Excess Post-Exercise Oxygen Consumption Following Continuous and Interval Cycling Exercise

William McGarvey, Richard Jones, and Stewart Petersen

The purpose of this investigation was to examine the effect of interval (INT) and continuous (CON) cycle exercise on excess post-exercise oxygen consumption (EPOC). Twelve males first completed a graded exercise test for VO$_{2\text{max}}$ and then the two exercise challenges in random order on separate days approximately 1 wk apart. The INT challenge consisted of seven 2 min work intervals at 90% VO$_{2\text{max}}$, each followed by 3 min of relief at 30% VO$_{2\text{max}}$. The CON exercise consisted of 30 to 32 min of continuous cycling at 65% VO$_{2\text{max}}$. Gas exchange and heart rate (HR) were measured for 30 min before, during, and for 2 h post-exercise. Three methods were used to analyze post-exercise oxygen consumption and all produced similar results. There were no significant differences in either the magnitude or duration of EPOC between the CON and INT protocols. HR, however, was higher ($P < 0.05$) while respiratory exchange ratio (RER) was lower ($P < 0.05$) following INT. These results indicate that when total work was similar, the magnitude and duration of EPOC were similar following CON or INT exercise. The differences in HR and RER during recovery suggest differential physiological responses to the exercise challenges.

Key Words: metabolic rate, respiratory exchange ratio, heart rate, recovery

A number of authors have stated the importance of excess post-exercise oxygen consumption (EPOC) to energy balance and weight management (1, 3, 7, 8, 14-16). Sedlock et al. (16) reported that the energy value of EPOC was equivalent to approximately 10% of the exercise energy expenditure following 300 kcal of exercise at 75% VO$_{2\text{max}}$. Bahr et al. (3) reported an EPOC of approximately 15% of exercise energy expenditure following 80 min of exercise at 70% VO$_{2\text{max}}$. The energy value of EPOC might be increased by higher intensity exercise. Brockman et al. (7) concluded that high intensity exercise, either intermittent or continuous, led to a greater recovery oxygen consumption compared to low intensity exercise. This observation is supported by Gore and Withers (11), who showed that exercise intensity was the major determinant of EPOC.

---

McGarvey and Petersen are with the Faculty of Physical Education and Recreation, University of Alberta, Edmonton, Alberta T6G 2H9. Jones is with the university’s Faculty of Medicine and Dentistry.
Several studies have investigated EPOC following moderate exercise (1, 3, 4, 9-11, 15, 17). Relatively few investigations (7, 13, 21) have focused on the comparison of EPOC following high-intensity and moderate-intensity exercise, however. In order to make a direct comparison of the recovery oxygen consumption following continuous and interval exercise, it is important to ensure that exercise variables such as total work and duration are as similar as possible and to avoid confounding factors such as post-exercise feeding. Previous designs have utilized supramaximal intensities (13), nonequated work or exercise duration (7), post-exercise feeding (13), or different methods of determining EPOC (7, 13, 21) which make comparison of EPOC results following continuous and interval exercise difficult. One previous investigation (21) did equate work without post-exercise feeding but was published only as an abstract and investigated a relatively short recovery period (~ 48 min). It was felt this question would benefit from a more thorough investigation utilizing a significantly extended recovery period.

The purpose of the present study was to determine if oxygen consumption was different during the immediate 2-h post-exercise period following continuous and interval exercise protocols where total work was matched and there was no post-exercise feeding. Exercise duration and intensity were selected so as to be appropriate for recreational athletes and fitness program participants.

**Methods**

**Subjects**

Twelve physically active males who were not engaged in specific training volunteered to participate in this study that had been previously approved by the appropriate institutional research ethics board. Each subject provided written informed consent and complied fully with the research protocol. Subject characteristics (mean ± standard deviation) at entry were: age, 30 ± 7 y; height, 179.2 ± 7.5 cm; weight, 86.2 ± 13.1 kg; and cycling VO$_{2\text{max}}$, 49.7 ± 8.9 ml·kg$^{-1}$·min$^{-1}$.

**Metabolic Measurements**

All gas exchange measurements were conducted using a calibrated metabolic measurement cart (SensorMedics model 2900Z, Yorba Linda, CA) with results averaged every 20 s.

**Experimental Protocol**

Each subject reported to the laboratory on four separate days (day 1 to 4) that were separated by at least 72 h. Day 1 consisted of a graded exercise test for the assessment of ventilatory threshold (T$_{\text{vent}}$) and maximal oxygen consumption (VO$_{2\text{max}}$). T$_{\text{vent}}$ was determined through visual inspection of the exercise data as the power output that caused a systematic increase in the ventilatory equivalent for oxygen ratio (V$\text{E}$/VO$_{2}$) while the ventilatory equivalent for CO$_{2}$ was not rising. This point has been described as “Stage II” by Wasserman (19). Subjects were familiarized with the electro-magnetically braked cycle ergometer (SensorMedics model 800S) and use of the breathing valve (Hans Rudolph, Inc., Kansas City, MO) with noseclip attached. Heart rate (HR) was monitored using a Polar telemetry system.
McGarvey et al.

(Polar Electro Inc., Woodbury, NY). A 5 min warm-up at 50 W was followed by workload increases of 25W per min until the subject was unable to continue. Standard criteria for heart rate, respiratory exchange ratio, and plateauing of VO\textsubscript{2} were used to confirm VO\textsubscript{2max} (18). Minute power output and VO\textsubscript{2} values were used to generate a least-squares regression equation to determine power outputs (PO) corresponding to selected percentages of VO\textsubscript{2max} that were then used for the experimental exercise challenges.

On day 2, each subject practiced the interval exercise protocol (INT). The INT protocol was designed to fatigue the subject after seven intervals so that an eighth interval could not have been completed. During the practice sessions, two subjects failed to complete the protocol as planned so the high intensity workload was reduced by 25 W. Two subjects completed the practice with apparent ease, and subsequently their high intensity workload was increased by 15 W. These four subjects then repeated the practice session successfully at the new intensities.

Days 3 and 4 consisted of the continuous exercise protocol (CON) or the INT exercise protocol, which were randomly ordered. Subjects were asked to abstain from strenuous exercise for 36 h before each experimental day. Each subject maintained a record of his dietary intake for the 24 h prior to the first experimental day and then replicated the same intake prior to the second experimental day. The laboratory was kept as quiet as possible during the experiments. Ambient temperature was maintained at 23.5\( \pm \)0.7\( ^\circ\)C and each subject wore T-shirt, shorts, and training shoes for both experimental days. The CON and INT protocols each consisted of three phases: pre-exercise; exercise; and post-exercise. The pre- and post-exercise phases were identical for both INT and CON.

**Pre-Exercise Phase.** The resting metabolic rate (RMR) was determined during the pre-exercise phase. Each subject was picked up at his home after at least a 12 h fast and transported to the laboratory at approximately 07:00. On arrival, the subject voided and then body weight was measured. He was then fitted with a HR monitor and head-mount breathing mask (Hans Rudolph, Inc.) and rested quietly on a bed in the supine position. After at least 15 min of rest, the subject was connected to the metabolic measurement cart for 20 min of baseline data collection. Average heart rate and gas exchange data during the final 10 min were used as baseline. Immediately after baseline values were obtained, the subject was switched to a Hans Rudolph one-way breathing valve and mouthpiece and prepared to perform the exercise phase of either the CON or INT challenge on the electro-magnetically braked cycle ergometer.

**Exercise Phase.** The exercise phase consisted of a warm-up followed by either the INT or CON exercise protocol. The warm-up lasted for 6 min and was the same for each subject for both exercise protocols. The warm-up began at an intensity of 50 W which was subsequently increased each minute until a PO 5 W below 65\% of the subjects VO\textsubscript{2max}. The INT protocol was a 35-min session composed of seven intervals, each consisting of 2 min at the PO eliciting 90\% of VO\textsubscript{2max} followed by 3 min at the PO eliciting 30\% of VO\textsubscript{2max}. The CON protocol consisted of 30 to 32 min of exercise at a PO eliciting 65\% VO\textsubscript{2max}. The duration of the CON session was adjusted to match the work output to INT. The work intensity for the continuous exercise treatment was below the ventilatory threshold (\( T_{vent} \)) for all subjects. Gas exchange data were collected continuously throughout exercise.
**Post-Exercise Phase.** On completion of exercise, the post-exercise phase was initiated with the subject being seated in a chair immediately adjacent to the cycle ergometer while gas exchange and HR data were collected continuously. After 10 min, the mouthpiece and breathing valve were removed and the subject drank 125 mL of water. He then quickly re-donned the face mask used for the RMR measurement and moved to the adjacent bed for the remainder of the 2 h recovery period. Expired gases and HR were continuously monitored for the duration of the recovery period with the exception of two 10-min periods (minutes 60 to 70 and 90 to 100 post-exercise) when the mask was removed for subject relief and calibration of the metabolic measurement cart.

**Analysis of Post-Exercise Oxygen Consumption**

Three methods were used to analyze post-exercise oxygen consumption: two EPOC methods and an analysis of variance of total post-exercise oxygen consumption. The 1 standard deviation method (1 standard deviation), identified EPOC termination as the time when minute VO\textsubscript{2} values fell to within 1 standard deviation of baseline VO\textsubscript{2} for two consecutive minutes (8, 10). The 5-min EPOC method (5 min), identified EPOC termination as the time when the 5 min average of recovery VO\textsubscript{2} equaled the baseline VO\textsubscript{2} (15, 16). For both the 1 standard deviation and 5 min methods, the time from the end of exercise to EPOC termination was considered the EPOC duration, and EPOC magnitude was calculated as the integrated area between the recovery minute VO\textsubscript{2} curve and the baseline VO\textsubscript{2} (17).

**Statistical Analysis**

Comparisons between CON and INT were made using the Student $t$-test for paired groups. Post-exercise total oxygen consumption, respiratory exchange ratio (RER), and HR data were analyzed (in 10 min segments) using a two-way analysis of variance (ANOVA) with repeated measures. When ANOVA revealed significant differences, a post hoc test was used to correct for multiple comparisons (Newman-Keuls test). An alpha level of 0.05 was used to determine significance.

**Results**

Baseline values preceding INT and CON treatments were similar for VO\textsubscript{2} (CON: 273 ± 51 ml/min$^{-1}$, INT: 284 ± 54 ml/min$^{-1}$), RER (CON: 0.87 ± 0.07, INT: 0.86 ± 0.06), and HR (CON: 55 ± 9 bpm, INT: 56 ± 9 bpm) indicating that the subjects began the exercise treatments in comparable physiological states. These values were similar to those reported by others (9). Exercise data are displayed in Table 1. Despite the attempts to match work for the CON and INT exercise treatments, there was a small but statistically significant difference. Total work was higher by 3.63 kJ (< 1.0 kcal) in the CON treatment. In addition, we observed greater total exercise oxygen consumption and a higher RER during the INT treatment. The duration of the INT treatment was greater by an average of 4 min.

The Student $t$-test for paired samples revealed that there were no significant differences between the magnitude or duration of EPOC following interval or continuous exercise using either the 1 standard deviation or 5 min methods (Table 2).
In support, the ANOVA of post-exercise oxygen consumption revealed no difference in recovery values following continuous and interval exercise.

Figure 1 displays the 2 h oxygen consumption values (in 10 min segments) for the recovery period following CON and INT. Both CON and INT treatments produced a similar pattern during this period, dropping steadily from the immediate post-exercise elevated levels to near resting levels at the end of the 2-h period. The average oxygen consumed during the first 10 min segment of recovery was 597 ± 127 and 594 ± 99 ml/min−1 for CON and INT, respectively. The average oxygen consumed during the last 10 min segment of recovery was 281 ± 56 and 287 ± 68 ml/min−1 for CON and INT, respectively. The total 2 h post-exercise oxygen consumption was 34.2 ± 5.8 and 36.1 ± 6.1 liters for CON and INT, respectively, a difference of less than 2 L.

Table 1  Physiological Measurements and Duration for Continuous (CON) and Interval (INT) Exercise Conditions (N = 12)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Work (kJ)</th>
<th>VO₂ (L)</th>
<th>%VO₂max</th>
<th>Duration (min)</th>
<th>Avg. VO₂ (L/min)</th>
<th>HR (bpm)</th>
<th>RER</th>
</tr>
</thead>
<tbody>
<tr>
<td>CON</td>
<td>291.06*</td>
<td>84.11*</td>
<td>64.5*</td>
<td>31.0*</td>
<td>2.73*</td>
<td>154</td>
<td>0.94*</td>
</tr>
<tr>
<td></td>
<td>± 43.01</td>
<td>± 10.00</td>
<td>± 3.0</td>
<td>± 1.0</td>
<td>± 0.31</td>
<td>± 11</td>
<td>± 0.02</td>
</tr>
<tr>
<td>INT</td>
<td>287.43</td>
<td>89.38</td>
<td>60.5</td>
<td>35.0</td>
<td>2.55</td>
<td>156</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>± 41.95</td>
<td>± 9.23</td>
<td>± 2.9%</td>
<td>± 0.0</td>
<td>± 0.26</td>
<td>± 10</td>
<td>± 0.02</td>
</tr>
</tbody>
</table>

*Significant difference between conditions, P < 0.05; Work, total work of exercise; VO₂, total exercise oxygen consumption; %VO₂max, average exercise oxygen uptake as a percent of maximal oxygen uptake; Avg. VO₂, average oxygen uptake per minute (Avg. VO₂max = 4.22 ± 0.42 L/min); HR, average heart rate during exercise; RER, average respiratory exchange ratio during exercise.

Table 2  Comparison of Two Different EPOC Methods Following Continuous (CON) and Interval (INT) Exercise Conditions (N = 12)

<table>
<thead>
<tr>
<th>Method</th>
<th>EPOC</th>
<th>CON</th>
<th>INT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 standard deviation</td>
<td>Magnitude (liters O₂)</td>
<td>6.2 ± 2.0</td>
<td>6.7 ± 1.1</td>
</tr>
<tr>
<td></td>
<td>Duration (min)</td>
<td>50.8 ± 32.4</td>
<td>53.0 ± 19.0</td>
</tr>
<tr>
<td>5 min</td>
<td>Magnitude (liters O₂)</td>
<td>7.0 ± 1.8</td>
<td>7.6 ± 1.1</td>
</tr>
<tr>
<td></td>
<td>Duration (min)</td>
<td>94.9 ± 26.3</td>
<td>88.8 ± 29.1</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± standard deviation. There was no difference between CON and INT for either method (P < 0.05). EPOC, excess post-exercise oxygen consumption.
The similarities between post-exercise oxygen consumption following the two exercise treatments were contrasted by significant differences in post-exercise HR and RER (See Figure 2 for RER data). Throughout the 2-h recovery period, we observed significantly higher HR values ($P < 0.05$) and lower RER values ($P < 0.05$) following the INT exercise treatment.

**Discussion**

Three methods were used to analyze post-exercise oxygen consumption following the interval and continuous exercise treatments. Each of these methods has been reported previously in the scientific literature, however, the duration and magnitude of EPOC was dependent on the method selected. Regardless of the method used, there were no differences between exercise treatments for EPOC magnitude or duration (Table 2). Similarly, the ANOVA revealed no significant difference in total post-exercise oxygen consumption. These results provide compelling evidence that the recovery oxygen consumption is the same following interval or continuous exercise when the total work and duration are similar. These results contradict those published in abstract form from an investigation utilizing apparently similar interval and continuous exercise protocols (21). This abstracted study reported greater EPOC magnitude and duration following interval compared to continuous exercise. The duration of interval and continuous exercise, the precise method of

![Figure 1 — Oxygen consumption values averaged over 10 min intervals for the 2 h recovery period following continuous (CON) and interval (INT) exercise protocols ($N = 12$). Values expressed as mean ± standard deviation. Mean rest is the average of the CON and INT resting values.](image-url)
An interesting finding from the data is the effect of EPOC duration on EPOC magnitude. Although the 5 min method produced substantially longer EPOC duration (approximately 80% longer) there was only a small effect (approximately 13%) on EPOC magnitude. This might be understood by referring to the pattern of post-exercise oxygen consumption as illustrated in Figure 1. It is clear that the vast majority of increase in post-exercise oxygen consumption above resting level occurs during the early phase of the recovery period. As recovery continues, oxygen consumption gradually diminishes, resulting in a reduced increase in magnitude for a standardized increase in duration. Therefore, although the duration of EPOC from the 5 min method was much longer, the resulting increase in EPOC magnitude was relatively small.

A number of past investigations have used continuous exercise protocols similar in intensity and duration to the CON treatment in the present study. Many of these have reported EPOC magnitude results similar to those obtained in this investigation (8, 10, 11, 13). Although EPOC magnitude has been similar, EPOC duration has varied. Using the 1 standard deviation method to determine termination
of EPOC after eight healthy young women cycled at approximately 65% VO$_{2\text{max}}$ for 30 min, Dawson et al. (10) reported EPOC duration of only 13.9 min. Chad and Wenger (8) also used the 1 standard deviation method and reported EPOC duration of 128 min for a similar protocol. Sedlock et al. (16) cycled 10 male triathletes at 75% VO$_{2\text{max}}$ until they had expended 300 kcal. Subsequently the duration of EPOC was approximately 33 min using the 5 min method. As demonstrated in Figure 1, as EPOC duration is extended, there is a continual decrease in the contribution to EPOC magnitude.

Whether determined by the 1 standard deviation or 5 min methods, the duration of EPOC following interval exercise in this investigation was less than 2 h, an observation in keeping with the findings of Ziegenfuss and Sedlock (21) but not others (2, 13). Reports of longer EPOC duration following high-intensity exercise have typically resulted from experiments that have included both supra-maximal intensities and post-exercise feeding (2, 13). The duration and magnitude of EPOC has been shown to increase exponentially when exercise intensity approaches or exceeds 100% VO$_{2\text{max}}$ (12) and perhaps intensities at or over 100% VO$_{2\text{max}}$ lead to an extended EPOC. Ingestion of carbohydrate after exercise has been shown to increase the thermal effect of food and produce a higher rate of oxygen consumption (5). It is possible that the thermal effect of food was increased to a greater degree following high-intensity exercise and could have contributed to the extended EPOC duration.

The magnitude of EPOC that was observed in this study was not as large as has been previously reported in other investigations (3, 16). When considered as a percentage of total oxygen consumption during exercise, the magnitude of EPOC was slightly greater using the 5 min method (CON 8.3, INT 8.5%) than the 1 standard deviation method (CON 7.3, INT 7.5%). With respect to the influence of EPOC on energy expenditure, there seems to be little advantage in choosing interval exercise over a similar amount of continuous exercise. This point is made after considering that our subjects completed the CON protocol relatively easily, while completion of the INT protocol was difficult and pushed the subjects close to the point of exhaustion.

There could, however, be other benefits of high intensity exercise that were not investigated in this study. Our data suggest a differential physiological response to INT and CON exercise. For example, RER values (Figure 2) were lower following interval exercise for the majority of the 2-h recovery period. The dip in RER values during the first hour of recovery following both interval and continuous exercise is indicative of CO$_2$ retention to replenish bicarbonate stores with the more pronounced dip following interval likely the result of greater lactate buffering (13). The continued significantly lower RER values following interval for the second hour of recovery, however, suggests a greater reliance on fat oxidation and agrees with previous findings (13, 20).

In addition, heart rate was significantly higher throughout recovery from interval compared to continuous exercise, an observation that agrees with a previous report (6). The reason for the increased heart rate is unclear (17), but might be related to higher levels of circulating catecholamines (20). While heart rate and RER are fairly crude indicators of the physiological milieu during recovery, it is tempting to speculate that fat metabolism could be increased during the recovery period following interval exercise. This possibility warrants further investigation.
Summary

This investigation compared oxygen consumption following continuous and interval exercise protocols that were very similar in terms of duration and total work. Under these conditions, post-exercise oxygen consumption was the same regardless of the exercise protocol. Based on these results, it is unlikely that high-intensity interval exercise offers a greater EPOC benefit than a similar amount of moderate-intensity exercise. Our findings, however, demonstrate other responses (RER and HR) that might indicate differences in post-exercise metabolism following interval and continuous exercise. Further investigation should be performed to evaluate any potential effect on post-exercise energy metabolism.

Acknowledgment

The authors gratefully acknowledge financial support for this experiment from the Sport Sciences Association of Alberta.

References


