EPOC Based Training Effect Assessment

White paper by Firstbeat Technologies Ltd.

This white paper has been produced to describe a heart beat derived, physiology-based measure of training effect developed by Firstbeat Technologies Ltd. Parts of this paper may have been published elsewhere and are referred to in this document.

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EPOC BASED TRAINING EFFECT AT GLANCE

- EPOC (excess post-exercise oxygen consumption) measures the quantity of exercise-induced disturbance of body's homeostasis.
- Training effect indicates the effect of a single exercise session on improvement of cardiorespiratory fitness and fatigue resistance during prolonged exercise.
- EPOC based training effect is in accordance with current exercise prescription and training practices and studies.
- Training effect assessment provides key information on exercise for all individuals from beginners to athletes, for different disciplines and training stages.

INTRODUCTION

This paper introduces EPOC based method for the assessment of exercise-induced training effect. The method provides an exercise analysis tool for all who are interested in developing their cardiorespiratory fitness.

Training effect refers to training-induced development of fitness and performance. In this document, training effect refers especially to the development of cardiorespiratory fitness. Good cardiorespiratory fitness is related to the ability to perform moderate to high-intensity physical activity for prolonged periods. Increased cardiorespiratory fitness results from: 1) increased heart pumping capacity, 2) improved pulmonary function, 3) increased oxygen transport capacity of blood, and 4) improved oxygen extraction and utilization. Maximal oxygen uptake (VO_{2max}) is accepted as a measure of cardiorespiratory fitness (ACSM 2001).

Effective training

An overload must be applied to the body to disturb its homeostasis and a sufficient recovery period is required to allow a training effect to occur (see figure 1). This means that exercise must load organs and tissues to a greater extent than the body is accustomed to: the harder the exercise (higher intensity and/or longer duration), the greater the overload and related disturbance in body's homeostasis. This results in a larger training effect than less demanding exercise.

It is possible for everyone to improve their cardiorespiratory fitness: Effective exercise sessions must be performed often enough and easier exercise sessions must be included regularly between the more demanding sessions. In addition to the changes in daily training load, also weekly and seasonal training must include variation. The variation in training load is needed to avoid injuries and the development of overtraining symptoms.

The development of fitness is fastest at the beginning of training. Training load must be gradually increased to improve the fitness level in long term. As the level of fitness improves, the balance between training and recovery becomes very important: training must be hard, but adequate recovery must also be allowed (e.g. Brooks & Fahey 1984; McArdle et al 1996; ACSM 2001; Foss & Keteyian 1998).

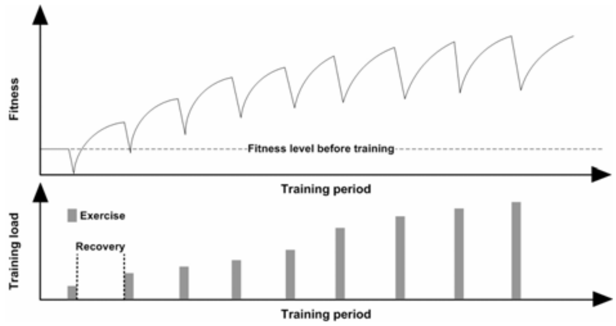

Figure 1. A schematic example of training and the related fitness development. The continuous line represents the current fitness level and the grey columns the load of single exercise sessions. Initially even easy an exercise develops fitness. After the initial rapid development, harder and harder exercise is needed to get further increases in fitness.

METHOD TO ASSESS TRAINING EFFECT (TE)

Excess post-exercise oxygen consumption (EPOC) reflects the disturbance of body's homeostasis related to exercise (e.g. Brooks & Fahey 1984; Gaesser & Brooks 1984; Brehm & Gutin 1986; Gore & Withers 1990). Firstbeat Technologies Ltd. has developed a heart rate based model to estimate EPOC and further TE during exercise.

The described training tool provides exact information on the effects of exercise on cardiorespiratory fitness, for example, whether the exercise has been maintaining or improving. For this purpose, training effect is divided into five levels (1 – 5) which describe the effect of single exercise on cardiorespiratory fitness. Different types of TE's are described in a more detail in table 1.

To determine the training effect of a single exercise, peak EPOC achieved during exercise (see figure 3) and the activity class of an individual must be known (see figure 2). The activity class value representing the activity level of the previous month must be defined to individualize training effect interpretation according to training level. The values from 0 to 7 are equal to Ross & Jackson's (1990) scale. The values from 7.5 to 10 have been added by Firstbeat to include more seriously training individuals and athletes in the scale (see table 2).

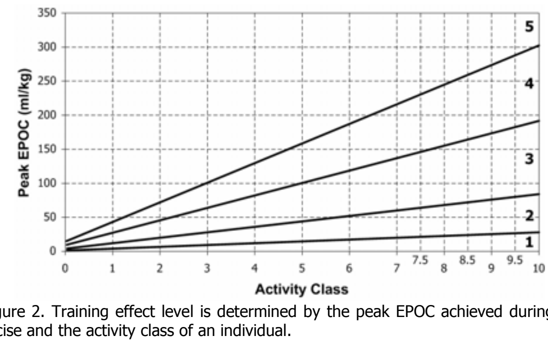

Figure 2. Training effect level is determined by the peak EPOC achieved during exercise and the activity class of an individual.

Table 1. Different training effects and their interpretation.

Training effect category		Interpretation
1.0 – 1.9	Minor training effect	Exercise does not improve cardiorespiratory fitness. This type of exercise is also suitable for the purposes of enhancement of recovery and for development of endurance base with long duration exercise (over 1h).
2.0 – 2.9	Maintaining training effect	Exercise maintains cardiorespiratory fitness. Builds up foundation for better cardiorespiratory fitness and harder training in future.
3.0 – 3.9	Improving training effect	Exercise improves cardiorespiratory fitness if done 2 – 4 times per week. No special recovery requirements.
4.0 – 4.9	Highly improving training effect	Exercise sharply improves cardiorespiratory fitness when done about 1 – 2 times per week. A few (2 – 3) easier exercise sessions (TE 1 – 2) is also recommended to balance the training. More attention on recovery.
5.0 –	Overreaching	Dramatic increases occur in cardiorespiratory fitness after an overreaching exercise if only adequate recovery is applied after the exercise. This kind of exercise should be performed only occasionally. Special attention on recovery.

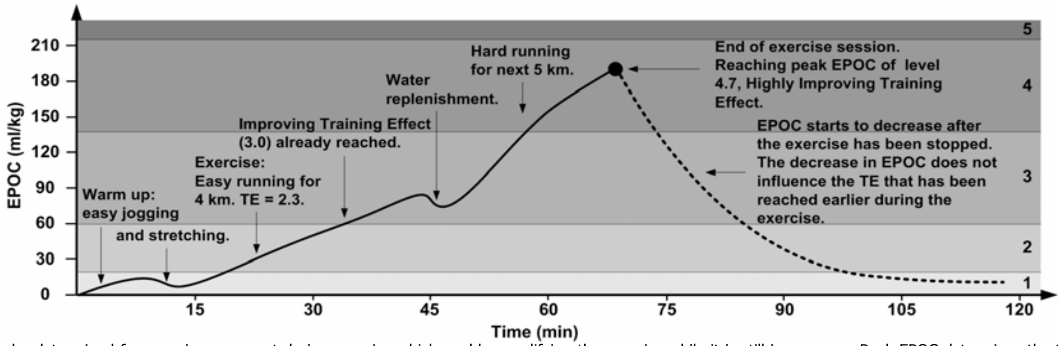

Figure 3. TE can be determined for any given moment during exercise which enables modifying the exercise while it is still in progress. Peak EPOC determines the training effect of the exercise.

Table 2. Description of activity requirements for different activity classes.

Activity description		Activity class
No regular participation in recreational sports or heavy physical activity.	Always avoid exertion, when- ever possible.	0
	Walk for pleasure, routinely use stairs, occasionally exercise suf- ficiently to cause heavy breath- ing or	1
Regular participation in recreation or work requiring modest physical activ- ity.	10–60 min per week	2
	Over 1 hour per week	3
Regular participation in heavy physical exercise 2-5 times per week.	Less than 30 min per week	4
	30 – 60 min per week	5
	1 – 3 hours	6
	3 – 5 hours	7
	5 – 7 hours per week	7.5
Training almost daily. (For a regional level endurance athlete VO_{2max}* female > 59, male > 65)	7 – 9 hours per week	8
Training daily. (For a national level endurance athlete VO_{2max} female > 63, male > 69)	9 – 11 hours per week	8.5
	11 – 13 hours per week	9
Training daily. (For an international level endurance athlete VO_{2max} female > 71, male > 77)	13 – 15 hours per week	9.5
	More than 15 hours per week	10

*VO_{2max} values are typical values observed in corresponding athletes.

It has been observed in many studies that active and fit individuals need harder exercise than less active and less fit individuals to improve cardiorespiratory fitness (see figure 4) (ACSM 2001; Rusko 2003). EPOC based TE assessment has been constructed based on these observations. In TE assessment an active person needs therefore a higher EPOC than a less active person in order to reach similar TE (See figure 2).

TE assessment also takes into account changes in a person's in physical activity level: less disturbance to homeostasis and less EPOC are required to increase fitness if the physical activity level has dropped. On the contrary, a more powerful disturbance of homeostasis and more EPOC are required for fitness improvement if the physical activity level has increased.

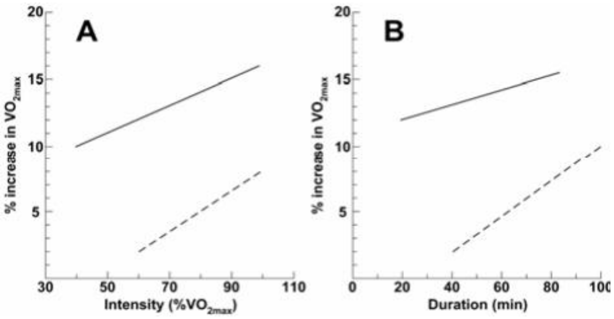

Figure 4. Training-induced increases in VO_{2max} as a function of exercise (A) intensity, (B) duration. The solid line presents the increases in untrained and the dotted line in trained individuals (Modified from Rusko 2003).

EPOC in short:

- The higher the intensity (proportion of VO_{2max} used = $\%VO_{2max}$) and the longer the duration of exercise, the more the EPOC accumulates.
- The shorter the recovery periods during exercise, the higher the EPOC
- Exercises recruiting large muscle mass (e.g. cross country skiing) result in higher cardiorespiratory load and intensity of exercise and lead to higher EPOC as compared to exercises recruiting smaller muscle mass.
- EPOC can be evaluated for any given moment during exercise.
- The higher the EPOC, the higher the TE.
- For more detailed information on the laboratory measurement and heart rate based estimation of EPOC, see the EPOC White Paper.

TRAINING PROGRAMS

Training effect assessment is used to determine the effect of a single exercise session on cardiorespiratory fitness. For development of fitness, exercise must be performed regularly and the use of training program that matches individual needs and goals supports long term development of fitness.

Although exercise that cause an improving effect in fitness are necessary for development, also maintaining workouts are needed in successful training. For example, performing high TE (3 – 5) exercise too frequently is not necessarily effective. When continued for several weeks or months, training that is too hard may lead to an overtraining syndrome and a long-term decrease in fitness level. Of course, too easy training does not either improve fitness.

Training programs for beginners

Focus:

- Exercise should be performed regularly 2 – 5 times per week.
- Easy exercise sessions should be scheduled between harder ones.
- In addition to endurance exercise, also other types of exercise sessions are needed: strength and flexibility 2-3 times per week each.

Figure 5 represents a training program for a beginner (Activity Class = 0 – 2). The program is based on ACSM's (2001, 154) exercise "Initial stage prescription". It is preferable to start training easily and to make it harder as the training progresses. One should start with the easy week and continue with the medium and hard weeks. After about one month of training, it is possible – and recommended – to start following a more demanding training program.

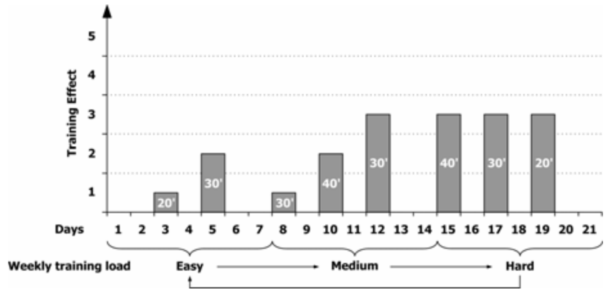

Figure 5. A 3-week training program for an individual at the very beginning of training (activity class = 0–2). The columns represent a target TE and recommended duration on a given day. The arrows illustrate the sequence of three different weeks (easy, medium and hard).

Figure 6 represents a training program designed for an individual (Activity Class = 3 – 5) who wishes to improve his/her fitness level further after the initial training phase (corresponds to ACSM's "Improvement stage"). As can be seen, the frequency of training is much higher than in the initial program. This program must be followed for about two to three months to be able to move to the next level. It is important to vary the training load between consecutive days. To optimize training, it is preferable that some of the easier exercise sessions (TE = 1 – 2) are of long duration and low intensity. An adequate amount of rest must also be included to avoid overuse injuries and overtraining.

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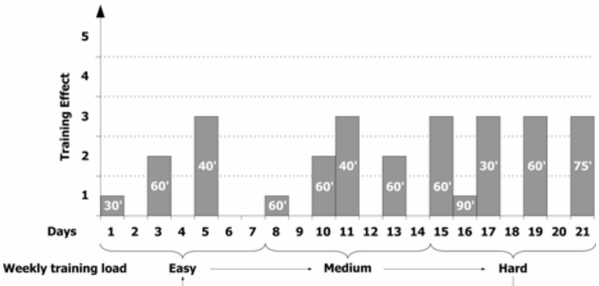

Figure 6. A 3-week training program for an individual already engaged in training (activity class = 3–5). For further explanations, see Figure 5.

Training programs for trained individuals

Focus:

- Effective exercise sessions should be done 1 – 4 times per week.
- Training should be focused on the specific sport in which one wishes to improve.
- Workouts of long duration and low TE are needed between more demanding workouts to maintain an endurance base.
- Easier training periods must be scheduled between the more demanding ones.

Figure 7 represents a training program for a highly fit individual (Activity Class = 6 – 7, corresponds to the higher end of ACSM's "Maintainance stage"). It is not necessary to significantly increase training frequency unless one wishes to improve to athlete level. However, higher daily TE's are needed, which means that either the intensity or duration of training, or both, must be increased. When an individual wants to improve his or her performance closer to the level of an endurance athlete, the quantity and quality of training must be further increased.

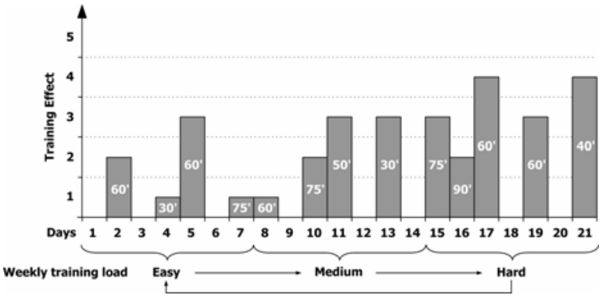

Figure 7. A training program for a highly fit individual (activity class = 6–7). For further explanations, see Figure 5.

Figure 8 represents a training program for an elite endurance athlete. In athletic training, it is important to maximize VO_{2max}, fatigue resistance, sport-specific technique and the economy of movement by increasing the number of intensive sport-specific exercise sessions. Even if a large part of training is performed at high intensities, it is also important to take care of the endurance base by doing long workouts with low TE.

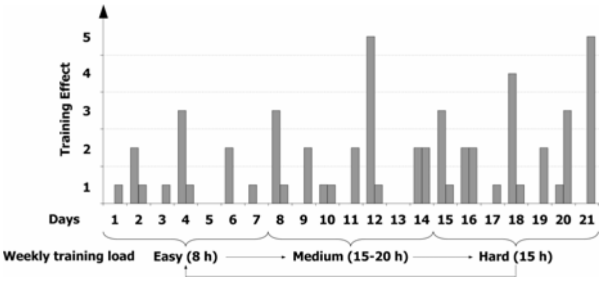

Figure 8. A training program example of an elite endurance athlete (activity class = 9–10). For further explanations, see Figure 5.

It is essential to remember that the overall training load of highly active individuals is often very high due to the high intensity, long duration and high frequency of workouts. High training frequency causes single workouts to load the body to a greater extent than otherwise expected, due to residual fatigue. Therefore, all workouts cannot be improving; a few of the weekly training sessions must remain maintaining. Furthermore, even the top endurance athletes need easy weeks between the harder ones to ensure that the body has time to adapt and recover, which allows the level of fitness/performance to improve. Replacing the easy workouts and easier training weeks with harder ones may, in the long term, lead to the development of an overtraining syndrome.

SPECIFIC TOPICS IN USE OF TRAINING EFFECT

Low intensity training for endurance base and enhancing recovery

Despite the fact that TE assessment considers continuous high intensity exercises with long duration to be the most effective, exercise sessions with low TE are also necessary to build a firm endurance base. The base is most efficiently improved with long easy workouts, during which only Minor (1) or Maintaining (2) TE is achieved (see Figure 10 A). This kind of training does not directly improve maximal cardiorespiratory fitness and the TE is low but is necessary to be able to train intensively and reach a top-level VO_{2max}.

Volume of low intensity training is quite high in elite endurance athletes. Typically only 3-4 intensive exercise sessions can be carried out during one week corresponding about 10-15% of the total training volume (see figure 9).

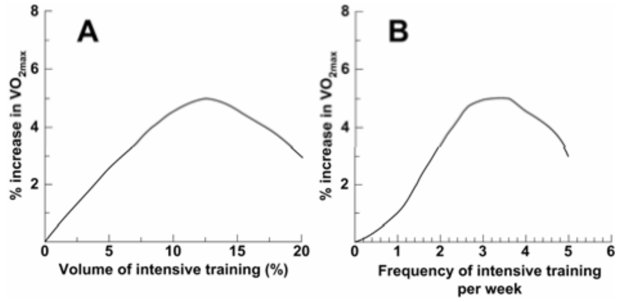

Figure 9. (A) Frequency and (B) percentage of intensive exercise sessions (aimed at enhancing cardiorespiratory fitness, TE ≥ 3) in relation to the increases in performance in trained individuals (Modified from Rusko 2003).

Another reason to perform low-intensity exercise is to enhance recovery. If an individual feels exhausted and recovery enhancement is needed, short recovery exercise with low TE (1 - 2) is preferred (see Figure 10 B).

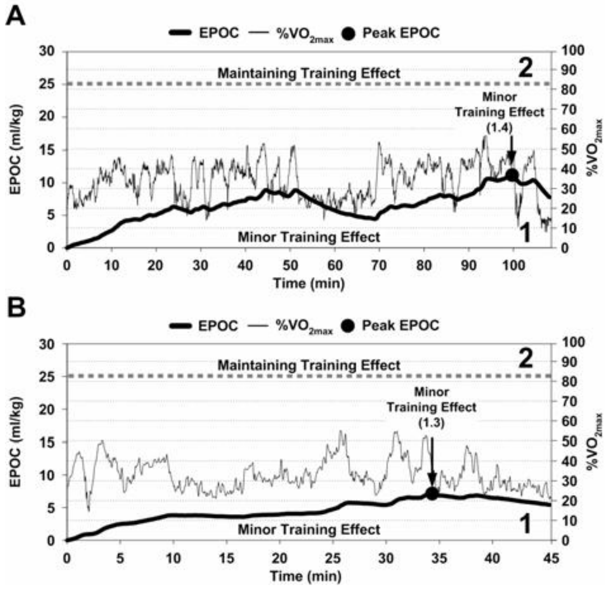

Figure 10. Two different workouts performed by national-level endurance athletes (activity class = 9). A) Long basic endurance exercise with Minor TE. B) Recovery exercise, also with Minor TE.

Peaking performance

It is clear that VO_{2max} is best improved by performing moderate to high intensity exercises from short to long duration. Adequate TE (3–5, improving to overraching) must therefore be reached in VO_{2max} training. In addition to VO_{2max} there are also other factors affecting performance, which can be improved by different workouts. In short, these include capabilities to achieve a high performance velocity and to maintain that high performance velocity for prolonged periods. Optimizing these muscular characteristics for fast force production, good economy and fatigue resistance is essential for achieving a peak performance.

To improve all performance characteristics, different exercise sessions must be performed. For example, an interval workout or short continuous workout with high intensity (and velocity) probably has more effects on muscle fast force production and economy of movement than a workout with longer duration and lower intensity, despite the same TE. On the other hand, a longer exercise results in improved fatigue resistance despite slightly lower intensity.

Similarly, an endurance exercise requiring greater muscle force production (e.g. rowing) offers extra benefits for strength-endurance development as compared to exercise requiring less muscular force (e.g. running) although the same TE was reached in both exercises. Two examples of high intensity peaking exercises are presented in figure 11.

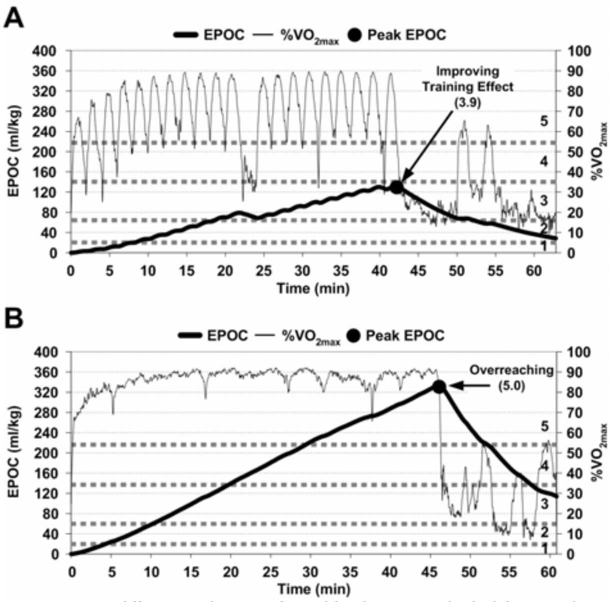

Figure 11. Two different workouts performed by the same individual (activity class = 7). A) Nordic walking/running interval exercise with an intensity of about 90%VO_{2max} during the high-intensity periods. B) Continuous running with a similar (90%VO_{2max}) intensity. Note the lower TE in interval exercise due to the low-intensity recovery periods between high-intensity bouts.

Heart rate level based training and training effect

Heart rate level provides indirect information on exercise intensity and is therefore commonly used to control training workload. For example, to avoid too high intensity, one should try to remain at about 65 – 85 % of maximal heart rate throughout the exercise. Similar to that, excessive load is avoided by assuring that EPOC does not accumulate beyond training effect of 1.0 - 2.9, indicating that the exercise as a whole had either minor or maintaining effect.

Momentary heart rate level does not alone provide sufficient information for controlling the load of whole exercise, since the overall load accumulates during the course of the exercise. For healthy individuals, the main advantage of EPOC based training effect is that it can be used to control training across different types of exercises and with different durations, allowing also changes in the intensity of exercise. Control of heart rate level is, however, required especially in cases when it is necessary to control the pace of the heart itself, such as in clinical rehabilitation and cardiac patients.

Heart rate is also commonly used to control that during high-intensity training heart rate is above certain level (e.g., above 85% of maximal heart rate) to improve cardiorespiratory fitness. This requires interpretation of the effects of different exercise profiles, such as variations in intensity and duration, on aerobic fitness. EPOC based training effect indicates directly the effects of exercise as whole on cardiorespiratory fitness. EPOC should be relatively high during an exercise that is planned to improve cardiorespiratory fitness, imposed as training effect at least 3.0 or higher.

Overtraining

Overtraining state is characterized by a decrease in performance capacity that develops during a long time of hard training without a sufficient recovery. Training effect assessment gives information on physiological training load that can be used to prevent overtraining state. Accordingly, it may be used to support scheduling optimal amounts of training sessions with high intensity training (TE 3 – 5) and low intensity training (TE 1 – 2), with emphasis on periods of temporal overload (overreaching) and recovery.

Overtraining state may occur after a prolonged and intensive training period that includes repeated training sessions with a high TE (4 – 5) without sufficient recovery. In this case, for typical exercise sessions, EPOC and training effect may be higher than before overtraining. These higher than usual responses may be caused by increased sympathetic arousal and hormonal responses.

A very long period of excessive high volume training may lead to overtraining state that is characterized by attenuated physiological and hormonal responses. In this case, EPOC and training effect reached during exercise may be significantly lower than expected, even if the effort in exercise would be high.

Despite changes in EPOC and TE gained in similar exercise, overtraining should not be verified if performance has not decreased. Decreased performance is still the best marker of overtraining. Recovery from the overtraining state requires rest from weeks to months. Generally, a long training history leading to overtraining requires also a long period of recovery.

Changes in fitness level and other factors that influence training effect

Training effect assessment suits for individuals whose level of physical activity and cardiorespiratory fitness change during the course of training. TE assessment provides feedback on training effect according to current activity and fitness. Figure 12 shows the development of training effect limits during a ten-week training period with changes in training frequency and volume. This requires proper adjustment of personal background parameters to provide accurate information on training effect.

In addition to incorrect personal background information, also some other factors may cause inaccuracy for the assessment of TE. EPOC is modeled based on information on exercise intensity (%VO_{2max}), which is affected by the levels of heart rate and respiration rate. Factors that cause significant changes in normal exercise-related heart rate and respiratory responses, such as illnesses, exceptional environmental conditions and abnormally hard training, may have an impact on EPOC and TE assessment. Most common factors and appropriate interpretation of these situations are reviewed in Table 3.

Table 3. Factors causing inaccuracy in training effect assessment.

Sources of inaccuracy		**Impact on TE**	**Appropriate interpretation and reaction**
False personal background parameters		TE is underestimated if maximal heart rate, maximal respiration rate or activity class has been set too high.	Background parameters should be corrected.
		TE is overestimated if maximal heart rate, maximal respiration rate or activity class has been set too low.	
Illness (e.g. a flu)		Higher EPOC and TE when compared to similar exercise in good health due to illness-induced increases in heart rate and respiration rate.	Training effect does not occur during an illness despite high EPOC responses. <u>Exercise should not be performed when suffer-</u> ing from an illness due to risk of serious complications.
Hard environmental conditions (high temperature and/or humidity, high altitude).		Higher TE when compared to similar exercise in normal condi- tions due to increased heart rate and respiration.	One should slow down the pace/work rate while exercising in hard environmental conditions to decrease the cardiovascular load and get the same TE as in normal conditions.
Overtraining	Long high-volume training period.	TE may be lower than expected due to attenuated physiological responses.	Emphasis on recovery until normal training state is reached.
	High intensity training period	TE may be higher than expected due to increased physiological responses.	

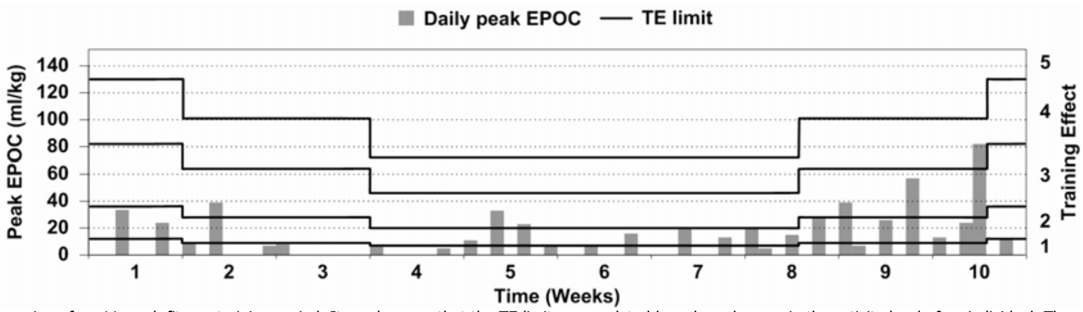

Figure 12. Progression of an 11-week fitness training period. It can be seen that the TE limits are updated based on changes in the activity level of an individual. The activity class is at level 4 at the beginning and at the end of the training period.

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