Using heart rate variability, rest and recovery and the duration-intensity-recovery line for optimum endurance performance

In two earlier Peak Performance articles Eddie Fletcher outlined the use of Heart Rate Variability to enhance athletic performance (issue 237) and to assess whether athletes are achieving adequate rest and recovery (Issue 246). In this article he explains how to combine these concepts to optimise physiological adaptation for endurance performance and to avoid over training.

At A Glance

- The concept of heart rate variability, cardiovascular fatigue and rest and recovery are briefly reviewed;
- The duration-intensity-recovery line and training concepts are explained and presented.

If you measure the beat-to-beat interval of the heart, it soon becomes apparent that heart rate is not constant but alters from beat to beat. This is known as heart rate variability (HRV). At rest this beat-to-beat interval fluctuates with the breathing cycle – it speeds up during inhalation and slows down during exhalation.

The measurement of HRV for use in monitoring training and recovery involves analysis of the beat-to-beat variation. By accurately measuring the time interval between heartbeats, the detected variation can be used to measure the psychological and physiological stress and fatigue on the body during training. Generally speaking the more relaxed and unloaded (free from fatigue) the body is, the ***more*** variable the time between heartbeats.

Physical training with incomplete recovery can produce significant cardiovascular fatigue, which HRV can detect [1]. There is also evidence to suggest that when recorded, overnight HRV seems to be a better tool than resting heart rate to assess accumulated fatigue and that HRV may be a valuable tool for optimising individual training plans[1,2].

The duration-intensity-recovery line

The effectiveness of training in terms of physiological adaptation, cardiovascular fatigue, and therefore the need for rest and recovery is duration and intensity dependent. High-intensity training is by its nature short in duration and low-intensity training is longer duration. This leads to a concept of a 'duration-intensity-recovery guideline'.

The duration-intensity-recovery line is an athlete-specific 'Z diagram' that links duration (in minutes) with intensity (by heart rate and percentage of VO2max) and cardiovascular fatigue (using a numerical recovery scale). This fatigue is calculated from a sport specific maximal fitness test that uses HRV technology (see issue 237 for full explanation of HRV).

The duration-intensity-recovery line is a flexible tool that attempts to answer the questions - How long should I train for? How hard should I train and how long do I need for recovery? Breaking the duration-intensity-recovery guideline for any session will hasten the approach of cardiovascular fatigue, lengthening rest and recovery periods needed and increasing the risk of overtraining and reduced performance.

When working with the *duration-intensity-recovery* line it is important to factor in and recognise the psychological condition of an individual athlete together with environmental conditions such as heat, cold, humidity etc. Psychological stress has a significant affect on cardiovascular fatigue, and the stress of normal everyday activities exerts a larger influence on training and race performance than is currently realised.

It may seem obvious that the effectiveness of any training plan is duration, intensity and recovery dependent, but is it? One of the key issues to address is how much time can an athlete spend at a particular intensity before the session induces more cardiovascular fatigue than intended, thereby reducing the effectiveness of the training and increasing the recovery period needed between sessions.

For example, suppose an athlete trains for 45 minutes at intensity X. Is the training effect and recovery the same if the athlete trains for 60, 75 or 90 minutes at the same intensity? Clearly not, but many believe it is. Some of the misunderstanding is from the interpretation and application of standard tests, which identify thresholds for training zones linked to heart rate, pace and lactate readings – tests which in themselves are fine but lose something in translation.

These tests do not identify the cardiovascular fatigue that builds up over time, the effective duration-intensity-recovery for any particular session or how each subsequent session should be adjusted to ensure adequate recovery.

Duration-intensity terminology

The concept of duration-intensity-recovery also introduces ‘durational effectiveness’, ‘durational breakdown’ levels and a ‘durational collapse’ point:

- ***Durational effectiveness*** denotes the recovery period needed in hours or days following a training session where cardiovascular fatigue is increased significantly and which requires increased recovery or a lower duration-intensity-recovery session to compensate; Durational effectiveness levels are on a 1-5 scale with each level scaled in tenths. *The values for each level are athlete-specific and derived from test data using HRV*;
- ***Durational breakdown*** level is the limit at which severe cardiovascular fatigue sets in – eg overtraining, maximal endurance efforts or the point at which a planned session exceeds its intended durational effectiveness. The need here is for prolonged rest and recovery;
- ***Durational collapse*** point is the limit of physiological performance. It is the point at which the body cannot continue to perform (*eg* the ‘wall’ in marathon running) and is associated particularly with long endurance efforts.

Duration-intensity-recovery line in practice

The start point for explanation of the duration-intensity-recovery line is to delve into an analysis of a traditional approach and then compare it against a duration-intensity-recovery line for a particular athlete.

A standard rowing aerobic endurance session is 3 x 6000 m (90 seconds rest between intervals) at 18 strokes per minute using a standard Concept 2 indoor rowing machine. The perception is that this type of session can be rowed at a set power percentage of an all-out 2000m effort or at a heart rate established by a standard rowing step test linked to a lactate reading. Let's consider a real athlete:

Athlete's perception

This session can be rowed at a pace (mins:secs) per 500 m equating to 60% of the power of a 2000m maximal effort, with blood lactate reading of 2-4mmols and recovery over a period of hours, up to 24 hours.

Athlete's reality:

Interval	Stroke rate	Max HR (bpm)	Lactate (mmol)	Pace per 500m
1	18	165	1.87	2.02.1
2	18	174	3.62	2.02.1
3	18	181	6.82	2.01.1

How does this look on a duration-intensity-recovery line and what is the durational effect level?

Duration (mins)

0	**2**	**15**	**40**	**60**	**76**

Intensity (HR)

-	**146**	**156**	**170**	**175**	**181 (Average 163)**

Recovery (durational effectiveness level*)

** established from a test of the athlete*

0	**2**	**3**	**3.9**	**4.5**	**5+**

Scale of durational effectiveness levels

(recovery time – depends on the time spent at each level):

Scale	Recovery time in hours/days
1-2	3 hours to 1 day
2-3	1 to 2 days
3-4	1 to 4 days
4-5	2 to 7 days
5	7 days +

Level 5 is a 'durational breakpoint' inducing significant cardiovascular fatigue but note that durational breakpoint occurs whenever a session is beyond the intended durational effectiveness level for any session.

Our athlete's session was at the lower limit of the intended training effect until the end of the first interval (2mmol lactate) and after 40 minutes was beyond the recovery, durational effectiveness level 3-3.9 (because recovery within 24 hours was desired) and lactate parameters.

After 15 minutes the session was already at durational effectiveness level 3. By the end of interval 2 the session was at a durational breakpoint level for this session, level 3.9, and continued to rise during interval 3 into level 5. The time required for recovery was days, in a session believed to have a recovery period of only 24 hours!

While not all training sessions should be shorter, high intensity at the expense of longer, low intensity efforts, this session was more than 30 minutes longer than required to achieve the intended training effect and was extremely fatiguing.

Using the duration-intensity-recovery line, our athlete's session description would change to 3 x 6000 m at 18 strokes, limited by a HR range of 136-155. The calculated duration-intensity-recovery line (following testing) for this athlete might look like this:

Duration (mins)					
0	**60**	**90**	**75**	**60**	**30**
Intensity (HR)					
-	**111-123**	**124-136**	**137-155**	**156-174**	**175-198**
Recovery (durational effectiveness level)					
0	**1-1.9**	**2-2.9**	**3-3.9**	**4-4.9**	**5+**

Using a duration-intensity-recovery line and durational effectiveness level methodology, a 3 x 6000m session for this athlete should have been rowed within a HR range of 136-155 to achieve the intended physiological training effect required (durational effect of 3-3.9).

Figures 1 and 2 below illustrate what happened in reality and how it the data should have looked using duration-intensity-recovery line to set the training intensities:

Figure 1: The reality of 3 x 6000m intervals – notice steadily rising intensity

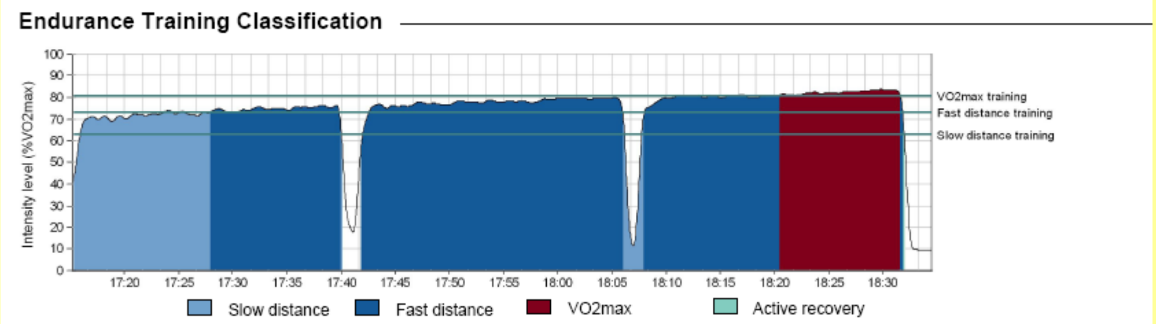
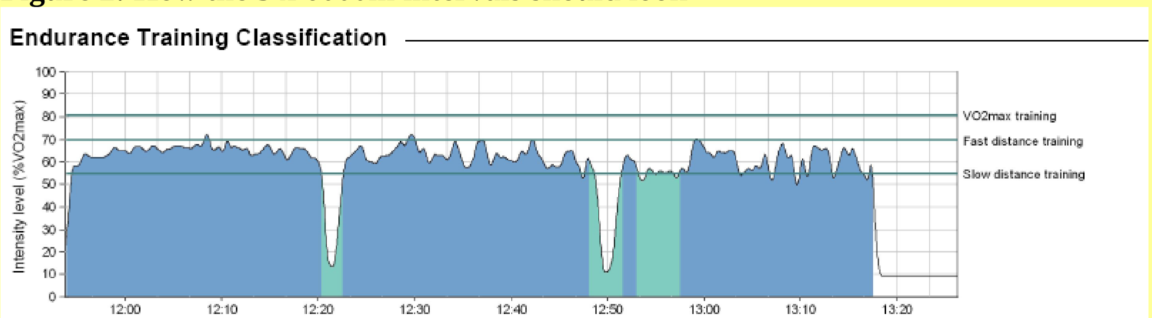


Figure 2: How the 3 x 6000m intervals should look



Duration-intensity-recovery line– short duration/high intensity

To illustrate the top end of the duration-intensity-recovery line we can look at another standard rowing session known as a 30R20, 30 minutes at 20 strokes per minute but a maximum effort (high watts/pace), known as a power/endurance session (see table 1). This session, on a duration-intensity-recovery line scales from 15 minutes up to 35 minutes depending on the fitness level of the rower.

Heart rate rises rapidly, near to maximum in last few minutes and despite the short duration, the durational effect level is between 4 and 5. This necessitates a rest day followed by a long duration/low intensity recovery session in the 2-3 durational effect level to give a 3-day recovery period for a top class rower.

Table 1: Actual result for a 30R20 session paced very evenly at 2:01.3 mins:secs per 500 m

Time (mins)	5	10	15	20	25	30
Heart rate (bpm)	168	172	174	175	176	178
Durational effectiveness level	2.5	3.3	3.7	4.0	4.6	5.0

Using the duration- intensity-recovery line for long endurance events

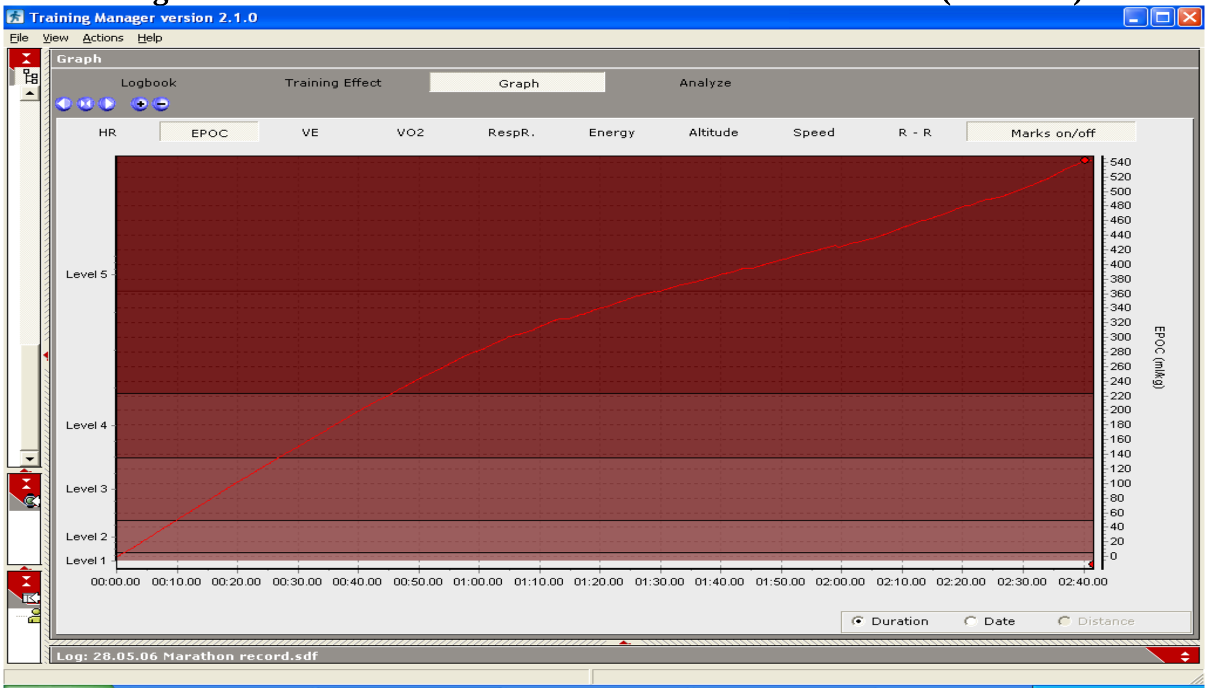
It is possible to calculate the required training intensity for ultra distance events such as marathons, triathlons (Olympic and Ironman distances), long cycling or swimming activities or any other long endurance event.

For a rowing marathon over the classic distance of just over 26 miles, the calculated maximum heart rate needed to ensure optimum performance is in the 4-4.9 durational effectiveness level. This is only the start point; as can be seen from the duration- intensity-recovery lines in this article, durational effectiveness level 4-4.9 gives an optimum duration for training purposes of up to 60 minutes.

Clearly rowing the full marathon distance, at a level heart rate in the duration-intensity-recovery 4-4.9 range and, at a power ratio to optimise performance will elevate the durational effectiveness level well into durational breakdown (level 5). It is possible to remain in level 5 for some considerable time; however the longer an athlete spends in level 5, the longer the post-exercise recovery period will be (due to excessive cardiovascular fatigue) and the nearer he or she gets to total breakdown (durational collapse).

The marathon row below (see figure 1) was a British age group row of 2 hours 41 minutes 7.3 seconds – a wattage of 233W and pace per 500m of 1:54.5. The tested durational effectiveness heart rate at level 4.9 was 150bpm.

Figure 1: Durational effectiveness level for a marathon row (real data)



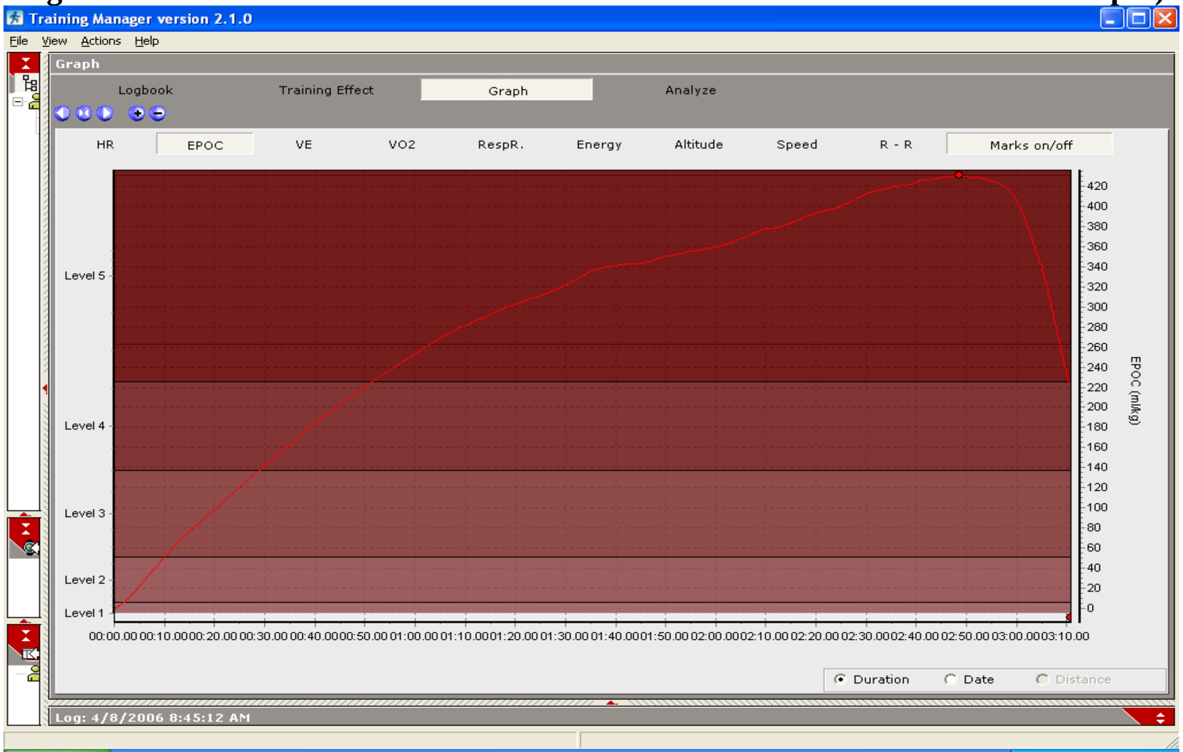
Time (mins)	20	40	60	80	100	120	140	161
Heart rate (bpm)	149	150	148	147	150	152	154	158
Durational effectiveness point	3.8	4.8	5 rising	5 rising	5 rising	5 rising	5 rising	5 rising

Looking at the data, an important point to recognise is that although heart rate and pace were held level, cardiovascular fatigue continued to rise with the duration. This is an obvious statement, but a point often missed by athletes and coaches. This athlete was in level 5 for close to 2 hours and recovery is counted in weeks rather than days!

Durational collapse

It is a fine line between getting it right and hitting ‘the wall’ – durational collapse. Consider yet another rowing age group British marathon record (see figure2). This marathon row was of 3 hours 10 minutes 50 seconds – a pace per 500 m of 2:15.2 per 500m. The athlete tested durational effectiveness heart rate at level 4.9 is 156.

Figure 2: Durational effectiveness level for a marathon row and durational collapse)



Time (mins)	20	40	60	80	100	120	140	160	180	190
Heart rate (bpm)	155	163	160	156	159	159	161	161	155	146
Durational effectiveness point			5 rising	5 rising	5 rising	5 rising	5 rising	5 rising	5 reducing	5 reducing

This entire row was marginally above the designated heart rate and the athlete was in level 5 for over 2 hours. Durational effectiveness peaked after 2 hours 48 minutes and 30 seconds when this rower hit ‘the wall’ (durational collapse). The body was in severe distress for the last 22 minutes 20 seconds. Fortunately on this occasion it did not prevent a record row. When tackling a long endurance event it is imperative to get the duration-intensity-recovery heart rate correct to optimise the performance.

Using the duration-intensity-recovery line in practice

Using the duration-intensity-recovery approach, training sessions may be structured to ensure optimum training effect and recovery. The first objective is to establish consistency in training by matching the durational effectiveness to heart rate, keeping variation to a minimum and ensuring correct recovery between sessions. It is important to watch for rising durational effectiveness over a series of sessions as this may indicate lack of recovery, illness or the beginning of overtraining.

Once consistency has been established, improvement may be indicated by a reducing durational effectiveness for similar sessions. If reduced durational effectiveness is observed consistently over time then a retest to establish a new duration-intensity line may be necessary so that any improvement may be consolidated into future training sessions.

Summary

This is quite a technical subject, so let's just summarise the key points. The ***duration-intensity-recovery*** line is an athlete specific Z diagram that links duration (in minutes) with intensity (by heart rate or % of $V0_{2max}$) and cardiovascular fatigue (by a numerical recovery scale). Moreover, it is also a flexible tool that attempts to answer the questions "How long should I train for? "How hard should I train?" "How long do I need for recovery?"

The durational effective levels for a given heart rate depend on the athlete and are assessed by tests using HRV data. They are especially valuable because these levels denote the recovery period needed in hours or days. Durational breakdown level is the limit at which severe cardiovascular fatigue sets in, while Durational collapse point is the limit of physiological performance

The data from the duration-intensity-recovery line shows that a shorter session at high intensity can produce the same effect as a long session at low intensity. Also, even when heart rate and pace are held constant, cardiovascular fatigue continues to rise with increased duration. Associated with duration-intensity-recovery are regular recovery tests to detect signs of overtraining or illness

References

1. Med Sci Sports Exerc. 2001; 33 (7): 1120-1125.
2. Med Sci Sports Exerc. 2000; 32 (10): 1729-1736.

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