INTRODUCTION
This document describes a method for EPOC (excess post-exercise oxygen consumption) prediction based on heart rate (HR) measurement. EPOC is defined as the excess oxygen consumed during recovery from exercise as compared to resting oxygen consumption. The EPOC prediction method has been developed to provide a physiology-based measure for training load assessment.

Training load assessment
It is difficult to select an optimal exercise dose. Sufficiently strenuous exercise causes a disturbance in body’s homeostasis which is reflected in recovery result in improved fitness (E.g., Brooks & Fahey 1984; Astrand & Rodahl 1986). Easy training does not improve fitness but too hard training may in long term lead to overtraining. It is therefore important to measure the training load.

Methods used in assessing training load may be broadly characterized as subjective and physiological measures. Subjective measures are easy to access, but do not always reflect physiological responses and recovery demand. Traditional physiological measures, such as oxygen consumption (VO2), heart rate and blood lactate, reflect mainly momentary intensity of exercise and not length of exercise or cumulative exercise load. There are also training load measures such as training impulse (TRIMP), but which does not have physiological basis or scale and therefore may be difficult to interpret.

EPOC is a physiological measure (amount of oxygen consumed in excess after exercise as measured in liters or ml/kg) that reflects the recovery demand and the disturbance of body’s homeostasis brought by the exercise. Measurement of EPOC has been possible only by analyzing respiratory gases with laboratory equipment, thus being expensive, time consuming and not applicable to everyday purposes.

The lack of valid and easy-to-apply physiology based method for the assessment of training load has led to us to develop a method to estimate EPOC indirectly from heart rate measurement.

EPOC in exercise sciences
The first observation of an elevated resting metabolic rate after exercise was made in 1910 by Benedict and Carpenter and was later studied as “oxygen debt” (Hill and Lupton 1923). The present name EPOC has been used not only to represent oxygen repayment during recovery but also to reflect the general exercise-induced disturbance of body’s resting metabolism (Gaesser & Brooks 1984; Gore & Withers 1990) and resting homeostasis (Brech & Gutin 1986): “the cause of Excessive Post-Exercise Oxygen Consumption (EPOC) is the general disturbance to homeostasis brought on by exercise” (Brooks & Fahey 1984).

EPOC reflects the body’s recovery requirements after exercise. Active oxygen-consuming recovery processes occurring in the body are due to replenishment of body’s resources (O2-stores, ATP, CP) and increased metabolic rate (increased HR and respiratory work, elevated body temperature) caused by metabolic by-products and hormones produced during exercise. (Brooks & Fahey 1984; Astrand & Rodahl 1986; Bøtsch & Bahr 2003)

- EPOC reflects a general disturbance in body’s homeostasis caused by exercise.
- EPOC is calculated by subtracting the area under resting VO2 from the area under the recovery VO2 curve (see Figures 1 and 4).
- EPOC gets higher with higher intensity and/or longer duration of exercise (e.g. Bøtsch & Bahr 2005).
INDIRECT EPOC PREDICTION

The accumulation formula of HR-based EPOC is a combination of up-slope (Fig. 4 A) and down-slope (Fig. 4 B) formulas. When the intensity of exercise is high, EPOC accumulates, whereas during periods of rest or low-intensity activity, the combination of these formulas results in decreasing EPOC.

There may be a time lag of about 15 s between the cessation of exercise and reaching the peak value of heart beat derived EPOC. This is due to the slow recovery pattern of VO₂ after exercise, which lags behind the true intensity (the calculation model is not able to recognize the exact end point of exercise).

MODEL VALIDATION (Data published, Rusko et al. 2003)

Methods
Subjects were 32 healthy adults (8 fit and 8 less fit males and females), age 38±9 years (mean±SD), weight 69±120.8 kg, height 171±6±8.5 cm and VO₂max 44.0±8.8 ml/kg/min. The procedure is presented in Figure 6.

Measurements included two 10-min submaximal steady state exercise sessions at 40% and 70% VO₂max, with a constant load, and a maximal incremental bicycle ergometer (Ergoline, Bitz, Germany) test to voluntary exhaustion. Heart period data was collected beat-by-beat with an RR-recorder (Polar Electro Ltd., Kempele, Finland) and VO₂ data breath-by-breath with a Vmax-analyzer (Sensor Medics, California, Palo Alto, USA).

Results
HR-based EPOC was found to correlate with measured EPOC and the goodness of fit (r²) value was 0.79 (see Figure 7). Mean absolute error (MAE) values for the HR-based EPOC, when compared to the measured EPOC values, were 9.4, 14.0 and 16.9 ml/kg for 40% and 70% constant load exercise and for maximal incremental exercise, respectively. For the pooled data, MAE was 13.7 ml/kg. HR-based EPOC was also tightly connected with blood lactate levels, with the r²-value being 0.79 (see Figure 8).
Figure 7. The correlation of heart beat derived EPOC (EPOCpred) with measured EPOC (EPOCmeas) during cycle ergometry exercise. (Modified from Rusko et al. 2003)

Figure 8. The correlation of HR-based EPOC (EPOCpred) with blood lactate levels (Bla) during cycle ergometry exercise. (Modified from Rusko et al. 2003)

EPOC: ESSENTIAL INFORMATION ON EXERCISE

Table 1 summarizes the properties of exercise that determine the magnitude of EPOC. During exercise, EPOC increases or decreases depending on whether disturbance or recovery in homeostasis is expected. EPOC starts to decrease if the intensity decreases enough during exercise. This implies that the physiological training load is not increasing further, but is decreasing instead.

Table 3. Summary of different types of targeted exercises and the related EPOC.

<table>
<thead>
<tr>
<th>Exercise type and purpose</th>
<th>Exercise characteristics</th>
<th>Expected EPOC-response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery exercise:</td>
<td>To speed up lactate removal after exercise and cycle metabolic by-products in muscles.</td>
<td>Constant workload low-intensity exercise (80-90%Vo2max) of short duration (15 to 30 min). Blood lactate (Bla) levels remain at resting level or decrease towards the resting level. No disturbance or recovery of body’s homeostasis.</td>
</tr>
<tr>
<td>Basic endurance/slow distance training:</td>
<td>To enhance the oxidation of fat and build up the endurance base (aerobic threshold).</td>
<td>Constant workload low-intensity exercise (40-60%Vo2max) of long duration (1 to several hours). Bla remains at resting level. No significant disturbance in body’s homeostasis.</td>
</tr>
<tr>
<td>Pace endurance/fast distance training:</td>
<td>To enhance the oxidation of carbohydrates and lactate clearance (anaerobic threshold).</td>
<td>Constant exercise workload (60-85%Vo2max) of moderate to long duration (30 min to 1 hour). Bla increases above resting level. Significant disturbance of body’s homeostasis.</td>
</tr>
<tr>
<td>Vo2max training:</td>
<td>To improve maximal cardiopulmonary performance (Vo2max), oxidation of carbohydrates, lactate tolerance and fast force production specific to race pace) of skeletal muscles.</td>
<td>Constant load or interval exercise with high intensity (&gt;85%Vo2max), short to moderate duration (15 to 30 min). Bla increases rapidly and fatigue emerges quickly.</td>
</tr>
</tbody>
</table>

High EPOC-values are typically attained in exercise where cardiopulmonary load and oxygen consumption remain at high level without possibility to recover. Exercise that recruits large muscle mass, such as cross-country skiing and running, results in higher EPOC values than exercise that recruits small muscle mass. High EPOC values are also gained in intermittent exercise, such as interval training, soccer or squash, if recovery periods are short and intensity remains moderate. When applied to same exercise type, EPOC can be used to compare the demand of different exercises.

EPOC reflects mainly aerobic properties of the exercise and therefore, does not reflect optimally exhaustion due to local muscular fatigue and/or acidity. Thus, in strength exercise, EPOC may be low although the individual would be exhausted.

The day-to-day variation in the physiological training state of an individual can be tracked with EPOC. Short-term changes in performance, environmental factors and possible illnesses affect EPOC accumulation. EPOC is a sensitive measure for both cardiac and respiratory responses. Even slightly unusual responses can be tracked (see Table 2).

APPLICATIONS OF EPOC IN TRAINING

Controlling the training load during a single exercise session

EPOC can be applied across sports, as can be seen from Table 4. An individual willing to improve his/her fitness level can try different sports and check which ones are the best for his/her purpose.

EPOC can be used to confirm whether exercise fulfilled the purpose set before the exercise session. Table 3 represents the main types of aerobic exercise and the expected EPOC response. If the purpose is to enhance cardiopulmonary fitness, EPOC should be high (see Figures 10 A and B). During low-intensity basic endurance exercise and separate warm-up exercises, EPOC should be kept at a low level (see figure 9 A and B). During cool-down, a decline in EPOC should be, indicating active recovery after exercise.

Figure 9. Two examples of recovery exercises from an athlete. A) The intensity of this recovery exercise is slightly too high and EPOC accumulates rapidly at the beginning of session. B) A successful recovery exercise during which intensity and EPOC accumulation remain relatively low throughout the exercise. Note the small difference in intensity but a significant difference in the accumulated training load (peak EPOC) between the two exercises.
EPOC is useful in monitoring day-to-day changes in the physiological response to training. If there is an unexpected EPOC response, the training program can be adjusted depending on the cause of the different response (See table 2).

EPOC reflects changes in the level of cardiorespiratory fitness. If peak EPOC is lower during the same exercise with the same workload (control exercise), the fitness level has probably improved because the disturbance of homeostasis is lower. Similarly, if EPOC is higher, the fitness level has most likely decreased. See Table 2 for additional explanations for higher or lower EPOC levels than usual. More fit individuals are able to exercise at the same relative intensity for a longer period of time than less fit individuals, which leads to higher EPOC.

When coaching a team, it is important to get information on the physiological responses of each individual. Team training sessions and games have a different impact on each player due to individual differences in e.g. the level of cardiorespiratory fitness, position, game style and motivation. With EPOC, the training load of each individual player can be monitored and the training program adjusted (e.g. some players may need more intense training while others need more rest after the games). See Figures 9 C and 9 D for an example in soccer.

**Programming and periodization of training**

The overall load that accumulates during training periods can also be evaluated with EPOC. A schematic example of training load over a training period of an endurance athlete is presented in Figure 10. The integration of training intensity and duration enables easier quantitative analysis of training. More accurate analysis of previous training loads helps in determining recovery requirements and designing subsequent training sessions optimally: the training load can be increased if the previous load is considered to have been too low, or decreased if the load had been higher than planned.

![Diagram](image)

**Figure 9.** Examples of the accumulation of HR-based EPOC in different exercise sessions: (A) High-intensity interval training session (Nordic walking/running in a steep hill). (B) High-intensity constant velocity running exercise. (C) A soccer player (defense) from the Finnish national league during a pre-season practice match. (D) A player from the same team (mid-fielder) in the same match. Note the difference in physiological load between the two players. The match was preceded by a 20-min warm-up and there was a half-time of about 10 min between the two halves.

![Diagram](image)

**Figure 10.** A schematic representation of an endurance athlete’s training load during eight successive weeks (the columns represent daily values of EPOC). This two-month period prepares the athlete for the most important races of the season. The daily values are highest during weekends mainly due to races. Note also the less loading days before race days.

<table>
<thead>
<tr>
<th>EPOC is higher than usual</th>
<th>Possible cause</th>
<th>Recommended action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased cardiorespiratory fitness</td>
<td>Continue training: If possible, reduce the EPOC level back to normal or slightly below it.</td>
<td></td>
</tr>
<tr>
<td>Environmental conditions: increased altitude, temperature or humidity</td>
<td>Decrease absolute work rate to match previous EPOC levels.</td>
<td></td>
</tr>
<tr>
<td>Not fully recovered from previous exercise</td>
<td>Decrease training load and maximize recovery.</td>
<td></td>
</tr>
<tr>
<td>Illness</td>
<td>Do not exercise if you suffer from an illness.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EPOC is lower than usual</th>
<th>Possible cause</th>
<th>Recommended action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent monotonous, high-volume training period</td>
<td>Assure recovery in your training program.</td>
<td></td>
</tr>
<tr>
<td>Increased cardiorespiratory fitness</td>
<td>Increase intensity and/or duration of training to reach or slightly exceed former EPOC levels.</td>
<td></td>
</tr>
<tr>
<td>Sport/activity</td>
<td>Typical exercise</td>
<td>Impact on cardiorespiratory fitness (VO_{2max})</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Running</td>
<td>10-km race (27-50 min, 70-90% VO_{2max})</td>
<td>High – Very high</td>
</tr>
<tr>
<td></td>
<td>Marathon 42 km (2 h (0-30min, 60-65% VO_{2max})</td>
<td>High – Very high</td>
</tr>
<tr>
<td></td>
<td>60 min low intensity (55-65% VO_{2max})</td>
<td>Low – Moderate</td>
</tr>
<tr>
<td>Walking</td>
<td>British walk 1h (40-50% VO_{2max})</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Trekking with a backpack in hilly terrain for 5h (50-60% VO_{2max})</td>
<td>Low – Moderate</td>
</tr>
<tr>
<td>Cycling</td>
<td>Spinning session 40 min (60-80% VO_{2max})</td>
<td>Moderate – Very high</td>
</tr>
<tr>
<td></td>
<td>Cycling to work 20 min (30-50% VO_{2max})</td>
<td>Low</td>
</tr>
<tr>
<td>Rowing</td>
<td>Aerobic workout with ergometer session 30 min (65-75% VO_{2max})</td>
<td>Moderate – High</td>
</tr>
<tr>
<td></td>
<td>Warm-up at gym with ergometer session 10 min (55-65% VO_{2max})</td>
<td>Low</td>
</tr>
<tr>
<td>Cross-Country Skiing</td>
<td>15-km race (55-60min, 70-85% VO_{2max})</td>
<td>High – Very high</td>
</tr>
<tr>
<td></td>
<td>2h low intensity (40-60% VO_{2max})</td>
<td>Low – Moderate</td>
</tr>
<tr>
<td>Soccer</td>
<td>Game 90 min, position back</td>
<td>Low – High</td>
</tr>
<tr>
<td></td>
<td>Game 90 min, position mid-fielder, offense</td>
<td>High – Very high</td>
</tr>
<tr>
<td>Aerobics</td>
<td>45 min aerobics class (65-85% VO_{2max})</td>
<td>Moderate – Very high</td>
</tr>
<tr>
<td>Badminton, Squash</td>
<td>1h game (70-80 %VO_{2max})</td>
<td>High – Very high</td>
</tr>
<tr>
<td>Tennis</td>
<td>1h game (50 - 70% VO_{2max})</td>
<td>Low – High</td>
</tr>
<tr>
<td>Golf</td>
<td>Playing 18 holes (about 3 hours, 30-40% VO_{2max})</td>
<td>Very low – Low</td>
</tr>
</tbody>
</table>

**REFERENCES AND FURTHER READING**


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- VO2 Estimation Method Based on Heart Rate Measurement

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