PRE-PREDICTION OF EPOC: A TOOL FOR MONITORING FATIGUE ACCUMULATION DURING EXERCISE?

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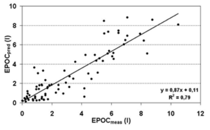
ABSTRACT

At present, there are no useful methods for monitoring fatigue accumulation during training exercises. Excess Post-exercise Oxygen Consumption (EPOC) after exercise is the greater the more exhausting the exercise. **PURPOSE**: To pre-predict the amount of EPOC measured after exercise from information recorded before and during exercise. **METHODS**: Based on meta-analysis of 48 peer-reviewed studies including 158 subjects in different exercise settings (duration and intensity ranging from 2 to 90 minutes and 18% to 108% of VO_{2max}, respectively) a computational model based on heart function (patent pending) for pre-predicting EPOC ($EPOC_{pred}$) was constructed. A total of 32 healthy adult subjects (16 males, 16 females) with age of 38 ± 9 years (mean ± SD), weight 69.6 ± 10.8 kg, height 171.6 ± 8.5 and VO_{2max} 44.0 ± 8.8 ml/kg•min^{-1}, served as a separate validation set. Subjects carried out two 10-min constant load exercises at intensities of 40% and 70% VO_{2max} and a maximal stepwise test to voluntary exhaustion. $EPOC_{pred}$ was pre-predicted from ECG RR-interval data collected with Polar RR-recorder. After exercises 15-min EPOC was measured ($EPOC_{meas}$) using V_{max} analyzer (Sensor Medics). **RESULTS**: $EPOC_{pred}$ vs. $EPOC_{meas}$ in 40%, 70% and maximal test conditions were 0.45 ± 0.21 vs. 0.96 ± 0.88 l ($p<0.05$), 1.94 ± 0.73 vs. 2.05 ± 1.06 l (ns), and 5.91 ± 1.64 vs. 6.28 ± 1.52 l (ns), respectively. Correlations between $EPOC_{pred}$ and $EPOC_{meas}$ and Mean Absolute Error over all exercises and for maximal exercise were r = 0.889 ($p<0.001$) and 0.612 ($p<0.001$), and MAE = 0.96 l and 1.17 l, respectively. **CONCLUSION**: EPOC can be pre-predicted from RR interval data recorded during exercise. Consequently, EPOC pre-prediction may serve as a tool for monitoring fatigue accumulation during exercise.



INTRODUCTION

At present, there are no useful methods for monitoring fatigue accumulation during exercise. Heart rate during exercise gives information on the intensity of exercise but it does not take into account the cumulative effect of exercise duration. Information on body fatigue can be obtained using invasive procedures (e.g., blood sampling and analysis) or measurements (e.g. heart rate) during recovery after exercise.

After exercise, oxygen consumption (VO_2) does not return to resting level immediately but rather in a curvilinear fashion. The causes of Excess Post-exercise Oxygen Consumption (EPOC) after exercise may not be totally clear but based on literature it is hypothesized that the greater the fatigue accumulation during exercise the greater the EPOC and the longer the time required for VO_2 to recover to pre-exercise level.

PURPOSE

The purpose of this study was to develop a method for pre-predicting the amount of EPOC from the information recorded before and during exercise and to compare the pre-predicted EPOC with the actual measured EPOC after exercise.

METHODS

Pre-prediction

Based on meta-analysis of 48 peer-reviewed articles including 158 subjects in different exercise settings (duration and intensity ranging from 2 to 90 minutes and from 18% to 108% of VO_{2max}, respectively) a computational model based on heart function (patent pending) for pre-predicting EPOC ($EPOC_{pred}$) was constructed. The prediction is based on the relations between EPOC vs. the intensity of exercise as the $\%VO_{2max}$ ($\%HR_{max}$) and the duration of the exercise. The computational part of the exercise-phase dependent accumulation of EPOC may be described with the following functional notation:

$$EPOC_{t+1} = EPOC_t + f(EPOC_t, exercise\_intensity_t, \Delta t),$$

The amount and recovery time of EPOC were estimated by using a module for cardiac data modelling provided by Firstbeat Technologies Ltd (patent pending).

Validation

A total of 32 healthy adult subjects (8 fit and 8 less fit males and females) served as a separate validation set.

Table 1. Characteristics of the subjects at rest and at maximal exercise.

	Males		Females	
	Mean ± SD	Range	Mean ± SD	Range
Age (yrs)	37 ± 9	24 – 53	39 ± 10	25 – 54
Weight (kg)	76 ± 8	65 – 88	62 ± 5	52 – 69
Height (cm)	178 ± 6	168 – 185	165 ± 5	158 – 176
Body fat (%)	15 ± 4	8 – 23	26 ± 3	20 – 33
Heart rate (bpm)	72 ± 11	54 – 92	71 ± 8	56 – 82
Peak exercise:				
Work load (W)	264 ± 41	190 – 326	192 ± 41	123 – 270
Heart rate (bpm)	186 ± 10	161 – 202	180 ± 9	169 – 196
VO_2 (l/min)	3,60 ± ,52	2,62 – 4,76	2,50 ± 0,48	1,80 – 3,61
(ml/min/kg)	48 ± 10	30 – 66	41 ± 7	30 – 53

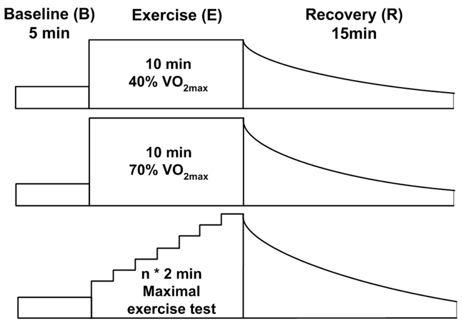


Figure 1. Submaximal and maximal exercise protocols on cycle ergometer.

RRIs and VO_2 were continuously recorded at rest, during baseline and exercise and for 15 minutes after all three exercises using Polar RR-recorder and V_{max} analyzer (Sensor Medics), respectively. After each exercise the actual 15-min EPOC was calculated ($EPOC_{meas}$). Relative exercise intensity was calculated using measured maximal heart rate and VO_{2max}.

The accuracy of the estimates was evaluated as mean absolute differences, Pearson correlation coefficients and goodness-of-fit statistics (R^2) between the measured and estimated values.

RESULTS

Table 2. Mean ± SD data for the submaximal and maximal exercises.

	40%	70%	100%
n	22	27	27
VO_2 (l/min)	1.16 ± 0.32	2.05 ± 0.51	3,05 ± 0,75
Heart rate (bpm)	107 ± 10	145 ± 11	183 ± 10
$EPOC_{meas}$ (l)	0.96 ± 0.88	2.05 ± 1.06	6.28 ± 1.52
$EPOC_{pred}$ (l)	0.45 ± 0.21	1.94 ± 0.73	5.91 ± 1.64
Blood lactate (mM/l)	1.71 ± 0.69	4.80 ± 1.41	10.26 ± 2.10

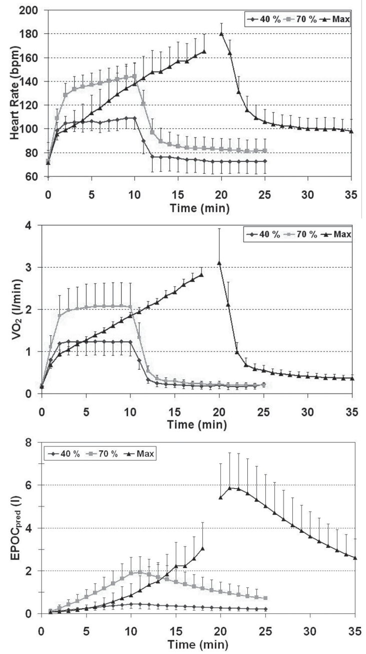


Figure 2. Heart rate, VO_2 and $EPOC_{pred}$ accumulation during exercises.

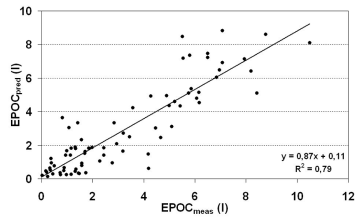


Figure 3. Correlation between pre-predicted and measured EPOC.

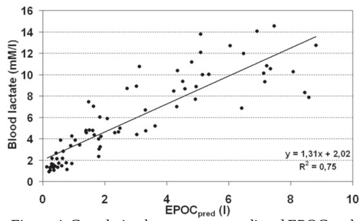


Figure 4. Correlation between pre-predicted EPOC and blood lactate concentration.

	n	r	p	MAE
40% + 70% + Max. exerc.	76	0.889	0.001	0,96
40% + 70% exercises	49	0.424	0.01	0,85
Maximal exercise	27	0,612	0.001	1,17

Table 3. Correlations between $EPOC_{pred}$ and $EPOC_{meas}$ and Mean Absolute Error (MAE) for the pooled data of all exercises, for the pooled data of 40% and 70% submaximal exercises and for the maximal exercise.

DISCUSSION

The results indicate that the EPOC could be pre-predicted from the RR-interval data recorded during the exercises. The results also indicate that at low intensity exercises (~40-70%VO_{2max}) there was a significant correlation between $EPOC_{pred}$ and $EPOC_{meas}$, as well as between $EPOC_{pred}$ and the corresponding blood lactate concentration. At maximal exercise the correlation between $EPOC_{pred}$ and blood lactate concentration was low confirming that other factors, such as body temperature and hormonal changes may influence the EPOC, fatigue accumulation and prolongation of recovery during high intensity exercise.

Figure 5 presents data from a typical training session in field conditions. Heart rate and $EPOC_{pred}$ decreased and increased along with the changes in training intensity.

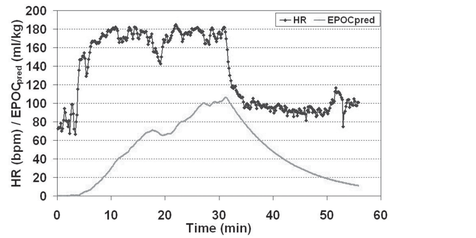


Figure 5. Heart rate and $EPOC_{pred}$ accumulation during a training session.

CONCLUSIONS

(1) EPOC can be pre-predicted from data recorded during exercise.
(2) Only RR-interval measurement is needed for the pre-prediction.
(3) If blood lactate concentration and actual EPOC can be regarded indicative of fatigue accumulation during exercise then the RR-interval based calculation of $EPOC_{pred}$ can be used as a tool for monitoring the accumulation of fatigue during exercise.
(4) Requiring only RR-interval (heart rate) monitoring $EPOC_{pred}$ is especially suitable for field use.
(5) The accuracy of the present system can be improved by taking into consideration the individual differences in the relation between fatigue accumulation and the relative exercise intensity.

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