, under many conditions, be a better indicator of the latter. Heart rate can be used to evaluate a cyclist after training or competition, or to determine the exercise intensity during training. Heart rate monitoring is very useful in the detection of early overtraining, especially in combination with lactate curves and questionnaires. During overtraining, maximal heart rates as well as submaximal heart rates may be decreased, while resting – and, in particular, sleeping – heart rates may be increased.

Keywords: cycling, exercise intensity, heart rate, overtraining, power.

Introduction

The key components of athletic training are frequency, duration and intensity. Frequency and duration are easily controlled, but the intensity of exercise in cycling is dependent on many factors and therefore more difficult to control. Exercise intensities that are too low may not result in the desired training effect, whereas a too high training intensity may cause overtraining (Kuipers and Keizer, 1988). It is important, therefore, to have practical means of monitoring the exercise intensity during training. Although the term 'intensity' is used daily by athletes, coaches and scientists, the term is vague and poorly described. What do we mean by exercise intensity? Is it speed, heart rate, percentage of maximal heart rate (%HR_{max}) or heart rate reserve (%HRR), the percentage of maximal oxygen uptake ($\dot{V}O_2$ max), or is it power output, energy expenditure or perceived exertion? (see Table 1). For instance, unlike in swimming and running, speed is not always a good indicator of exercise intensity in cycling. Environmental and physiological factors have a large impact on speed. Factors such as wind, air temperature, air density, humidity and terrain may change the speed at a given power output. Therefore, heart rate monitors may provide a more accurate index of exercise intensity than speed.

Table 1 Different indicators of 'intensity' that have been used

Speed	Heart rate
$\dot{V}O_2$	% Maximal heart rate
% $\dot{V}O_2$ max	% Heart rate reserve
Power	% Lactate threshold
Energy expenditure	%Ventilatory threshold
Perceived exertion	Maximal lactate steady state
Multiples of resting metabolic rate (MET)	

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0264–0414/98

Here, we try to define the term 'exercise intensity' and describe some recent developments in cycling, methods to measure exercise intensity, the use and the limitations of heart rate monitors and provide some recommendations. Case studies of professional cyclists will be used to support some of our conclusions.

Defining 'exercise intensity'

In the past, exercise intensity has been expressed in terms of speed, heart rate, the percentage of $\dot{V}O_2$ max, the percentage of lactate threshold and power output. However, we believe that exercise intensity should be determined as the amount of ATP that is hydrolysed and converted into mechanical energy each minute, and may therefore best be defined as the amount of energy expended per minute to perform a certain task (kJ min^{-1}). Unfortunately, it is difficult to measure energy expenditure continuously in the laboratory and virtually impossible to monitor in the field. Therefore, exercise intensity should be determined from a variable that is closely related to energy expenditure and easy to monitor. In the laboratory, the preferred variable has usually been $\dot{V}O_2$ (Åstrand, 1984), although others have used power output (Kuipers *et al.*, 1985; Hawley and Noakes, 1992; Jeukendrup *et al.*, 1996). In the field, speed and heart rate have been used. Technological innovations have led to the development of a power measuring device which allows the measurement of power output in cyclists. This system, which is claimed to be accurate to within 1%, consists of a number of strain gauges mounted within a deformable disc between the crank arm and the chain ring. The signals are transferred to a computer mounted on the handlebars. Before discussing some of the ways to monitor exercise intensity, we describe some of the recent developments in cycling.

Developments in cycling: Speed and power

Over the last decade, bicycle racing speeds have increased considerably (Fig. 1). This is best reflected in the hour world record. Henri Desgrange was the first to set an hour record in Paris in 1893 (35.325 km). Since then, the record has been held by cycling champions like Fausto Coppi (45.848 km in 1942), Jacques Anquetil (46.159 km in 1956) and Eddy Merckx (49.431 km in 1972). In 1984, Francesco Moser recognized the importance of aerodynamics. Using a special bike, including the first disc wheel, he broke Merckx' record, which had stood for 14 years, by totalling 51.151 km. This was also the first time the 50-km barrier was passed. Nine years later, in 1993, Graeme Obree rode 51.596 km in a highly aerodynamic position (tuck position). This riding position was later to be banned by the UCI (Union Cycliste Internationale). Since that time, speeds have increased rapidly (Fig. 1). Chris Boardman rode 52.270 km in 1993, but Obree successfully regained the record in 1994 (52.713 km), riding in a new aerodynamic position ('superman' position). In 1994, on the same track, both five-times winner of the Tour de France, Miguel Indurain, and Tony Rominger, broke the record. Rominger's second attempt took the distance covered to an incredible 55.291 km. In 1996, Boardman attacked the hour record on the velodrome in Manchester and achieved a distance of 56.375 km, the current record. As shown in Fig. 1, over the last few years speeds have increased dramatically. The current record is 10% faster compared to Moser in 1984 and as much as 14% faster compared to Merckx in 1972.

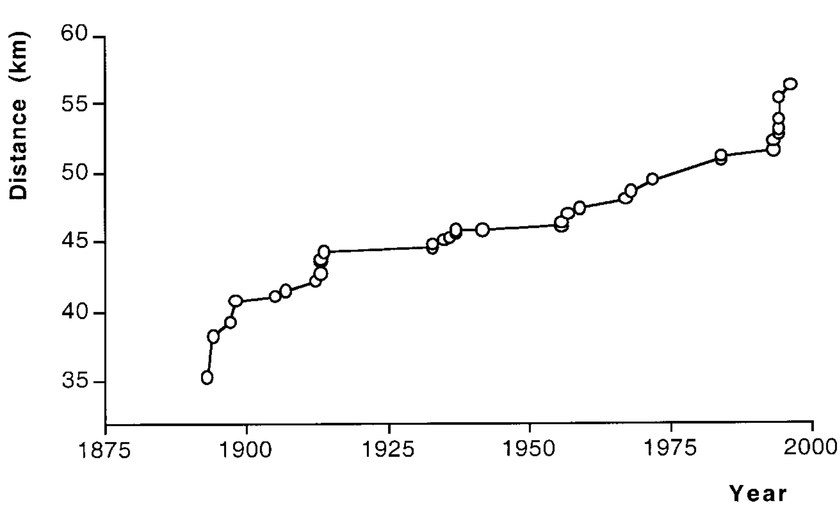

Figure 1 The hour record over time.

These changes have been attributed in the main to changes in aerodynamics – changes in body position and improvements in equipment – which have caused a significant reduction in the energy cost of cycling. The improved aerodynamics are impressive, but may only explain in part the increased speeds. Modern cyclists are also more powerful.

Speed as a method of monitoring exercise intensity

In running and swimming, speed is often used as an indicator of exercise intensity. Speed is often an accurate reflection of energy turnover in the exercising body. However, in cycling, this may not be the case. An example may be the hour record. For example, wind tunnel measurements revealed that Obree experienced a 15% reduction in drag when he broke the record in 1993 compared with his normal aerodynamic position. This provided an advantage of 2 km h^{-1} at a speed of 50 km h^{-1}, so with the same power output he could be 2 km h^{-1} faster. The lack of a relationship between cycling speed and exercise intensity is even more clear when cycling on hilly roads. Uphill, speeds will be lower, while power output and heart rate are high; downhill, speeds are high, but power output and heart rate are low.

Another example when the speed–intensity relationship is disturbed is during 'drafting'. When drafting behind cyclist A, cyclist B will have the same speed as cyclist A, but because of reduced air drag, the power output of cyclist B will be lower and therefore his oxygen uptake and heart rate will be reduced (McCole *et al.*, 1990). Figure 2 plots speed versus power output during a 3-h training session. It is evident that there is a poor correlation between these two variables. In fact, in the example displayed, the correlation is negative. This indicates that speed is not a good indicator of intensity in cycling and therefore alternatives have to be found.

Power as a method of monitoring exercise intensity

Recent technological developments have made it possible to measure power output on a bicycle with a power measuring device. Although several manufacturers have developed power measuring devices (e.g. Look MaxOne, France), the current most reliable and most commonly used system is the SRM Training System (Schoberer Rad Messtechnik SRM, Jülich, Germany), which can be mounted on a bicycle and which is able to record power and store the data in its memory (together with information about speed, distance covered, cadence and heart rate). By using this device, it is possible to estimate exercise intensity by monitoring the actual outcome of muscular work – that is, power output. Data from such measurements during a mountain stage in the 1996 Tour de France are displayed in Fig. 3. This figure also displays the stochastic nature of road cycling (Palmer *et al.*, 1994).

Power output may be the most direct indicator of exercise intensity (i.e. energy expenditure). Power output may predict energy expenditure (exercise intensity) very well, because gross efficiency is believed to be

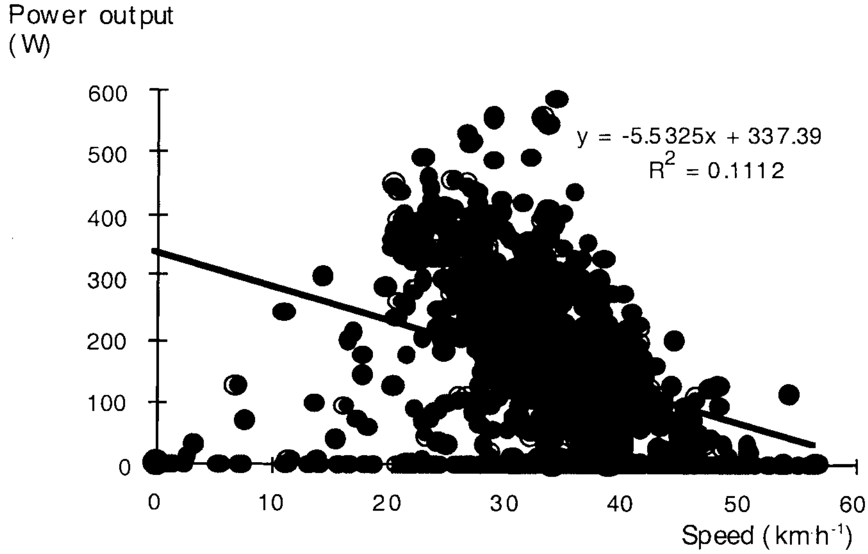

Figure 2 Correlation between cycling speed and power output during a 3-h training session for a cyclist on the road (SRM sample interval = 10 s).

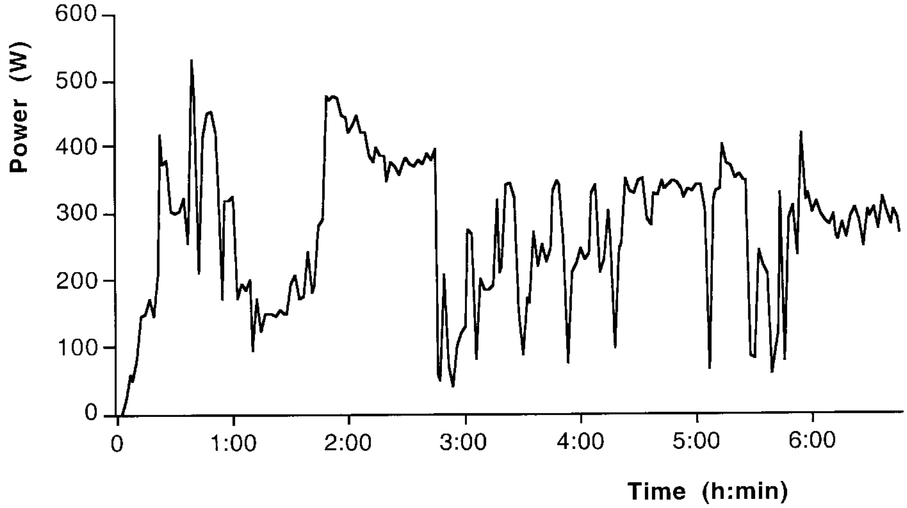

Figure 3 Power of one professional cyclist (body mass 70 kg) during a mountain stage of the 1996 Tour de France (SRM sample interval = 60 s) (Leinders and Jeukendrup, unpublished observations).

relatively constant (Gaesser and Brooks, 1975). (Gross efficiency is calculated as work accomplished divided by energy expended.) However, it is not always possible to use power output to maintain a certain exercise intensity, because power output is much more variable than, for example, heart rate. Figure 4 shows that, during a 170-km race, there are variations in power output, whereas heart rate is much more constant.

Heart rate as a method of monitoring exercise intensity

Using heart rate monitoring alone, Conconi proposed a method to determine the exercise intensity that coincides with the 4 mmol l^{-1} lactate exercise intensity (Conconi *et al.*, 1982). This so-called 'heart rate breakpoint' is based on the deflection point in the sigmoidal heart rate versus power output (or speed) curve that results from a progressive incremental exercise test. Some studies (Conconi *et al.*, 1982; Droghetti *et al.*, 1985; Bunc *et al.*, 1995), but not others (Coen *et al.*, 1988; Kuipers *et al.*, 1988; Leger and Tokmakidis, 1988; Tiberi *et al.*, 1988; Francis *et al.*, 1989), found a breakpoint or deflection point when the exercise intensity was rapidly increased towards exhaustion. We recently argued that the deflection point is an artefact rather than a physiological phenomenon (Jeukendrup *et al.*, 1997). The reason for this is as follows. When the duration of each exercise intensity is very short (< 1 min), the adaptation of the circulatory system to a certain speed or work rate will be incomplete and heart rate will start to lag behind progressively. When heart rate is plotted as a function of speed or work rate, a deflection point is automatically found. However, when the duration of each step (i.e. each exercise intensity) is longer, some adjustment of the cardiovascular system will take place and it is more difficult or even impossible to find the deflection point. Therefore, we believe that the heart rate deflection point, as determined by the Conconi test, is an artefact rather than a reflection of the lactate threshold.

Evidence against a causal relationship between the heart rate deflection point and the lactate threshold was provided by two recent studies. Thorland *et al.* (1994) observed a different relationship between the heart rate deflection point and the lactate threshold when the nutritional status of subjects changed. They concluded that only 4% of the variance in the change in the lactate threshold could be explained by changes in the heart rate deflection point. Maffuli *et al.* (1987) found similar results when both points were determined before and after a marathon. However, despite scientific criticism, many coaches and athletes apply the Conconi test successfully and find it useful.

Heart rate may change with position

When using aerobars, the frontal area will be lower and the drag coefficient is reduced. However, it has been suggested that this position may be less efficient and oxygen uptake and heart rate may be increased in the laboratory (Gnehm *et al.*, 1997). Gnehm *et al.* (1997) studied 14 male elite cyclists in three different positions: upright, hands on drops and hands on clip-on aerobars. In the aerodynamic position, heart rate was on average

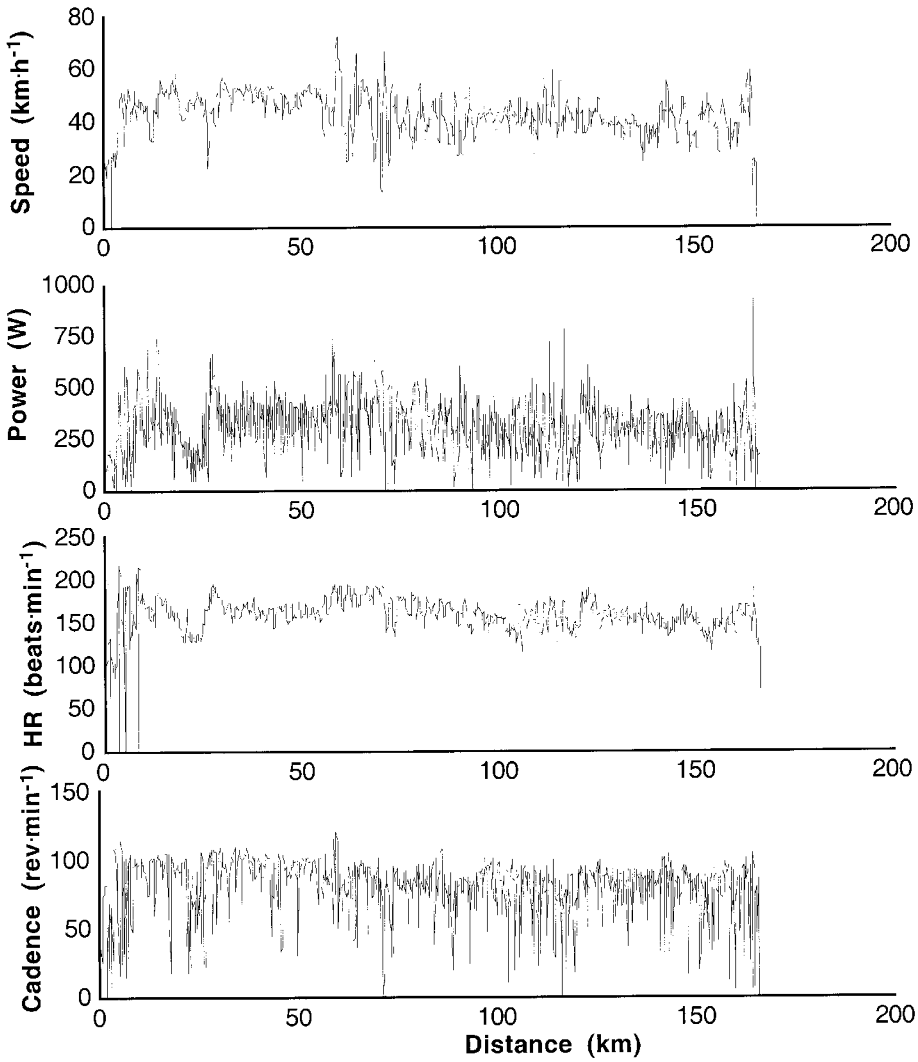

Figure 4 Information from SRM obtained during a 170-km race with a sample interval of 10 s. There is a large variation in the power output, while heart rate is much more constant. Besides power output and heart rate, the SRM provides information about speed and cadence.

5 beats min^{-1} higher compared to the upright position. This was attributed to the increased contribution of the shoulder musculature and a less efficient hip angle.

Heil *et al.* (1995) reported that submaximal heart rate was higher with a 69° seat tube and 20° trunk angle compared to 76°, 83° and 90° seat tube angles. It should be noted, however, that a 69° seat tube angle is fairly extreme, since most bicycles have seat tube angles between 72° and 76°. It has also been suggested that an aerodynamic position on the bike (low trunk angle) may increase the static load on the shoulder musculature and thereby dissociate the heart rate–$\dot{V}O_2$ relationship (Heil, 1997). These studies suggest that extreme hip angles result in a higher metabolic cost. However, the effects on heart rate may be small compared with, for example, the effect described as 'cardiac drift'.

Cardiac drift

The phenomenon of cardiac drift (an increased heart rate during exercise over time) is another factor that may limit the use of heart rate monitors in training. Heart rates have been shown to drift upwards by as much as 20 beats min^{-1} during exercise lasting 20–60 min, despite unchanged work rates and steady or decreasing plasma lactate concentrations (Kindermann *et al.*, 1979; Mognoni *et al.*, 1990). In a recent study, Boulay *et al.* (1997) had their subjects exercise at a fixed heart rate by adjusting the work rate continuously. The heart rate selected corresponded to 5% below the heart rate at the ventilatory threshold. Although heart rate was relatively stable (176–180 beats min^{-1}), the work rate had to be reduced significantly over time (17% reduction, from

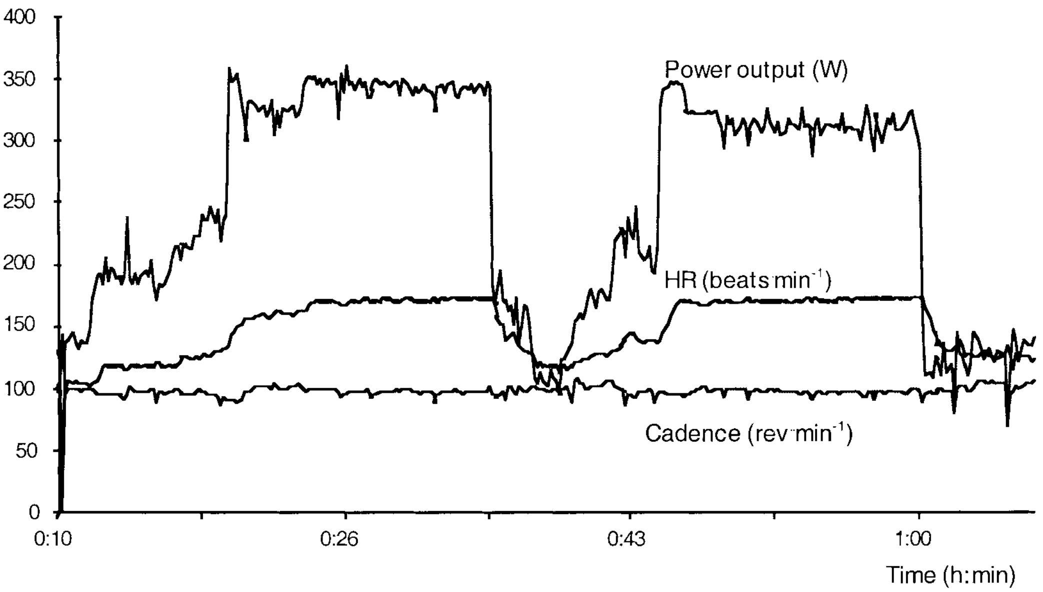

Figure 5 An example of a training session for a professional cyclist in which heart rate was kept constant (between 167 and 170 beats min^{-1}) during two bouts of 15 min each. In the second 15-min block, power output decreased by 23 W (SRM sample interval = 10 s).

about 220 to 183 W). Similarly, oxygen uptake was reduced from 80% $\dot{V}O_2$ max at 20 min to 73% $\dot{V}O_2$ max after 80 min. Comparable observations have been made in the field. Figure 5 shows a 1-h training session for an elite cyclist. This cyclist exercised twice for 15 min at heart rates between 167 and 170 beats min^{-1}. In the second 15-min block, power output decreased by 23 W.

Both exercising in a hot environment and dehydration increase cardiac drift even further. In a study by Montain and Coyle (1992), in which subjects exercised at 62–67% $\dot{V}O_2$ max in the heat (33°C, 50% relative humidity), heart rate increased 40 beats min^{-1} after 100 min of exercise when no fluid was ingested. Fluid ingestion helped to restrict the increase in heart rate, but it still increased by 13 beats min^{-1}. Although dehydration increases cardiac drift, euhydration or hyperhydration may not always prevent cardiovascular drift (Hamilton *et al.*, 1991; Montain and Coyle, 1992). These results indicate that the relationship between heart rate and exercise intensity (i.e. energy expenditure) is susceptible to changes, and heart rate recorded during training may not reflect muscular work.

Altitude

Altitude also affects the relationship between heart rate and energy expenditure. When exercising at a certain work rate in hypoxic conditions, heart rate will be elevated compared to the same work rate at sea level and normoxic conditions. This implies that training at a certain heart rate at sea level may result in positive training effects, whereas, at high altitude, this training may result in overtraining.

Heart rate as an indicator of cardiac stress

The examples of exercise in the heat and at altitude show that the relationship between heart rate and exercise intensity (defined as energy expenditure) is sometimes dissociated. However, in these conditions, heart rate may be a better indicator of cardiac stress and may even be a better indicator of overall exercise-induced stress. In fact, it may sometimes be better to describe training in terms of heart rate, as this may better reflect whole-body stress levels. Training at a given power output that, in a thermoneutral environment, may lead to a positive training effect, may, in a hot environment, lead to overtraining.

How heart rate is used by athletes

Heart rate monitors are mainly used to motivate athletes to work at high intensities (at or above lactate threshold) (Gilman and Wells, 1993; Gilman, 1996) or to prevent athletes from training at too high intensities. Heart rate can be used to determine the exercise intensity during a training session or to evaluate the intensity after the session. If heart rates are recorded during a race or during training, exercise intensities can be evaluated retrospectively. When using a heart rate monitor during training, heart rate zones are usually defined. Often, four zones are recognized: a low heart rate zone which is believed to result in a minimal training effect; a second zone at slightly higher intensities but still below the lactate threshold; a third zone around the lactate threshold; and a fourth zone above the lactate threshold. In races, heart rate monitors can be used to help identify the appropriate pacing strategy.

How heart rate could be used by athletes

Unfortunately, very little is known about the ideal exercise intensity for training. In general, very little is known about the effects of training programmes on training adaptations and performance in already trained athletes (Hawley *et al.*, 1997). There is abundant information about the effects of training programmes on sedentary individuals. However, in this population, relatively little training will result in an increase in the respiratory capacity of the muscle fibres, and adaptations in the cardiovascular system, resulting in increased $\dot{V}O_2$ max and endurance performance. Because only a few training sessions are needed for these effects, there is enough time in between training sessions for recovery. In elite, well-trained cyclists, this is different: training has to be frequent and of a long enough duration to provoke further training adaptations. Therefore, there is little time for recovery and the timing of the next training session becomes critical. Unfortunately, we know little of the time course of recovery and adaptations in already well-trained athletes. Future research should attempt to elucidate the effects of different training stimuli and subsequent recovery. With more information on the effects of different training stresses, we will be able to monitor these stresses using heart rates. Heart rate monitoring is also useful for identifying insufficient recovery between training sessions (i.e. overtraining).

Overtraining

Heart rate monitors have also been used to detect overtraining at an early phase. When competing at a high level, there is a fine and critical balance between the training load and recovery. Too much training and too little recovery may disturb this balance and result in a phenomenon generally referred to as 'overtraining'. Although overtraining may lead to several symptoms which vary from individual to individual, there is one common symptom to all forms of overtraining: a reduced exercise performance. Overtraining may start as fatigue, but develop into a more severe form with such symptoms as irritability, sleep problems and a lack of motivation, which in the long term may turn into an overtraining syndrome. Although the symptoms of this syndrome are less alarming (no sleeping or eating problems, no irritability), it includes major disturbances in the hypothalamo-hypophyseal-thyroid axis, as well as disturbed neuromuscular function (Kuipers and Keizer, 1988). It is therefore important to recognize the early symptoms of overtraining. To determine what measures could be used to detect these early symptoms, we had eight well-trained cyclists undergo a training programme in which the weekly training duration was increased by 45% and the duration of high-intensity training was increased by 350%. After 2 weeks, performance decreased significantly in all subjects. One observation we made was that maximal heart rate dropped significantly with overtraining (Table 2). Time-trial performance measured on an 8.51-km hilly course was decreased (average speed dropped from 36.9 to 35.2 km h^{-1}). Heart rate during the time-trial dropped in parallel with the decreased performance, but no differences in perceived exertion were observed. With overtraining, submaximal as well as maximal lactate concentrations during exercise may be decreased (Table 2) (Jeukendrup *et al.*, 1992; Jeukendrup and Hesselink, 1994).

It has been suggested that resting heart rate may be a sensitive indicator of overtraining: an increased heart rate (usually measured by palpation after waking up in the morning) may indicate fatigue or even overtraining (Israel, 1958; Kindermann, 1986). A more sensitive and reliable measure, however, may be the heart rate measured during sleep (Jeukendrup *et al.*, 1992). Sleeping heart rate can be measured easily with a wireless heart monitor with memory. Besides an increased average sleeping heart rate, we observed changes in the heart rate pattern during the night after overtraining: the pattern is less regular and peaks are higher (Jeukendrup and Hesselink, unpublished observations).

Table 2 Effects of 2 weeks overtraining (mean ± *s*)

	Before overtraining	After overtraining
HR_{max} (beats min^{-1})	185 ± 3	178 ± 2*
La 200 W (mmol l^{-1})	1.4 ± 0.2	0.9 ± 0.1*
La 300 W (mmol l^{-1})	6.3 ± 1.1	3.8 ± 0.6*
La_{peak} (mmol l^{-1})	11.8 ± 1.1	5.9 ± 0.5*
W at 4 mmol l^{-1} (W)	234 ± 10	267 ± 13*
W_{max} (W)	336 ± 7	310 ± 5*
Time trial HR (beats min^{-1})	178 ± 2	169 ± 2*
Average time-trial speed (km h^{-1})	36.9 ± 0.5	35.2 ± 0.7*
Sleeping HR (beats min^{-1})	49.5 ± 3.8	54.3 ± 3.2*

* Significantly different from before overtraining. Adapted from Jeukendrup *et al.* (1992).

Conclusions

In cycling, speed is not an accurate indicator of exercise intensity and therefore alternatives have to be found to monitor exercise intensity during training and competition. Power output may be the most direct indicator, but heart rate is easier to monitor and measure. There are, however, a few limitations that have to be taken into account when using a heart rate monitor. For example, the rider's position on the bicycle may result in a change in heart rate at a given exercise intensity. More important, however, is the increase in heart rate over time, a phenomenon described as 'cardiac drift'. Cardiac drift can change the heart rate–power output relationship drastically, especially in hot environments. It is important to determine whether one is interested in monitoring exercise intensity *per se* or measuring whole-body stress. Power output may be a better indicator of the former and heart rate may, under many conditions, be a better indicator of the latter. Heart rate can be used to evaluate a cyclist after training or competition, or to determine the exercise intensity during training. Heart rate monitoring can be very useful in the detection of early overtraining.

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