The Effects of Physical Fitness and Body Composition on Oxygen Consumption and Heart Rate Recovery After High-Intensity Exercise

Abstract

The aim of this study was to investigate the potential relationship between excess post-exercise oxygen consumption (EPOC), heart rate recovery (HRR) and their respective time constants (t\textsubscript{1/2}VO\textsubscript{2} and t\textsubscript{1/2}HR) and body composition and aerobic fitness (VO\textsubscript{2max}) variables after an anaerobic effort. 14 professional cyclists (age = 28.4±4.8 years, height = 176.0±6.7 cm, body mass = 74.4±8.1 kg, VO\textsubscript{2max} = 66.8±7.6 mL·kg\textsuperscript{-1}·min\textsuperscript{-1}) were recruited. Each athlete made 3 visits to the laboratory with 24 h between each visit. During the first visit, a total and segmental body composition assessment was carried out. During the second, the athletes undertook an incremental test to determine VO\textsubscript{2max}. In the final visit, EPOC (15-min) and HRR were measured after an all-out 30 s Wingate test. The results showed that EPOC is positively associated with % body fat (r = 0.64), total body fat (r = 0.73), fat-free mass (r = 0.61) and lower limb fat-free mass (r = 0.55) and negatively associated with HRR (r = -0.53, p < 0.05 for all). HRR had a significant negative correlation with total body fat and % body fat (r = -0.62, r = -0.56 respectively, p < 0.05 for all). These findings indicate that VO\textsubscript{2max} does not influence HRR or EPOC after high-intensity exercise. Even in short-term exercise, the major metabolic disturbance due to higher muscle mass and total muscle mass may increase EPOC. However, body fat impedes HRR and delays recovery of oxygen consumption after effort in highly trained athletes.

Introduction

Excess post-exercise oxygen consumption (EPOC) is defined as an elevated rate of oxygen consumption after a period of exercise [21]. The EPOC response to exercise is influenced by certain factors that include body core temperature and the intensity and duration of exercise [27], which have, respectively, a curvilinear and linear relationship with EPOC [25].

The post-exercise recovery period is characterized by a return of the heart rate (HR) to the pre-exercise level, and heart rate recovery (HRR) results from sympathetic withdrawal and parasympathetic reactivation [7, 14, 17, 22]. The autonomic nervous system influences the reestablishment of HR after exercise, and monitoring the velocity of parasympathetic reactivation can reduce the chances of arrhythmic cardiac death [7, 14].

Tomlin and Wenger [30] have proposed that an increase in aerobic power can facilitate recovery after anaerobic exercise by both improving energy from aerobic and anaerobic sources during exercise and providing aerobic energy during recovery [24]. In a recent study, Stupnicki et al. [28] analyzed 5 min of recovery after different intensities and durations of exercise and observed that individuals with higher maximal oxygen consumption (VO\textsubscript{2max}) had a faster recovery.

Investigations into the relationship between VO\textsubscript{2max}, fat-free mass (FFM) and EPOC have shown that subjects with greater muscle mass exhibit greater oxygen consumption for 40 min after anaerobic exercise [29]. On the other hand, Short and Sedlock [27] observed that subjects with higher VO\textsubscript{2max} have lower EPOC after the same period of absolute intensity exercise. The conflicting results may be resolved if differences in exercise intensity and duration are considered, since this may affect the underlying metabolic processes [4]. However, the studies cited used practically the same recovery length, although the exercise intensity was different. Thus, the effects of short-term exercise and recovery remain unclear.
The use of HRR as a monitoring tool has increased progressively and could be important to monitoring the effect of exercise in different populations [8, 11] as well as the training load for athletes [18, 19]. The distinct influences of aerobic fitness and body composition on autonomic cardiovascular control (HRR) may be frequently confounded because physically fit subjects generally have a healthy body composition due to training [12]. To our knowledge, however, no study has examined the relationship between body composition and VO\textsubscript{2}max using autonomic tonic and EPOC in highly trained subjects.

Although there have been several studies investigating moderate intensity long-term exercise protocols [20, 27] and others investigating either high intensity training [2, 28, 29] or both of these [15, 23], little research has been carried out on EPOC and HRR after short supramaximal exercise. Therefore, the aim of this study was to investigate whether there is any relationship between EPOC, HRR and their respective time constants (t\textsubscript{vO\textsubscript{2}} and t\textsubscript{HR}) with body composition and VO\textsubscript{2}max variables after anaerobic effort. We hypothesized that athletes with higher VO\textsubscript{2}max, higher muscle mass and lower body fat would have greater HRR values and lower EPOC.

Materials and methods

Subjects

14 professional cyclists participated in the study. The competition level of the subjects ranged from national to international. All subjects were tested during the competitive cycling period and presented no complaints of injury or pain. The characteristics of the subjects are presented in Table 1. Each subject provided written informed consent and fully completed the research protocol. The experimental protocol was approved by the Research Ethics Committee of the associated institution and was performed in accordance with the ethical standards of the IJSM [16].

Experimental protocol

All tests were performed between 3:30 pm and 7:30 pm. All participants made 3 visits to the laboratory, with 24 h between each visit. During the first visit, a total and segmental body composition assessment was carried out. In the second, the athletes underwent an incremental test to determine VO\textsubscript{2}max. In the final visit, EPOC and HRR were measured after an all-out 30 s Wingate test. The intensity was not equal for all subjects, as there they were instructed only to use their highest power output during all tests. Unfortunately, there was a technical error in the device during the experiment and the generated power output was not recorded during the Wingate test.

The subjects were asked to refrain from vigorous exercise and to avoid alcohol and caffeine for 24 h prior to each test session. The subjects were also instructed not to eat a meal less than 2 h prior to each test. Each test was performed in a quiet laboratory under controlled conditions (temperature: 21–23°C, relative humidity: 40–60%).

Assessment of body composition

The total and segmental (trunk and lower limbs) body composition, i.e., percent of body fat (%BF), total body fat (TBF), fat-free mass (FFM) and lower limb fat-free mass (LLFFM) were estimated using dual-energy x-ray absorptiometry (DXA) equipment, model DPX-NT (General Electric Medical Systems, USA). The subjects wore light clothing and remained still in the supine position with their arms by their sides during the scan [13].

Table 1  Anthropometric and physiological characteristics of subjects (n = 14).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>age (years)</td>
<td>28.4 ± 4.8</td>
</tr>
<tr>
<td>height (cm)</td>
<td>176 ± 6.7</td>
</tr>
<tr>
<td>body mass (kg)</td>
<td>74.4 ± 8.1</td>
</tr>
<tr>
<td>BMI (kg·m\textsuperscript{-2})</td>
<td>24.0 ± 1.7</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>11.5 ± 3.2</td>
</tr>
<tr>
<td>total body fat (kg)</td>
<td>8.1 ± 2.9</td>
</tr>
<tr>
<td>fat free mass (kg)</td>
<td>61.7 ± 5.7</td>
</tr>
<tr>
<td>LLFFM (kg)</td>
<td>24.8 ± 2.8</td>
</tr>
<tr>
<td>EPOC (L)</td>
<td>5.7 ± 2.1</td>
</tr>
<tr>
<td>VO\textsubscript{2}max (ml·kg\textsuperscript{-1}·min\textsuperscript{-1})</td>
<td>66.8 ± 7.6</td>
</tr>
<tr>
<td>t\textsubscript{vO\textsubscript{2}} (s)</td>
<td>88.2 ± 17.9</td>
</tr>
<tr>
<td>HRR (bpm)</td>
<td>41.9 ± 12.8</td>
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<tr>
<td>t\textsubscript{HR} (s)</td>
<td>84.6 ± 27.3</td>
</tr>
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Values are mean ± SD

Determination of maximal oxygen consumption

Cardiorespiratory variables were measured at 10 s intervals with a MedGraphics VO\textsubscript{2000} Portable metabolic measurement system (MedGraphics, Minnesota, USA). The equipment was automatically calibrated prior to each evaluation according to manufacturer specifications. Heart rate was checked at the end of each stage with a Polar S810i heart-rate monitor (Polar Electro, Kempele, Finland) [31].

The subjects remained at rest for 5 min with the flow device connected to a neoprene facemask (by means of a silicone adapter) that covered the mouth and nose. Pre-exercise oxygen consumption was assessed. Next, the athletes warmed up for 3 min at 150 watts (W). Testing commenced with the power set at 175 W; every minute thereafter, a 25 W increment occurred until voluntary exhaustion [9]. Standard criteria for heart rate (HR within 10 bpm of the age-predicted maximum), respiratory exchange ratio > 1.1 and plateauing of VO\textsubscript{2} despite an increasing work load were used to confirm VO\textsubscript{2}max [8]. Aerobic power was tested on a Cateye (CS-1000®) cycle simulator attached to each athlete’s personal bicycle. The athletes exerted their maximum work capacity until exhaustion to determine VO\textsubscript{2}max. Strong verbal encouragement was provided to the subjects throughout the effort.

Post-exercise oxygen consumption and heart rate recovery after the all-out 30 s test

The Wingate test was used as the all-out 30 s test and consisted of 30 s of maximal effort with 7.5 % body mass. Prior to the test, each athlete adjusted the seat height to the appropriate level. Participants warmed up for 2 min by pedaling at a cadence of 80 rpm and with the constant power output set to 50 W. At the end of the warm-up, 2 brief (2–3 s) bouts of sprinting were conducted. After the warm-up period, the subjects performed the 30 s all-out trial. At the end of the trial, subjects remained on the cycle simulator for 1 min and then reclined on a nearby bed for 15 min, during which time the gas exchange and HR were measured as previously described.
The magnitude of EPOC was calculated as the integrated area between VO\(_2\) and 15 min after the end of the test. This mathematical model was developed using OriginPro 8.0 (Origin Lab) software [28]. Prior to the anaerobic test, the subjects remained at rest for 5 min for the recording of baseline VO\(_2\) value, which was established as the mean of the last 30 s. Due to the possible influence of other variables and the different VO\(_2\) baselines presented by some subjects, we chose to use the average baseline VO\(_2\) [3]. HRR was measured by subtracting the highest HR (HR\(_{\text{high}}\)) at the end of the test from the HR registered one minute after test (HR\(_{1\text{min}}\)) [8] in the following equation: HRR = HR\(_{\text{high}}\)− HR\(_{1\text{min}}\). Both variables were plotted graphically and cleaned up to exclude any outlying data points. The VO\(_2\) and HR data were analyzed using a first order exponential decay with Origin 8.0 software; the \(t\) constant was furnished by the program [7].

Statistical analysis
The distribution of each variable was examined with the Kolmogorov-Smirnov normality test. The correlations between the metabolic, anthropometric and post-exercise responses were calculated with the Pearson product-moment correlation. Statistical significance was set at \(p<0.05\), and the analysis was performed using SPSS version 17.00 (SPSS Inc., Chicago, Illinois). The data are presented as mean and standard deviation (SD) of the investigated variables.

Results
The subjects had average values of 5.7±2.1 L for EPOC and 41.9±12.8 bpm for HRR. EPOC was negatively correlated with HRR (\(r = -0.53\), \(p = 0.04\)) and positively correlated with \(t\)\(_{HR}\) (\(r = 0.19\), \(p = 0.52\)). Moreover, EPOC was positively related to \(t\)\(_{VO_2}\) (\(r = 0.57\), \(p = 0.03\)). Conversely, there was no association between VO\(_2\)max and EPOC (\(r = 0.19\), \(p = 0.52\)) (Fig. 1) and HRR (\(r = 0.16\), \(p = 0.69\)) (Table 2).

Table 2  Correlation coefficient between physical fitness and body composition indices with heart rate recovery and time constant of heart rate (\(t\)\(_{HR}\)).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Heart rate recovery</th>
<th>(t)(_{HR})</th>
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<tbody>
<tr>
<td>VO(_2)max (mL·kg(^{-1})·min(^{-1}))</td>
<td>0.16 ((p = 0.69))</td>
<td>-0.37 ((p = 0.18))</td>
</tr>
<tr>
<td>(t)(_{VO_2}) (s)</td>
<td>-0.47 ((p = 0.09))</td>
<td>0.61 ((p = 0.02))</td>
</tr>
<tr>
<td>body mass (kg)</td>
<td>-0.57 ((p = 0.03))</td>
<td>0.43 ((p = 0.12))</td>
</tr>
<tr>
<td>% body fat (%)</td>
<td>-0.56 ((p = 0.03))</td>
<td>0.63 ((p = 0.01))</td>
</tr>
<tr>
<td>total body fat (kg)</td>
<td>-0.62 ((p = 0.02))</td>
<td>0.66 ((p = 0.01))</td>
</tr>
<tr>
<td>fat free mass (kg)</td>
<td>-0.41 ((p = 0.14))</td>
<td>0.34 ((p = 0.23))</td>
</tr>
<tr>
<td>LLFFM (kg)</td>
<td>-0.43 ((p = 0.12))</td>
<td>0.28 ((p = 0.32))</td>
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</table>

VO\(_2\)max: maximal oxygen consumption; \(t\)\(_{VO_2}\): time constant of oxygen consumption; LLFFM: lower limb fat free mass.
There was a negative correlation between HRR and TBF ($r = -0.62$, $p = 0.02$), %BF ($r = -0.56$, $p = 0.03$) and body mass ($r = -0.57$, $p = 0.03$) and a positive correlation between $t_{HR}$ and TBF ($r = 0.66$, $p = 0.01$). Moreover, $t_{HR}$ was positively related to %BF ($r = 0.63$, $p = 0.01$) and $t_{VO2}$ ($r = 0.61$, $p = 0.02$). There was no significant association among the other variables (Table 2).

All body composition variables were positively correlated with EPOC: %BF ($r = 0.64$, $p = 0.01$), TBF ($r = 0.73$, $p = 0.001$), FFM ($r = 0.61$, $p = 0.02$) and LLFFM ($r = 0.55$, $p = 0.03$) (Fig. 2). A positive association was found between body mass and TBF ($r = 0.62$, $p = 0.01$).

### Discussion

The results of this study indicate that: 1) there was a significant negative correlation between EPOC and HRR; 2) EPOC was positively correlated with all body composition variables; 3) HRR was negatively associated only with %BF and TBF. Our hypothesis was incorrect and the more relevant findings included the correlations between EPOC, body composition measurements and parasympathetic reactivation ($t_{HR}$), as well as the relation between both HRR and $t_{HR}$ and TBF and %BF.

Contrary to our hypothesis, VO$_2$max was not correlated with EPOC or time decay of oxygen consumption. Despite the association between higher VO$_2$max and several cardiovascular and muscular adaptations that may favor faster recovery [24, 27], this was not found in the present study. Perhaps the duration of high-intensity exercise was too short to demonstrate any association between EPOC and VO$_2$max. In a study comparing 2 groups of individuals (trained and untrained) at an effort of the same relative intensity (70% VO$_2$max) [27], the trained subjects had a faster recovery beginning with the change in VO$_2$. Besides the length of exercise, the intensity of effort could influence the association with EPOC. The intensity was not equal for all subjects, since they were instructed only to use their highest power output during all tests.

The non-correlation between EPOC and VO$_2$max is at odds with the results of Tahara et al. [30], who observed a significant correlation ($r = 0.37$, $p < 0.001$) between EPOC (40 min) and VO$_2$max in 250 Japanese athletes. Higher VO$_2$max seems to influence EPOC when the recovery period is extended beyond 15 min, which was the limit set in present study.

Thus, some factors may be important to EPOC: (i) the relative intensity and duration of exercise [27] and (ii) the duration of recovery, which according to previously published data may be more than 15 min [28, 30]. However, the training status (highly trained athletes) may have also influenced the association between EPOC and VO2. Further studies on the influence of exercise in highly trained athletes at different intensities and recovery times on EPOC are required.

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**Fig. 2** Correlation between excess post-oxygen consumption (EPOC) and (a) % body fat, (b) total body fat, (c) fat free mass and (d) low limb fat free mass (LLFFM).
EPOC was positively related to body composition, fat composition (%BF and TBF) as well as total muscular content and active muscle mass (FFM and LLFFM). However, even with a larger sample size, this association was less significant in Tahara et al. [29]. According to authors [29], the association between FFM and EPOC is due to a larger volume of myoglobin, which plays an important role in the re-synthesis of ATP. However, this statement is a hypothesis. A greater LLFFM would lead to higher anaerobic power output during the effort and, consequently, major metabolic disturbance (increasing EPOC). On the other hand, the association between %BF and TBF with EPOC remains unclear and might be related to a higher absolute load, which would also lead to greater metabolism disturbance. Therefore, this hypothesis, together with the myoglobin analysis, should be tested in future studies in order to further elucidate the real association underlying body composition and physiological variables.

The small sample size was a study limitation, as was the absence of force and power output variables due to the technical error. Furthermore, different exercise modes and distinct body composition measurements impair the comparison of our results with those of other researchers. Moreover, we did not evaluate VO_2 during the anaerobic test, which would have clarified the aerobic contribution and helped confirm the hypothesis of the study. It appears that the primary variable related to autonomic system recovery and EPOC in highly trained subjects is not VO_2max, but rather that body composition parameters are more associated with HRR (TBF and %BF) and EPOC (%BF, TBF, FFM and LLFFM). It would be important to investigate whether training or fitness changes affect EPOC and HRR in highly trained athletes as well as their relation with VO_2max and body composition. Moreover, any relation discovered between these variables and performance could lead to the use of EPOC and HRR during field testing, which would be important for both conditioning and strength coaching.

Conclusion

Our findings indicate that there was a positive relationship between EPOC and HRR in highly trained athletes after high-intensity exercise. EPOC was positively associated with all body composition variables. HRR was negatively correlated with TBF and %BF, while physiological variables that could predict performance (i.e., VO_2max) were associated with neither EPOC nor HRR. In conclusion, VO_2max does not influence EPOC or HRR during short-term recovery in well-trained subjects. While TBF and %BF impair HRR, both fat mass and lean mass (FFM and LLFFM) enhance EPOC due to higher anaerobic disturbance in highly-trained cyclists after a high-intensity exercise session.

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