Relationship Between Aerobic Fitness and Metabolic Recovery From Intermittent Exercise in Endurance Athletes

Gordon J. Bell, Gary D. Snydmler, Diane S. Davies, and H. Art Quinney

Catalogue Data

Key words: maximal oxygen consumption, recovery oxygen consumption, ventilation threshold, lactate, heart rate
Mots-clés: consommation maximale d’oxygène, consommation d’oxygène de récupération, seuil ventilatoire, lactate, fréquence cardiaque

Abstract/Résumé
This investigation examined the relationship between several different aerobic fitness test results and measurements of metabolic recovery from intermittent, high-intensity exercise in 16 male cyclists. No significant correlations were found between maximal oxygen consumption, ventilation threshold, various submaximal endurance measures and the rate of metabolic recovery, net excess postexercise oxygen consumption, or blood lactate removal after intermittent high-intensity exercise except for submaximal heart rate (r = .66, p < .05). These data indicate that aerobic fitness assessments do not indicate the ability to recover after intermittent, high-intensity exercise in endurance-trained cyclists.

Cette étude analyse les relations entre les résultats à divers tests d’efficience aérobie et les analyses de gaz faites au cours d’une récupération d’un effort intermittent de haute intensité chez 16 cyclistes masculins. Après un tel effort,

aucune corrélation significative, sauf pour la fréquence cardiaque sous-maximale ($r = .66; p < .05$), n’est observée entre les valeurs de consommation maximale d’oxygène, de seuil ventilatoire, de diverses mesures d’endurance sous-maximale et la rapidité de récupération métabolique, l’excédent de consommation d’oxygène nette ou la quantité de lactate oxydée. Ces observations suggèrent que les résultats des cyclistes d’endurance aux tests d’efficience aérobie ne fournissent pas d’indication sur leur aptitude à récupérer après un effort intense et intermittent.

**Introduction**

Recovery from exercise may be defined as the ability of an individual to return to or toward the rested state. A variety of physiological indicators have been used to measure recovery from exercise, including oxygen consumption, heart rate, and blood lactate (Gaesser and Brooks, 1984; Hagberg et al., 1980; Hickson et al., 1978; Petersen et al., 1989). The physiological adaptations associated with endurance training enhance the adjustment to, and the recovery from, submaximal (Hickson et al., 1978; Hagberg et al., 1980) and maximal exercise (Hakkinen and Myllyla, 1990; Jansson et al., 1990; Kuno et al., 1992; McCully et al., 1989, 1992), and these training improvements are associated with increases in measurements of aerobic fitness such as maximal oxygen consumption. This association has led to the implication that measurements of aerobic fitness may indicate the ability of an individual to recover from exercise of various intensities (especially high-intensity exercise) or modes (e.g., strength, sprint, or endurance exercise), despite little research to indicate that such a relationship exists. While this may be a reasonable assumption when monitoring endurance training changes with untrained subjects or when comparing untrained individuals to endurance trained athletes, it is not known whether a relationship exists between measurements of aerobic fitness and recovery within a group of endurance trained athletes.

Therefore, the purpose of this investigation was to examine the relationship between indices of aerobic fitness (maximal oxygen consumption, ventilation threshold, submaximal endurance, and efficiency) and metabolic recovery (rate and net recovery oxygen consumption and blood lactate removal) from intermittent, high-intensity exercise in endurance-trained cyclists. Our hypothesis was that if aerobic fitness indicates recovery from exercise, then there may be a positive correlation between aerobic fitness tests and metabolic recovery.

**Methodology**

The subjects were 16 endurance-trained athletes who volunteered to participate and signed an informed consent form approved by a university ethical review committee. The mean ($\pm SD$) age, height, and weight was 22.9 $\pm$ 3.2 years, 178.2 $\pm$ 7.4 cm, and 72.0 $\pm$ 8.7 kg, respectively. All subjects were club-level cyclists or triathletes
who were involved in competition and had been actively training for a minimum of 3 years.

Fitness testing involved an incremental test on a Monark 818 cycle ergometer to determine ventilation threshold (VT) and maximal oxygen consumption (VO$_{2 \text{max}}$), starting with a power output (PO) of 118 W that was increased every 3 min by 40 W until VT occurred (see below). Subsequent to one complete workload after VT was achieved, PO increased by 40 W every minute until volitional exhaustion. Expired air was collected and analysed using a Beckman metabolic measurement cart (Sensor Medics, California). Ventilation threshold (L · min$^{-1}$) was determined as the lowest point on the VE/VCO$_2$ versus PO graphical relationship that corresponded to the highest point on the FECO$_2$ versus PO relationship prior to a systematic increase (Bhambhani & Singh, 1985). Power output, VO$_2$, and heart rate (HR) at VT were also determined. The criteria for VO$_2\text{max}$ was a peak and plateau (e.g., change of VO$_2$ < 100 ml · min$^{-1}$) in oxygen consumption, with continual exercise that was associated with a respiratory exchange ratio (RER) of >1.1, achievement of age-predicted or known maximum heart rate and volitional exhaustion. Heart rate (b · min$^{-1}$) was measured every minute using a electrocardiogram for all tests (Cambridge Model VS46).

Submaximal steady state exercise responses were assessed on a separate day using the steady state data (e.g., change of VO$_2$ < 100 ml · min$^{-1}$) during a 10-min cycle ergometer test on the same Monark cycle ergometer at a power output of 200 W that was below VT for all but one subject. Mean VO$_2$ and HR was determined from the final 5 min of the steady state submaximal exercise test. Gross and net mechanical efficiency was calculated as a percentage (%) from the submaximal steady state VO$_2$, RER, and work done during the last 5 min (Fox et al., 1991, pp. 71-82). Blood samples (2 ml) were taken from an antecubital vein using venipuncture at rest and after 1 and 5 min of rest recovery after the submaximal exercise test. A 0.5 ml sample of whole blood was immediately deproteinized in 2 ml of chilled 4% perchloric acid, centrifuged at 3,000 × g for 10 min and the supernatant was stored at −70 °C. Venous blood lactate concentration (mmol · L$^{-1}$) was determined using a modification of the spectrophotometric method of Sigma (No. 826-UV, Sigma Chemical Company, St. Louis). The modification involved a two-thirds reduction in the total volume required while maintaining the ratio of sample to reaction medium.

The high-intensity intermittent exercise protocol was performed on a separate day and consisted of cycling at a power output equivalent to 125% of the power output that elicited VO$_2\text{max}$ for 1 min followed by 5 min of no exercise (rest). This was repeated three times (three intervals) and physiological data (VO$_2$ and HR) was collected continuously for a 5-min rest period immediately prior to exercise, during the intermittent work schedule and for 10 min postexercise. Half times (T1/2) for the rate of decrease in VO$_2$ (L · min$^{-1}$) were calculated for the "fast" and "slow" components of the recovery oxygen consumption versus time relationship as previously described (Hagberg et al., 1980; Hickson et
al., 1978). Net excess postexercise oxygen consumption (EPOC in L·min⁻¹) during the 10-min postexercise period was also determined (Gaesser & Brooks, 1984).

A 21-gauge indwelling Teflon catheter was inserted into an antecubital vein prior to the intermittent exercise protocol, and 2-ml blood samples were obtained at rest; immediately after each exercise bout, immediately before the subsequent exercise bout, immediately after the final exercise bout, and after 1, 5, 7, and 10 min of rest recovery. Clotting was avoided at the sample site by injecting a small (0.5 cc) amount of heparin into a cap attached to the catheter. Prior to the attainment of each blood sample, a 1-ml blood sample was removed and discarded to ensure that there was no heparin in the sample for analysis. Venous blood lactate concentration was determined as described above. Recovery blood lactate was calculated as the difference between the peak blood lactate concentration and the lowest value subsequent to this during the 10-min postexercise time period (Petersen et al., 1989).

Anaerobic power was determined using a 30-s Wingate protocol on a modified Monark cycle ergometer (Somerville and Quinney, 1987) using a resistance setting of 95 g per kilogram body weight (Evans and Quinney, 1981). Peak 5-s power output and mean 30-s power output were calculated using a custom designed computer software program.

STATISTICAL ANALYSIS

A stepwise multiple regression analysis was performed to determine the relationship between the metabolic recovery parameters and blood lactate recovery and the various aerobic fitness measurement variables. A Pearson’s correlation coefficient was used to determine the relationship between all the recovery variables and the aerobic fitness variables. Alpha was preset at $p < .05$.

**Results**

Table 1 shows the physiological characteristics of all subjects for the exercise fitness tests. Table 2 contains the half times for the fast and slow recovery oxygen consumption components, net excess postexercise oxygen consumption, and lactate recovery variables. These results indicate that the sample was an endurance-trained group with a reasonable range of fitness levels and recovery ability.

The results of a stepwise multiple regression analysis revealed that submaximal heart rate was the only significant predictor of recovery. No other variable accounted for any additional significant portion of the variance associated with recovery. The Pearson product-moment correlation also showed that HR during the submaximal test ($r = .66$, $p < .05$) was the only variable significantly correlated with postexercise oxygen consumption (Table 3).
Table 1  Physiological Characteristics of All Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{VO}_2\text{max} (L \cdot \text{min}^{-1})$</td>
<td>4.49</td>
<td>0.41</td>
<td>3.90–5.67</td>
</tr>
<tr>
<td>$\text{VO}_2\text{max} (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$</td>
<td>63.1</td>
<td>4.32</td>
<td>54.4–70.3</td>
</tr>
<tr>
<td>HRmax (b \cdot \text{min}^{-1})</td>
<td>192</td>
<td>6</td>
<td>182–204</td>
</tr>
<tr>
<td>PO at $\text{VO}_2\text{max}$ (W)</td>
<td>371.2</td>
<td>38.8</td>
<td>291–436</td>
</tr>
<tr>
<td>BLa at $\text{VO}_2\text{max}$ (mmol \cdot \text{L}^{-1})</td>
<td>8.05</td>
<td>1.35</td>
<td>6.1–11.0</td>
</tr>
<tr>
<td>VT (L \cdot \text{min}^{-1})</td>
<td>3.20</td>
<td>0.37</td>
<td>2.36–3.91</td>
</tr>
<tr>
<td>PO at VT (W)</td>
<td>235</td>
<td>29</td>
<td>196–275</td>
</tr>
<tr>
<td>Submax $\text{VO}_2$ (L \cdot \text{min}^{-1})</td>
<td>2.80</td>
<td>0.14</td>
<td>2.53–2.98</td>
</tr>
<tr>
<td>Submax HR (b \cdot \text{min}^{-1})</td>
<td>147</td>
<td>11</td>
<td>119–160</td>
</tr>
<tr>
<td>Submax BLa (mmol \cdot \text{L}^{-1})</td>
<td>1.61</td>
<td>0.6</td>
<td>0.9–2.7</td>
</tr>
<tr>
<td>Peak 5-s ANPO (W)</td>
<td>897.1</td>
<td>124.1</td>
<td>764.7–1160.0</td>
</tr>
<tr>
<td>Mean 30-s ANPO (W)</td>
<td>716.7</td>
<td>86.7</td>
<td>620.7–960.0</td>
</tr>
<tr>
<td>Net eff. at 200 W (%)</td>
<td>23.5</td>
<td>1.11</td>
<td>21.5–26.4</td>
</tr>
</tbody>
</table>

*Note. $\text{VO}_2\text{max}$ = maximal oxygen consumption; HRmax = maximum heart rate; BLa = blood lactate; PO = power output; VT = ventilation threshold; Submax = submaximal; ANPO = anaerobic power output; eff. = efficiency.*

Table 2  Physiological Measurements of Metabolic Recovery After the Intermittent Exercise Schedule

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast recovery $\text{VO}_2$ T1/2 (s)</td>
<td>55.6</td>
<td>11.2</td>
<td>25.1–73.2</td>
</tr>
<tr>
<td>Slow recovery $\text{VO}_2$ T1/2 (s)</td>
<td>53.8</td>
<td>22.3</td>
<td>12.9–96.0</td>
</tr>
<tr>
<td>Net EPOC (L)</td>
<td>4.12</td>
<td>0.54</td>
<td>3.48–4.98</td>
</tr>
<tr>
<td>Recovery lactate (mmol \cdot \text{L}^{-1})</td>
<td>1.61</td>
<td>1.23</td>
<td>0.30–4.50</td>
</tr>
</tbody>
</table>

*Note. T1/2 = half time; EPOC = excess postexercise oxygen consumption.*

**Discussion**

It has been well documented that aerobic endurance training can improve recovery from submaximal and maximal exercise (Hagberg et al., 1980; Hakkinen and Myllyla, 1990; Hickson et al., 1978; Jansson et al., 1990; Kuno et al., 1992; McCully et al., 1989, 1992). These findings suggest that the adaptations to endurance training are associated with an improved ability to recover from exercise. This has been one reason for prescribing aerobic endurance training to improve recovery for athletes participating in sports and events that involve repeated high-intensity, intermittent exercise. However, many fitness appraisers have assumed that a relatively high score on aerobic fitness tests (e.g., $\text{VO}_2\text{max}$) indicates an enhanced
Table 3  Pearson’s Correlation Coefficients Between Measurements of Aerobic Fitness and Metabolic Recovery

<table>
<thead>
<tr>
<th>Variable</th>
<th>Net EPOC (L min⁻¹)</th>
<th>T1/2 for fast recovery (s)</th>
<th>T1/2 for slow recovery (s)</th>
<th>Blood lactate change (mmol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ max (L min⁻¹)</td>
<td>-0.35</td>
<td>-0.06</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>VO₂ max (ml kg⁻¹ min⁻¹)</td>
<td>0.11</td>
<td>-0.03</td>
<td>0.07</td>
<td>0.03</td>
</tr>
<tr>
<td>HR max (b min⁻¹)</td>
<td>-0.01</td>
<td>0.06</td>
<td>0.02</td>
<td>0.41</td>
</tr>
<tr>
<td>PO at VO₂ max (W)</td>
<td>0.24</td>
<td>-0.05</td>
<td>0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>BLa at VO₂ max (mmol)</td>
<td>0.38</td>
<td>0.06</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>VT (L min⁻¹)</td>
<td>0.01</td>
<td>0.04</td>
<td>-0.35</td>
<td>0.07</td>
</tr>
<tr>
<td>PO at VT (W)</td>
<td>-0.06</td>
<td>0.01</td>
<td>-0.24</td>
<td>0.07</td>
</tr>
<tr>
<td>Submax VO₂ (L min⁻¹)</td>
<td>-0.09</td>
<td>-0.13</td>
<td>0.15</td>
<td>-0.06</td>
</tr>
<tr>
<td>Submax HR (b min⁻¹)</td>
<td>0.66</td>
<td>0.27</td>
<td>0.08</td>
<td>-0.01</td>
</tr>
<tr>
<td>Submax BLa (mmol)</td>
<td>0.27</td>
<td>0.33</td>
<td>-0.26</td>
<td>-0.16</td>
</tr>
<tr>
<td>Net eff. at 200 W (%)</td>
<td>-0.30</td>
<td>0.11</td>
<td>-0.05</td>
<td>-0.20</td>
</tr>
</tbody>
</table>

*Note. BLa = blood lactate; EPOC = excess postexercise oxygen consumption; PO = power output; VT = ventilation threshold; eff. = efficiency; T1/2 = half time.

* p < .05.

ability to recover from different modes of exercise or types of training (i.e., interval). It was hypothesized in the present study that measurements of aerobic fitness may indicate the ability of an athlete to recover from high-intensity exercise. Our findings do not support this latter hypothesis, as no correlation was found between a variety of commonly performed aerobic fitness assessments and measurements of recovery, except for submaximal heart rate. The physiological importance of this latter result was not apparent from the present data. Although not reported here, we also analysed all recovery variables between, as well as after, each intermittent exercise bout and found no significant correlations with the assessments of aerobic fitness.

The aerobic fitness variables measured in the present study have been used to assess the rate and capacity of the aerobic system to supply energy for exercise (Thoden, 1991), and the variables used to indicate recovery have also been previously reported (Bishop & Martino, 1993; Hagberg et al., 1980; Hickson et al., 1978; Petersen et al., 1989). The lack of relationship between the measurements of aerobic fitness and metabolic recovery after the high-intensity, intermittent exercise bouts suggests that the physiological factors underlying the different assessments of aerobic fitness are probably too diverse to be used as indicators for the ability to recover from high-intensity, intermittent exercise. Aerobic fitness depends on factors related to the cardiorespiratory system such as cardiac output,
oxygenation of blood, and blood flow, as well as peripheral factors associated with
the oxidative capacity of skeletal muscle. The ability to recover from high-inten-
sity intermittent exercise depends on at least the following: the restoration of ad-
enosine triphosphate and creatine phosphate levels, oxidation of accumulated lac-
tate, reestablishment of any ionic imbalance (e.g., calcium or hydrogen ions), the
level of circulating hormones (e.g., thyroxine or catecholamines), the magnitude
of the increase in core temperature, and the intensity and duration of exercise
(Gaesser and Brooks, 1984). Our results do not dispute the fact that there may be a
difference in the recovery ability of a trained athlete compared to an untrained
individual or that endurance training can improve some of the aspects of recovery
listed above. The present study indicates that it may be inappropriate to assume
that a relationship exists between measurements of aerobic fitness and recovery in
a group of endurance trained athletes.

The aerobic fitness levels of the subjects used in the present study reflected
an endurance-trained group with a reasonable range of fitness levels and recovery
ability (see Table 2). In this sample, a greater aerobic fitness level did not neces-
sarily indicate an enhanced ability to recover from high-intensity, intermittent exer-
cise. The possibility exists that continued improvements in aerobic fitness beyond
a particular level may not lead to a greater improvement in recovery. Thus, differ-
ences in aerobic fitness levels in a group of endurance-trained athletes cannot be
extrapolated to suggest that differences in recovery from exercise will also exist.

In summary, metabolic recovery from high-intensity, intermittent exercise
does not appear to be related to the various measurements of aerobic fitness in this
sample of endurance-trained cyclists. Therefore, statements regarding the ability
to recover from exercise should not be inferred from measurements of aerobic
fitness in endurance-trained subjects. Furthermore, commenting on the ability of
an athlete to recover from high-intensity, intermittent exercise using information
obtained from commonly used measurements of aerobic fitness may be mislead-
ing. However, it remains possible that some aspects of submaximal exercise re-
sponses (e.g., heart rate) may be an exception.

References

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