Effect of split exercise sessions on excess post-exercise oxygen consumption

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In this study the excess post-exercise oxygen consumption (EPOC), and related metabolic measures, following a 50 minute run compared to two 25 minute runs all at 70 per cent of peak VO_2 in six women were investigated. Open-circuit spirometry procedures were used and appropriate control conditions were maintained for all trials. Following exercise, VO_2 returned to baseline within 30 minutes for all three exercise trials. Magnitude of EPOC was also similar after all runs. However, the combined magnitude (expressed in kcals) of the two 25 minute runs was significantly greater than the continuous 50 minute run (13.88 vs 6.39). Heart rate remained elevated above baseline, and respiratory exchange ratio was lower than baseline 30 minutes after exercise. It is concluded that split exercise sessions can significantly increase post-exercise caloric expenditure. However, the overall magnitude of the increase is small.

Keywords: Excess post-exercise oxygen consumption, recovery energy expenditure, post-exercise respiratory exchange ratio, weight loss

Introduction

The existence of an increased metabolic rate following exercise (above the resting pre-exercise level) has been established in numerous studies dating back to the early 1900s. This phenomenon, which is usually documented as an elevated oxygen consumption, is presently termed excess post-exercise oxygen consumption (EPOC), although synonymous terms used previously are oxygen debt and recovery oxygen consumption (VO_2). EPOC is often cited as playing an important role in significantly increasing energy expenditure in weight loss programmes that employ exercise[1].

Exercise duration and intensity have been identified as the principal factors influencing EPOC. Brehm and Gutin[2] reported that exercise intensity is curvilinearly related to EPOC with a disproportionate increase in the magnitude of EPOC associated with exercise intensities greater than approximately 75 per cent of VO_2 max. Similarly, Hagberg *et al.*[3] reported no difference in recovery VO_2 between different exercise intensities until intensity was increased to 80 per cent VO_2 max. The results from studies examining the influence of exercise duration on EPOC are equivocal. A similar oxygen debt was reported between exercise durations of 35 and 55 minutes[4], between 20 and 40 minutes[5], and between 20 and 60 minutes[6]. However, a recent study by Bahr *et al.*[7] reported a linear relationship between EPOC and exercise durations of 20, 40, and 80 minutes.

The present research was designed to further study the influence of varying exercise duration on EPOC. This investigation examined the effect on EPOC of splitting an exercise session into two equal parts. Specifically, we studied the EPOC following one 50 minute run and two 25 minute runs that were all performed at an intensity of 70 per cent of peak VO_2. Since exercise is a fundamental component of a weight loss programme, it was of interest to discern if increasing exercise frequency, independent of exercise energy expenditure, would substantially increase post-exercise caloric expenditure.

Methods

Subjects were six women who were apparently healthy, according to guidelines established by the American College of Sports Medicine[8], with a mean age of 30 ± 4 years, body mass index of 22.0 ± 2.0 $kg.m^{-2}$, and peak VO_2 of 45.7 ± 2.6 $ml.kg.min^{-1}$. Each signed an informed consent in accordance with a policy statement of the American College of Sports Medicine.

Peak VO_2 was initially determined via an incremental treadmill protocol. The open-circuit spirometry method was used with inspired air measured with Parkinson–Cowan dry-gas meter and expired gas analyzed with Beckman OM-11 paramagnetic oxygen and LB-2 carbon dioxide analyzers (Sensor Medics, Anaheim, Calif., USA). Analysers were calibrated before each exercise period with a reference gas that was previously analysed using the Lloyd–Gallenkamp chemical gas analyser. All metabolic values were corrected to STPD and computed using software provided by Rayfield Electronics (Waitsfield, Vt., USA). Rating of perceived exertion, electrocardiogram, and blood pressure were monitored throughout the exercise test.

Subjects were transported to the laboratory in the morning immediately after arising on two separate days within a three day period for one of two exercise trials (order randomly assigned). All subjects were tested during the mid-luteal menstrual phase to

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0306-4179/90/020095-04

Table 1. Composition of the test meal

Item	*Amount*	*Protein* (g)	*Carbohydrate* (g)	*Fat* (g)	*kcal*
Breakfast bar	1	6	21	11	200
Apple juice	5.5	tr*	20.6	tr*	82.5
Total	–	6	41.6	11	282.5

* Trace

control for variation in resting metabolic rate[9]. Subjects were requested to refrain from any strenuous activity for a minimum of 24 hours before each trial and were given a standard 282.5 kcal meal to be consumed three hours prior to the exercise trial. The content and composition of the meal (*Table 1*) were selected to allow the thermic effect of the meal to be completed within three hours. Subjects rested quietly in a sitting position for 30 minutes prior to beginning the resting measurements. Baseline resting VO_2 was calculated by averaging five consecutive one minute readings. On one day the subjects ran continuously on a treadmill at 70 per cent of their peak VO_2 for 50 minutes (Trial A) and on the other day the exercise was divided into two 25 minute runs separated by a sitting rest period. After all three runs, subjects sat quietly with their legs elevated and were monitored until VO_2 returned to baseline (i.e. two consecutive measures within 1 SD of the pre-exercise value) or for a minimum of 30 minutes, whichever was the longer. Metabolic measurements were obtained every 10 minutes during exercise and every minute for the first five minutes post-exercise, every 2.5 minutes for the next 15 minutes then every 10 minutes thereafter. Energy expenditure was calculated from VO_2 and respiratory exchange ratio values[10]. The post-exercise energy expenditure was derived by summing the product of the caloric equivalent of the net (post-exercise – pre-exercise) increase in VO_2 by the time period of the measurement (i.e. 1, 2.5 or 10 minutes). This procedure results in a slight underestimation of the post-exercise caloric expenditure compared to breath-by-breath measurements.

Dependent t-tests were employed to analyse the differences between the pre- and post-exercise measurements within each run and the net energy expenditure between the two trials. Analyses of variance with repeated measures were used to evaluate differences between the three runs, with a Tukey *post-hoc* test performed when significant F-values were obtained (Statistical Analysis Systems, Cary, North Carolina, USA). Values were considered significant at an alpha level of 0.05.

Results

Resting and exercise VO_2 were not different between the three runs (*Figure 1*). Following exercise VO_2 remained significantly elevated for up to 10 minutes and returned to baseline within 20 minutes for all three treadmill runs. A comparison of the magnitude of EPOC for the three runs showed no significant differences between the 50 minute run (1.40 × 50 l) and the two 25 minute runs (1.80 ± 0.74 and 1.31 ± 0.54). However, the combined magnitude of the EPOC (expressed in kcals) from the two 25 minute runs was significantly greater than that of the continuous 50 minute run (13.88 vs 6.39 kcal, *Figure 2*).

Minute ventilation (V_E) followed the same post-exercise pattern as that for VO_2 (*Figure 3*). In recovery, V_E declined to approximately 44 per cent of the exercise value in the first minute and was

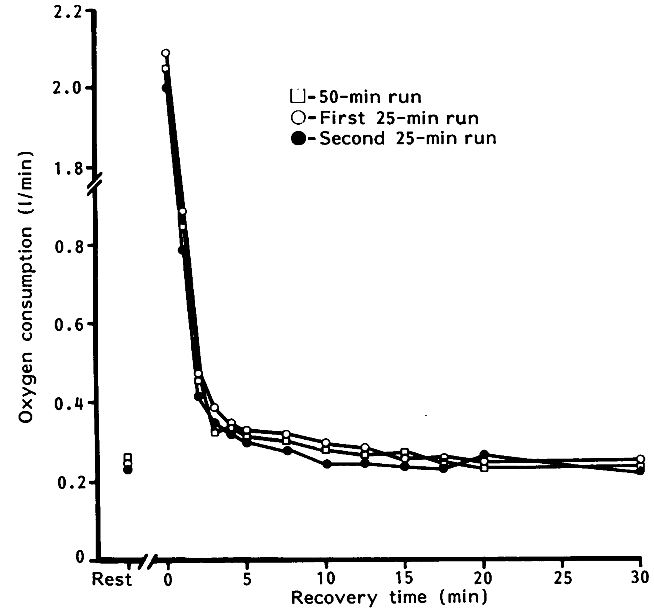

Figure 1. Oxygen consumption at baseline (pre-exercise) and following exercise for all three trials

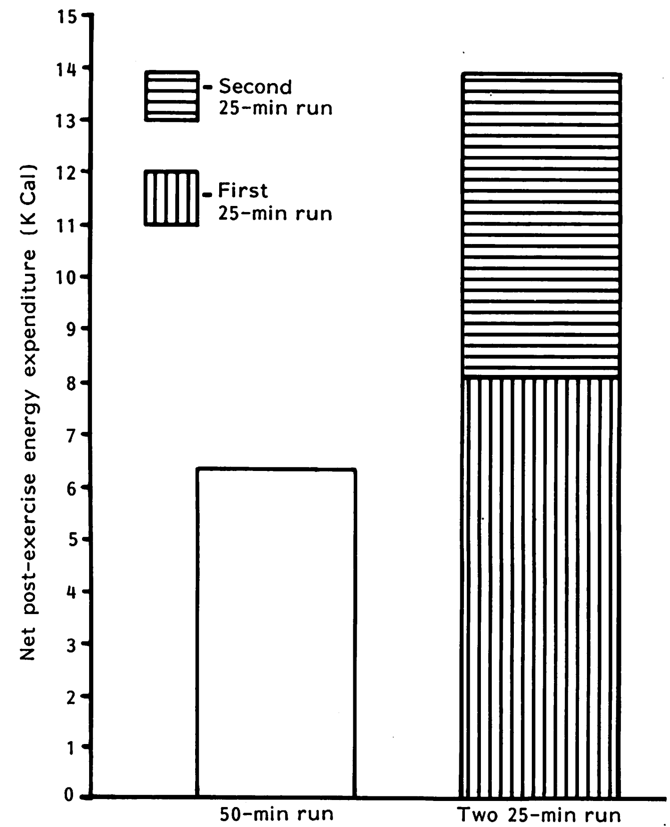

Figure 2. Comparison of the magnitude of the post-exercise energy expenditure between the continuous 50 minute run vs the sum of the two 25 minute runs

significantly elevated for no longer than 12.5 minutes.

Resting heart rate (b.p.m.) was the same prior to the 50 minute (64 ± 6) and the first 25 minute (64 ± 9) runs. However, it was significantly elevated prior to the second 25 minute (74 ± 5) run (this was probably a residual influence of the first 25 minute run). In recovery, heart rates remained significantly elevated for 20, 30 and 12.5 minutes after the 50 minute and the first and second 25 minute runs respectively. Heart rates did not return to the pre-exercise baseline value after 30 minutes of recovery (when data collection was terminated) in all three trials (*Figure 1*).

The resting, exercise, and post-exercise respiratory exchange ratio (R) responses were similar for all three runs. The 30 minute post-exercise R was significantly lower than the pre-exercise value for both the 50 minute (0.72 ± 0.07 vs 0.81 ± 0.7) and the first 25 minute (0.71 ± 0.04 vs 0.77 ± 0.04) run. The 30 minute post-exercise R for the second 25 minute run (0.72 ± 0.06) was lower than the pre-exercise value (0.76 ± 0.04), although the difference was not statistically significant.

Discussion

The present study investigated the effect of splitting a standard exercise session into two equal parts to determine if this would produce a beneficial increase in total energy expenditure. These data demonstrate that split exercise sessions will significantly increase post-exercise energy expenditure. However, the overall magnitude of the additional energy expenditure is rather small.

There is considerable controversy concerning the magnitude and duration of the EPOC. Reports of the magnitude of the EPOC range from 3–30 kcal[2,6] to 60–175 kcal[7]. Likewise, the duration of EPOC has varied in previous investigations from < 1 h[2,5–6,11] to > 12 h[7,12,13]. Much of the variability of these previous studies can be traced to different intensities and durations of exercise examined. Although it is difficult to generalize, it appears that exercise intensity must be relatively high (i.e. ⩾ 80 per cent VO_2 max) to create a substantial EPOC[2,3]. An exception to this is if a lower exercise intensity is combined with a prolonged exercise duration. For example, Bielinski *et al.*[13] found post-exercise, post-meal energy expenditure were significantly elevated for 4.5 hours following 3 hours of treadmill exercise at 50 per cent VO_2 max. Maehlum *et al.*[12] also reported elevated post-exercise, post-meal energy expenditures for 12–24 hours following up to 90 minutes of intermittent exercise (10–30 minutes bouts followed by 5 minutes rest) on a bicycle at 70 per cent of VO_2 max. Studies of more moderate exercise sessions (i.e. ⩽ 60 minutes, ⩽ 75 per cent of VO_2 max) have generally not found an appreciable EPOC. For instance, Kaminsky *et al.*[11], using walking at 35 per cent of VO_2 max for 60 minutes and running at 70 per cent for 30 minutes, Freedman-Akabus *et al.*[5] using work rates at or slightly above the anaerobic threshold for 20 and 40 minutes and Sedlock *et al*[6] using cycling at 50 and 75 per cent of VO_2 max for 30 and 20 minutes and at 50 per cent of VO_2 max for 60 minutes found the duration of EPOC to be 40 minutes or less. Only a study by Bahr *et al.*[7] reported a prolonged EPOC (> 12 hours) following exercise at 70 per cent of VO_2 max for 20 and 40 minutes. One factor that should be considered in the studies that showed a prolonged EPOC is the potential interaction with diet-induced thermogenesis. All three of the previously mentioned studies that reported a prolonged EPOC[7,12,13] had meals included in the post-exercise period. Although they attempted to control this by having a no-exercise, meal-only trial, the interaction between meal and exercise on post-exercise metabolism could not be analysed.

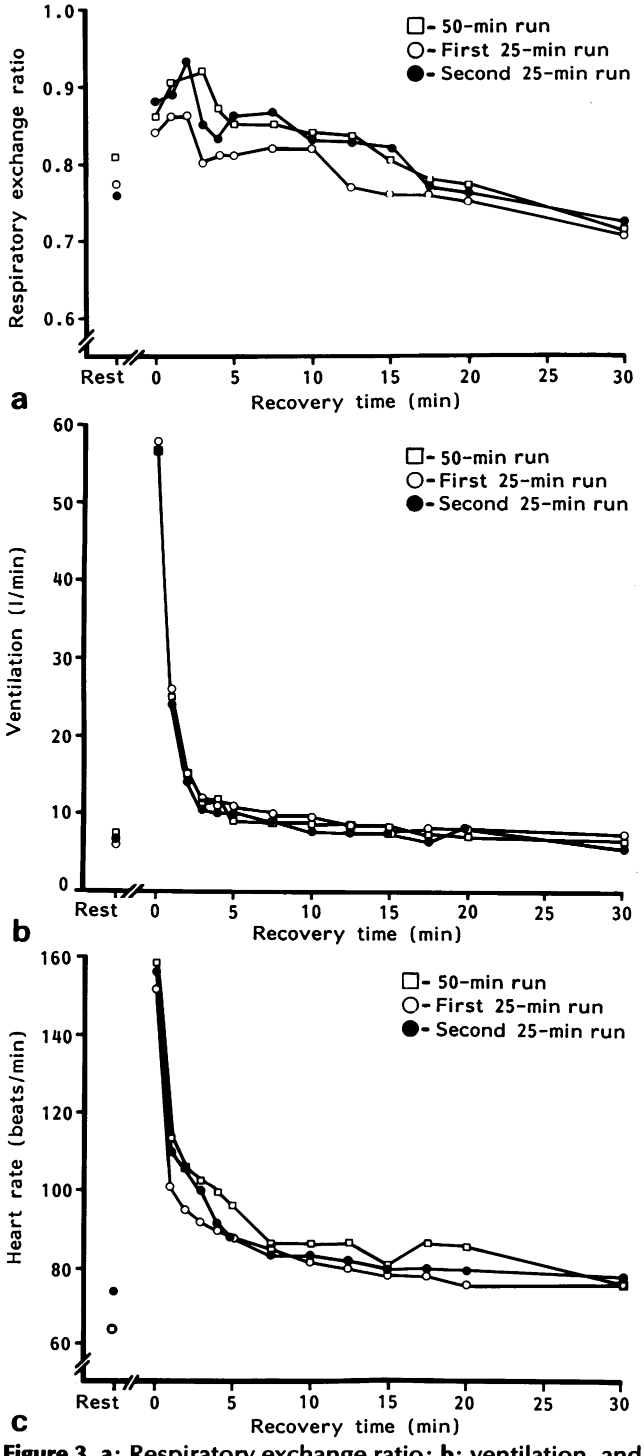

Figure 3. **a**: Respiratory exchange ratio; **b**; ventilation, and c: heart rate at baseline (pre-exercise), and following exercise for all three trials

The data from the present study supports the general consensus of previous findings that EPOC is of a relatively short duration and of a relatively small magnitude. This is especially evident if the exercise session is of a type (≤ 60 minutes, ≤ 75 per cent of VO_2 max) employed by individuals training for health-related fitness (i.e. improved aerobic fitness and body composition). A useful means of apprising the post-exercise effect was suggested by Bahr and Maehulum[14], who proposed using the ratio of EPOC to EOC (exercise oxygen consumption). Their studies suggested that the EPOC averaged approximately 14 per cent of EOC. Sedlock *et al.*[6] reported EPOC:EOC ratios of 2–4.7 per cent following low-intensity exercise and 9.7 per cent following high-intensity exercise. The present data showed smaller EPOC:ROC ratios of 1.3 per cent and 2.8 per cent following runs at 70 per cent peak VO_2 for 50 minutes and two 25 minutes runs respectively. Our values may be slightly lower due to the method used to calculate post-exercise energy expenditure, which results in an underestimation. It is also likely that Bahr and Maehlum values may be overestimated due to an exercise plus meal interaction.

Mechanisms of EPOC are not well understood: However, factors that have been proposed to contribute to EPOC include replenishment of high-energy phosphates in muscle[15], increased body temperature[3,16], excess catecholamines[17,18], and substrate cycling[19]. The findings of increased heart rate and ventilation in the post-exercise period in this study suggest that those two factors play both a direct and an indirect role in EPOC. The increased oxygen transport needed to resynthesize the body's energy stores, associated with other metabolic changes such as elevated temperature, excess catecholamines, and substrate cycling, are reflected indirectly as an increased V_E and HR. Additionally, the energy requirements of an increased V_E and HR contribute directly to the EPOC. It is of interest to note that some residual effects of exercise can be noted (i.e. increased HR and decreased R) that are not reflected in the VO_2 measurements.

Post-exercise substrate utilization is an area that has not received much study. Previous studies have suggested an increased lipid oxidation following exercise[7,12,13,20]. The present study is in agreement, as we observed a decreased R post-exercise. Increased lipid oxidation following exercise may be an important contributor to the metabolic adaptations which occur with training as it has been shown that trained individuals utilize more fat in the recovery period than untrained subjects[20]. More research is needed on the significance of the post-exercise changes in substrate utilization.

In summary, split exercise sessions increased the post-exercise energy expenditure compared to an equivalent (energy expenditure) single exercise session. The total magnitude of the EPOC was relatively small, averaging only 1.3 per cent and 2.8 per cent of EOC following the continuous and split exercise sessions, respectively. We conclude that split exercise sessions can significantly increase post-exercise caloric expenditure. However, the overall magnitude of the increase is small.

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