



Original research

Effect of continuous and intermittent bouts of isocaloric cycling and running exercise on excess postexercise oxygen consumption

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ABSTRACT

Objectives: The purpose of this study was to investigate excess postexercise oxygen consumption (EPOC) induced by isocaloric bouts of continuous and intermittent running and cycling exercise.**Design:** This was a counterbalanced randomized cross-over study.**Methods:** Ten healthy men, aged 23–34 yr, performed six bouts of exercise: (a) two maximal cardiopulmonary exercise tests for running and cycling to determine exercise modality-specific peak oxygen uptake ($\text{VO}_{2\text{peak}}$); and (b) four isocaloric exercise bouts (two continuous bouts expending 400 kcal and two intermittent bouts split into 2×200 kcal) performed at 75% of the running and cycling oxygen uptake reserve. Exercise bouts were separated by 72 h and performed in a randomized, counter-balanced order. The VO_2 was monitored for 60-min postexercise and for 60-min during a control non-exercise day.**Results:** The VO_2 was significantly greater in all exercise conditions compared to the control session ($P < 0.001$). The combined magnitude of the EPOC from the two intermittent bouts was significantly greater than that of the continuous cycling (mean difference = 3.5 L, $P = 0.001$) and running (mean difference = 6.4 L, $P < 0.001$). The exercise modality had a significant effect on net EPOC, where running elicited a higher net EPOC than cycling (mean difference = 2.2 L, $P < 0.001$).**Conclusions:** Intermittent exercise increased the EPOC compared to a continuous exercise bout of equivalent energy expenditure. Furthermore, the magnitude of EPOC was influenced by exercise modality, with the greatest EPOC occurring with isocaloric exercise involving larger muscle mass (i.e., treadmill running vs. cycling).

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1. Introduction

Aerobic training has been applied in weight management programs to increase daily energy expenditure (EE).^{1–3} The American College of Sports Medicine (ACSM) recommends for health promotion an exercise intensity of 40–85% heart rate reserve (HRR) or oxygen uptake reserve ($\text{VO}_{2\text{R}}$), and a target EE of 150–400 kcal (or 20–60 min) per exercise bout performed continuously or intermittently.^{1,3} Given the time constraints, exercise intolerance, or monotony that might be associated with continuous exercise, multiple short bouts of exercise have been recommended as an approach to increasing the leisure time allocated to physical activity and enhancing exercise adherence among sedentary individuals.^{4,5}

This approach has also been recommended within the context of weight management programs,⁴ since previous studies suggest that the increased metabolic demand during recovery, expressed by the excess postexercise oxygen consumption (EPOC), seems to be greater following intermittent compared to continuous exercise.^{6–8}

Although previous research investigating the effects of intermittent vs. continuous exercise upon EPOC superficially matched the exercise bouts for external work (same intensity and duration), the exercise volume was not matched by the actual EE [e.g., 2×25 -min vs. 50-min of treadmill running at 70% $\text{VO}_{2\text{peak}}$ ⁷; 2×15 -min vs. 30-min of cycle ergometry at 70% $\text{VO}_{2\text{max}}$ ⁶; or 3×10 -min vs. 30-min of arm ergometry at 60% $\text{VO}_{2\text{max}}$ ⁸]. Taking into account that the oxygen uptake (VO_2) kinetics at the onset of exercise, which reflect the adjustment of both systemic oxygen transport and muscle metabolism, is dependent on exercise intensity and cardiorespiratory fitness levels,⁹ it is possible that the exercise

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volume performed may not have been properly controlled by previous studies.^{6–8} This is an important methodological issue that confounds the interpretation of studies that compared the effects of continuous and intermittent exercise on the magnitude of EPOC.¹⁰

Another issue relates to the assessment of resting VO_2 . With one exception,⁶ previous studies defined baseline VO_2 as the average VO_2 determined during the final 5 or 10 min of a 30-min resting period in a seated position.^{7,8} This has been criticized by Børsheim and Bahr² in a systematic review, since it can lead to falsely high baseline VO_2 values that compromise the accuracy of the estimates of the magnitude of EPOC. Recently our group investigated the accuracy and test–retest reliability of the assessment of resting VO_2 in thirty healthy men (e.g., two trials of 60-min rest in a supine position) and reported that the largest decrease in VO_2 occurred during the first 30-min, followed by a small, but significant decrease in VO_2 in the final 30-min ($P = 0.007$). From a practical perspective, a control session where resting VO_2 is determined on a separate day under identical conditions applied in the exercise days should be considered when investigating the EPOC phenomenon.

It also is not clear to what extent the mode of exercise affects the magnitude of EPOC,² and previous studies have shown conflicting results.^{11,12} Considering that the physiological strain seems to be significantly greater during treadmill running than during cycle ergometry,^{13,14} it is plausible that EPOC may be affected by exercise modality. In brief, it would be important to investigate possible differences in EPOC induced by running and cycling bouts performed continuously and intermittently, since the EPOC may affect the total EE associated with exercise.

Thus, the main purpose of the present study was to compare the EPOC induced by continuous and intermittent isocaloric exercise bouts using two different exercise modalities (i.e., running vs. cycling) in healthy men. We hypothesized that isocaloric exercise performed continuously or intermittently, but recruiting different amount of muscle mass (i.e., cycling vs. running), would affect the magnitude of EPOC.

2. Methods

Ten healthy men (mean $\pm$ SD: age, 28 ± 4 yr; body mass, 78 ± 9 kg; body mass index, 26 ± 1 kg m⁻²; resting heart rate, 68 ± 5 beats min⁻¹; and resting VO_2 , 3.0 ± 0.4 mL kg⁻¹ min⁻¹) participated in this study. All participants were involved in moderate-to-vigorous intensity aerobic activities (e.g., treadmill running and/or cycling) lasting 30 min or more, three times per week, for at least six months prior to the study. The study was approved by the University of Rio de Janeiro State (UERJ) Human Research Ethics Committee. All participants provided written informed consent.

Each participant visited the laboratory seven times. On the first visit (control non-exercise day) resting VO_2 was determined, anthropometric measurements were taken, and participants were familiarized with equipment and test protocols. No participant presented difficulty or limitation of movement, as all had previous experience with treadmill and cycling exercise. On the second and third visits a maximal cardiopulmonary exercise test (CPET) for determining the maximal values of heart rate and VO_2 was performed. Seventy-two hours after performing the maximal CPETs, four isocaloric exercise bouts were performed at 75% VO_{2R} . The two continuous bouts expended each a total of 400 kcal. The two intermittent bouts were each split into 2×200 kcal sessions, separated by 1 h of passive rest during which VO_2 was assessed. Rehydration was not allowed between intermittent exercise sessions. The four isocaloric exercise bouts were performed in a randomized counter-balanced order, on different days separated by 24–48 h. All the visits were scheduled between

07:00 and 11:00 a.m., to negate confounding by time-of-day. The running tests were performed on the same motorized treadmill (Inbramed™ Super ATL, Porto Alegre, RS, Brazil) and the cycling tests were performed on a cycle ergometer (Cateye EC-1600, Cateye™, Tokyo, Japan). The seat height of the cycle ergometer was individually set before each of the cycling exercise bouts.

For the control non-exercise day, the resting VO_2 was determined in accordance with the recommendations of Compher et al.,¹⁵: abstention of physical exercise, alcohol, soft drinks and caffeine in the 24 h and fasting for 8 h preceding the assessment, and minimum effort when traveling to the laboratory. In the laboratory, the participants laid in a calm thermoneutral environment (mean $\pm$ SD temperature, 22 ± 1 °C) for an acclimation period of 10-min, after which the VO_2 was measured for 60-min in a supine position (control session). The average VO_2 data between 35 and 40 min was used to calculate the % VO_{2R} for prescription of the isocaloric exercise bouts, since this time period has been previously shown to elicit VO_2 steady-state and high test–retest reliability.¹⁶

The HR_{max} and $\text{VO}_{2\text{max}}$ were determined using a ramp protocol. The workload increments were individualized to elicit the subject's limit of tolerance in 8–12 min.¹⁷ The tests were considered maximal if at least three of the four following criteria were satisfied: (a) maximum voluntary exhaustion defined by attaining a 10 on Borg CR-10 scale; (b) 90% of predicted HR_{max} [$220 - \text{age}$] or presence of heart rate plateau (ΔHR between two consecutive work rates ≤ 4 beats min⁻¹); (c) presence of VO_2 plateau (ΔVO_2 between two consecutive work rates of less than 2.1 mL kg⁻¹ min⁻¹); (d) maximal respiratory exchange ratio (RER_{max}) > 1.10 .¹⁸

Based on $\text{VO}_{2\text{max}}$ obtained in the running and cycling ramp protocols, and on values of resting VO_2 , values corresponding to 75% VO_{2R} were calculated to determine the intensity of the isocaloric exercise bouts. The absolute VO_2 values obtained from the % VO_{2R} equation were used to calculate the associated running speeds and cycling power outputs by applying the ACSM metabolic equations.¹ The grade of the treadmill was set at 1%, which has been found to reflect the energetic cost of outdoor, level overground running.¹⁹ Each running and cycling exercise bout was preceded by a 5-min warm-up at 5.5 km h⁻¹ and 1% grade for running and 30 W for cycling. Cycling cadence was maintained at 70 (ranging from 65 to 75) revs min⁻¹ throughout the test. The EE was calculated individually from the net VO_2 , which is the VO_2 induced by the exercise bout (i.e., net $\text{VO}_2 = \text{gross } \text{VO}_2 - \text{resting } \text{VO}_2$).²⁰ The net VO_2 values expressed in mL kg min⁻¹ were converted to L min⁻¹ and then to kcal min⁻¹. Based on the values obtained for VO_2 and EE, the exercise bouts were terminated when each participant had achieved a total EE of 400 or 200 kcal in continuous or intermittent exercise bouts, respectively. To negate the confounding effects of the initial (fast) VO_2 on-kinetics (i.e., anaerobic EE component of total EE), the first 5-min interval of each exercise bout was omitted from all analyses.²¹ The EPOC was calculated by subtracting the baseline VO_2 determined during the control session from the VO_2 determined during the recovery from each exercise bout and was reported as the total EPOC for the 60 min recovery period.

Expired gases were collected during and postexercise using a VO2000 analyzer (Medical Graphics™, Saint Louis, MO, USA) and a silicone face mask (Hans Rudolph™, Kansas, MO, USA). The gas analyzers and pneumotacograph were calibrated according to the manufacturer's instructions. Immediately prior to each exercise bout, the gas analyzers were calibrated using a certified standard mixture of oxygen (17.01%) and carbon dioxide (5.00%), balanced with nitrogen (AGA™, Rio de Janeiro, RJ, Brazil) and the flows and volumes of the pneumotacograph were calibrated using a syringe graduated for a 3 L capacity (Hans Rudolph™, Kansas, MO, USA). During the determination of resting VO_2 participants were instructed to minimize movement and keep as relaxed as possible. For the purpose of statistical analyses, the breath-by-breath

VO₂ data were 6-min stationary time-averaged. For example, the VO₂ at 6 min into a post-exercise recovery period represented the average of the VO₂ during the sixth minute and the previous 5 min. Heart rate was measured continuously using a cardiometer (RS800cx, Polar™, Kempele, Finland) and beat-by-beat data were 30-s stationary time-averaged.

All statistical analyses were completed using IBM SPSS Statistics 22 (SPSS Inc., Chicago, IL, USA). The effects of Condition on EPOC were analyzed using the Mixed procedure. Where main effects were statistically significant, post hoc pairwise comparisons with Sidak-adjusted *P* values were performed. Model fit was evaluated by Hurvich and Tsai's Criterion. All statistical assumptions were checked using standard graphical procedures.²² Statistical significance was accepted as *P* ≤ 0.05.

3. Results

Table 1 shows the mean ± SD maximal physiological responses and time to exhaustion for the running and cycling CPETs, and heart rate, relative VO₂, respiratory exchange ratio (RER) and times to achieve 400 (or 200) kcal during continuous and intermittent isocaloric exercise bouts at 75% VO_{2R}, respectively. Mean values were significantly higher for running (*P* < 0.001 to *P* = 0.040), except for the RER_{max} during CPET and time to achieve 400 kcal during continuous and intermittent bouts, which were significantly higher for cycling (*P* = 0.001 to *P* < 0.001), and the maximal minute ventilation, which was not significantly different between exercise modalities (*P* = 0.67).

A significant main effect for Condition was observed for VO₂ (*F* = 553.7, *P* < 0.001). Post hoc pairwise comparisons showed that the VO₂ was significantly greater in the postexercise periods of all exercise conditions compared to the control session (*P* < 0.001, see Fig. 1).

There was a cumulative effect on the EPOC magnitude from the intermittent bouts (see Fig. 2). The EPOC was 4.9 L higher (95% CI = 3.9–6.0, *P* < 0.001) from the cumulative effects of the two intermittent bouts compared to the continuous bout when averaged across exercise modality, despite being matched for EE (i.e., 400 vs. 400 kcal). This cumulative effect was observed for both cycling (mean difference = 3.5 L, 95% CI = 2.2–4.9, *P* = 0.001) and running (mean difference = 6.4 L, 95% CI = 5.2–7.6, *P* < 0.001) bouts. When comparing the continuous bouts with the individual intermittent bout, the EPOC was higher in the continuous than the 1st intermittent cycling (mean difference = 2.7 L, 95% CI = 1.5–3.8, *P* < 0.001) and running bouts (mean difference = 2.9 L, 95% CI = 1.8–4.1, *P* < 0.001), but no significant differences were observed between the continuous and 2nd intermittent cycling (mean difference = 0.8 L, 95% CI = –0.3 to 2.0, *P* = 0.42) and running (mean difference = 0.4 L, 95% CI = –1.6 to 0.7, *P* = 0.99) bouts.

A significant effect of exercise modality was observed, with running resulting in a 2.2 L higher EPOC than cycling (95% CI = 1.7–2.6, *P* < 0.001) when averaged across exercise type (continuous and intermittent). Fig. 2 shows the mean ± SD EPOC during the 60-min recovery from each of the exercise bouts.

4. Discussion

The present study investigated whether isocaloric bouts of continuous and intermittent exercise using different modalities (running vs. cycling) influence the magnitude of EPOC. The major findings were: (a) the combined magnitude of EPOC from the two isocaloric bouts of short-term exercise (2 × 200 kcal) was significantly greater over continuous (400 kcal) cycling or running; (b) the total volume of exercise determined the recovery pattern of the metabolic response to aerobic exercise, where exercise bouts

with different modalities and same relative intensity (i.e., 75% VO_{2R}), but higher volume (400 kcal), promoted greater EPOC than bouts with smaller exercise volume (200 kcal); and (c) the magnitude of EPOC was significantly influenced by exercise modality, with increased EPOC observed in response to treadmill running (i.e., greater muscle mass involved) in comparison with cycling, regardless of whether the exercise was performed continuously or intermittently.

To date, few studies have investigated EPOC following aerobic exercise performed intermittently vs. continuously.^{6–8} Kaminsky et al.⁷ compared EPOC after continuous (50-min) and intermittent (2 × 25-min) bouts of treadmill running at 70%VO_{2peak} in six healthy women (age, 30 ± 4 yr). The sum of the two intermittent running bouts elicited an EPOC ~117% greater than in the continuous bout. Almuzaini et al.⁶ showed that intermittent cycling (2 × 15-min at 70%VO_{2max}) resulted in a combined magnitude of EPOC ~40% greater than in continuous exercise (30-min at 70%VO_{2max}) in ten healthy men (age, 23 ± 4 yr). Lyons et al.⁸ observed that the magnitude of EPOC from the sum of three 10-min bouts of arm ergometry at 60%VO_{2max} was ~190% greater than after 30-min continuous exercise in ten healthy men (age, 25.7 ± 5.8 yr). Our findings are in agreement with these previous reports, since the combined magnitude of EPOC for two intermittent bouts of cycling or running (2 × 200 kcal) was ~63% greater than that observed in a single continuous bout (400 kcal) with similar relative intensity (75% VO_{2R}) (see Fig. 2).

These results may have some practical applications to exercise prescription, such as: (a) intermittent exercise may be a better strategy to improve exercise adherence,²³ since it seems to be more palatable and easier to maintain⁵; and (b) since sedentary individuals have low tolerance to prolonged efforts (i.e., continuous exercise lasting 30–60 min), intermittent bouts could minimize this issue allowing higher intensity exercise, which may chronically result in greater benefits in improving cardiorespiratory fitness and body composition than continuous exercise with moderate intensity and long duration.²⁴ The majority of EPOC typically occurs over the first 30–60 min of recovery from exercise.^{7,11,12} This recovery period therefore represents the minimum time period that should separate exercise bouts to maximize the benefits of intermittent exercise on EPOC. In the present study the average time to complete the intermittent exercise was 155 min. Despite the advantages of an increased EPOC and allowing individuals with poor exercise tolerance to accumulate sufficient daily physical activity recommended for good health, performing exercise bouts twice per day might be challenging for many people with respect to time commitments. The best approach to prescribing aerobic exercise therefore depends on the acceptance of the exercise program by the exercising individual, taking into account likely adherence to the proposed program.

On the other hand, the aforementioned studies support the idea that the magnitude of EPOC may not be affected by exercise duration,^{6–8} since the EPOC observed after the 1st exercise bout (shorter duration) was not significantly different from that measured after the continuous bout (higher duration). Results of the present study are contrary to this premise, since the magnitude of EPOC after the first bout of exercise (200 kcal) was always lower than after continuous bouts (400 kcal), regardless of exercise modality (see Fig. 2). However, after the 2nd intermittent bout, the EPOC was very similar to continuous exercise, since the exercise volume expressed by EE was matched for the exercise performed continuously and intermittently (e.g., 400 vs. 400 kcal). This finding suggests that exercise volume (or duration) may have a key role in inducing a greater EPOC magnitude. Bearing in mind the different exercise protocols and populations, the comparisons between results of the aforementioned studies should be viewed with caution and further research is certainly warranted to clarify this issue.

Table 1
Mean $\pm$ SD values for cardiorespiratory variables and time to exhaustion during cycling and running incremental exercise tests and isocaloric exercise bouts of running and cycling. All participants satisfied at least three of the four maximal test criteria stipulated in the 'Procedures' section during the incremental exercise test. Values given for the accumulated isocaloric intermittent bouts represent the averaged values for the two intermittent bouts.

Moment	Variables	Running Mean $\pm$ SD	Cycling Mean $\pm$ SD	P Values
Incremental exercise test	Maximal heart rate (beats min ⁻¹)	196 $\pm$ 6	181 $\pm$ 1	<0.001
	Maximal oxygen uptake (L min ⁻¹)	4.2 $\pm$ 0.7	3.8 $\pm$ 0.6	<0.001
	Minute ventilation (L min ⁻¹)	116 $\pm$ 20	118 $\pm$ 22	NS
	Respiratory exchange ratio	1.09 $\pm$ 0.04	1.17 $\pm$ 0.02	<0.001
	Time to exhaustion (s)	686 $\pm$ 141	575 $\pm$ 40	0.04
Isocaloric continuous bout	Heart rate (beats min ⁻¹)	174 $\pm$ 7	159 $\pm$ 5	<0.001
	Oxygen uptake (L min ⁻¹)	3.0 $\pm$ 0.620	2.5 $\pm$ 0.603	<0.001
	Respiratory exchange ratio	0.97 $\pm$ 0.06	1.02 $\pm$ 0.06	<0.001
	Time to achieved 400 kcal (s)	1953 $\pm$ 362	2214 $\pm$ 452	<0.001
Accumulated isocaloric intermittent bouts	Heart rate (beats min ⁻¹)	168 $\pm$ 6	157 $\pm$ 10	0.009
	Oxygen uptake (L min ⁻¹)	2.9 $\pm$ 0.575	2.5 $\pm$ 0.7	0.002
	Respiratory exchange ratio	1.0 $\pm$ 0.06	0.93 $\pm$ 0.06	0.001
	Time to achieved 400 kcal (s)	2288 $\pm$ 554	2307 $\pm$ 438	0.002
1st isocaloric intermittent bout	Heart rate (beats min ⁻¹)	166 $\pm$ 6	156 $\pm$ 9	0.005
	Oxygen uptake (L min ⁻¹)	2.9 $\pm$ 0.6	2.5 $\pm$ 0.7	0.004
	Respiratory exchange ratio	0.92 $\pm$ 0.05	0.99 $\pm$ 0.06	<0.001
	Time to achieved 200 kcal (s)	1179 $\pm$ 219	1320 $\pm$ 287	0.002
2nd isocaloric intermittent bout	Heart rate (beats min ⁻¹)	170 $\pm$ 7	158 $\pm$ 11	0.010
	Oxygen uptake (L min ⁻¹)	3.0 $\pm$ 0.6	2.5 $\pm$ 0.6	0.001
	Respiratory exchange ratio	0.95 $\pm$ 0.06	1.03 $\pm$ 0.06	<0.001
	Time to achieved 200 kcal (s)	1128 $\pm$ 208	1268 $\pm$ 268	<0.001

NS, non-significant.

Another experimental finding was a significant main effect for exercise modality ($P < 0.001$; see Fig. 2), where on average, the magnitude of EPOC was $\sim 37\%$ higher from running (exercise recruiting larger muscle mass) compared to cycling (exercise with smaller muscle mass). The findings of Lyons et al.,¹¹ from ten untrained men (age, 25.7 ± 5.8 yr) were similar to our results, in that isocaloric bouts (200 kcal at $60\% \text{VO}_{2\text{peak}}$) of cycling elicited a greater magnitude of EPOC than arm ergometry (duration: 16.5 ± 7.4 vs. 11.5 ± 6.1 min, $P = 0.001$; EPOC: 2.93 ± 1.4 vs. 1.89 ± 0.7 L min⁻¹, $P = 0.02$, respectively). These results show that equating exercise EE at a given mode-specific relative intensity will elicit greater EPOC and thereby greater postexercise EE for exercise involving a greater muscle mass compared with lower muscle mass. Therefore, a question remains: what could explain the difference in the magnitude

of EPOC between the two exercise modalities (i.e., running vs. cycling)? Possible factors could be differences in lactate metabolism and replenishment of creatine phosphate, muscle glycogen resynthesis, body temperature, heart rate, ventilatory rate, circulating concentrations of catecholamine hormones, and replenishment of the body's resting oxygen levels.²⁵ A further possible explanation is that the greater EPOC magnitude might simply be due to higher VO_2 during the exercise bout performed with a greater muscle mass, which results in a higher VO_2 response during recovery.

Scott et al.,²⁶ compared the effects of isocaloric bouts of cycle ergometry and treadmill running with equivalent EE. The EPOC values were not statistically different between the exercise modes, which contrasts with the findings of the present study. One plausible explanation for the conflicting findings is the differences in

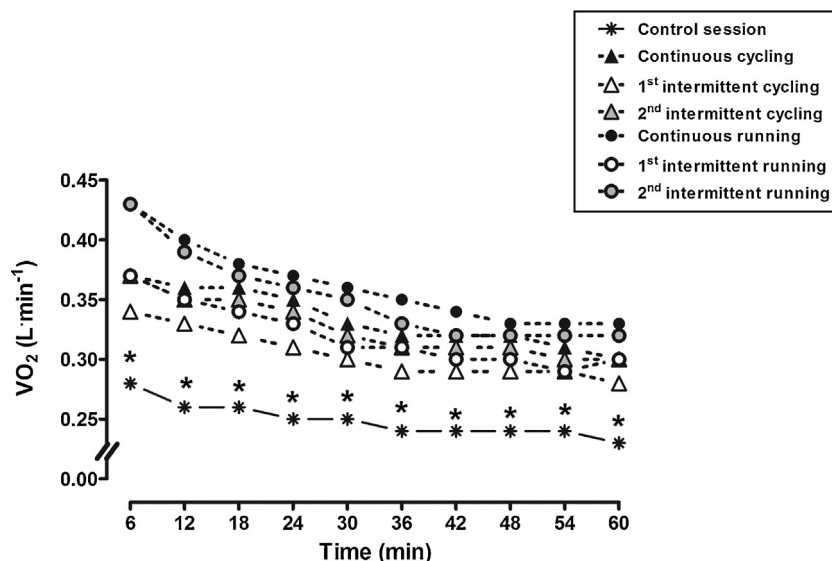


Fig. 1. Mean absolute oxygen uptake (VO_2) during the control session (non-exercise day) and after six trials of cycling and running performed continuously and intermittently during 60-min data collection. *Significantly different from exercise conditions ($P < 0.001$).

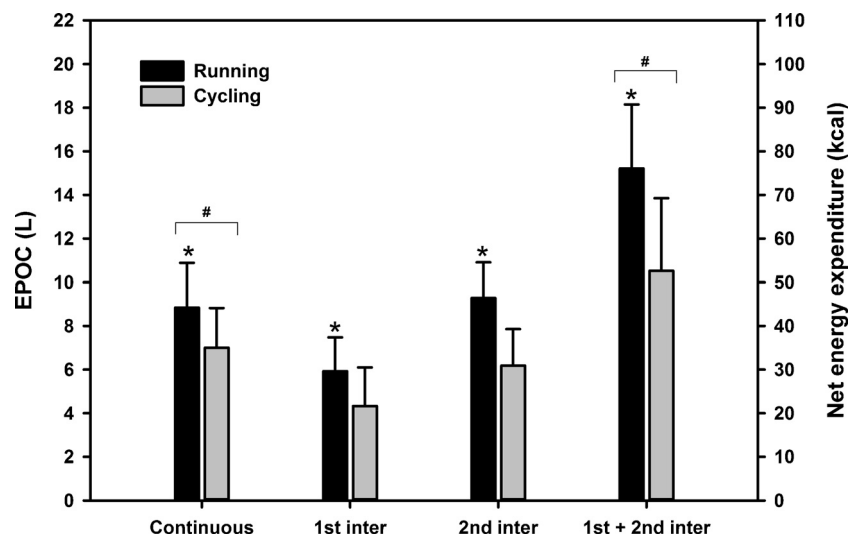


Fig. 2. Mean $\pm$ SD excess post-exercise oxygen consumption (EPOC) and net energy expenditure during 60-min of recovery from isocaloric bouts of continuous and intermittent (inter) running and cycling. *Running significantly higher than cycling ($P < 0.001$). #Sum of the 1st and 2nd intermittent bouts significantly higher than the continuous bout ($P < 0.001$).

baseline VO_2 assessment between studies.² In the present study, baseline VO_2 was determined during 60 min of rest on a separate day to the exercise bouts according to the guidelines of Compher et al.¹⁵ Scott et al.²⁶ used the average VO_2 during a 5 min period immediately before the exercise bouts whilst seated on the cycle ergometer or standing on the treadmill. Lyons et al.¹¹ used the average VO_2 during the last 10 min of 30 min of rest seated on a chair. Although using a non-exercise control day appears to be methodologically advantageous to investigate EPOC, future research should investigate the extent of any bias from within-subject day-to-day variability in baseline VO_2 .¹⁵ If any bias is shown to exist, then future studies evaluating the magnitude of EPOC should consider using a non-exercise control session prior to the exercise on each of the days that EPOC is assessed.

5. Conclusion

In conclusion, splitting the exercise into two bouts of short-term exercise (2×200 kcal) was shown to empower effects on EPOC, promoting greater increases in EPOC compared to a continuous bout of exercise with equivalent EE (400 kcal). However, the EPOC seems to be affected by the exercise volume/duration, with exercise bouts performed with higher volume (400 kcal) inducing greater EPOC than exercise bouts performed with lower volume (200 kcal). Additionally, albeit matched for overall volume, running induced greater EPOC than cycling bouts, suggesting that exercise modality may influence the EPOC.

Practical implications

- Splitting a dose of daily exercise into smaller bouts is sometimes recommended for individuals with poor exercise tolerance. The present study provides evidence that this strategy also increases post-exercise EE and is therefore recommended where a primary outcome of the exercise prescription is weight loss or maintenance.
- Treadmill running resulted in greater post-exercise EE than cycling. Where not contraindicated, treadmill running is therefore recommended as a more efficient mode of exercise than cycling for facilitating weight loss and maintenance.
- The observed differences in post-exercise EE between continuous and intermittent exercise, and between cycling and running,

were relatively modest. Over a prolonged period of time, however, the cumulative effects could result in important differences in weight loss. Individuals responsible for exercise prescription should therefore consider the type and mode of exercise when attempting to optimize weight loss.

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References

1. ACSM. *ACSM's guidelines for exercise testing and prescription*, 8th ed. Baltimore, Lippincott Williams & Wilkins, 2009.
2. Borsheim E, Bahr R. Effect of exercise intensity, duration and mode on post-exercise oxygen consumption. *Sports Med* 2003; 33(14):1037–1060.
3. Garber CE, Blissmer B, Deschenes MR et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc* 2011; 43(7):1334–1359.
4. Coquart JB, Lemaire C, Dubart AE et al. Intermittent versus continuous exercise: effects of perceptually lower exercise in obese women. *Med Sci Sports Exerc* 2008; 40(8):1546–1553.
5. Murphy MH, Blair SN, Murtagh EM. Accumulated versus continuous exercise for health benefit: a review of empirical studies. *Sports Med* 2009; 39(1):29–43.
6. Almuzaini KS, Potteiger JA, Green SB. Effects of split exercise sessions on excess postexercise oxygen consumption and resting metabolic rate. *Can J Appl Physiol* 1998; 23(5):433–443.
7. Kaminsky LA, Padjen S, LaHam-Saeger J. Effect of split exercise sessions on excess post-exercise oxygen consumption. *Br J Sports Med* 1990; 24(2):95–98.
8. Lyons S, Richardson M, Bishop P et al. Excess post-exercise oxygen consumption in untrained males: effects of intermittent durations of arm ergometry. *Appl Physiol Nutr Metab* 2006; 31(3):196–201.
9. Xu F, Rhodes EC. Oxygen uptake kinetics during exercise. *Sports Med* 1999; 27(5):313–327.
10. Cunha FA, Catalao RP, Midgley AW et al. Do the speeds defined by the American College of Sports Medicine metabolic equation for running produce target energy expenditures during isocaloric exercise bouts? *Eur J Appl Physiol* 2012; 112(8):3019–3026.
11. Lyons S, Richardson M, Bishop P et al. Excess post-exercise oxygen consumption in untrained men following exercise of equal energy expenditure: comparisons of upper and lower body exercise. *Diabetes Obes Metab* 2007; 9(6):889–894.
12. Sedlock DA. Post-exercise energy expenditure after cycle ergometer and treadmill exercise. *J Strength Cond Res* 1992; 6(1):19–23.

13. Abrantes C, Sampaio J, Reis V et al. Physiological responses to treadmill and cycle exercise. *Int J Sports Med* 2012; 33(1):26–30.
14. Cunha FA, Montenegro RA, Midgley AW et al. Influence of exercise modality on agreement between gas exchange and heart rate variability thresholds. *Braz J Med Biol Res* 2014; 47(8):706–714.
15. Compther C, Frankenfield D, Keim N et al. Best practice methods to apply to measurement of resting metabolic rate in adults: a systematic review. *J Am Diet Assoc* 2006; 106(6):881–903.
16. Cunha FA, Midgley AW, Monteiro W et al. How long does it take to achieve steady state for an accurate assessment of resting VO_2 in healthy men? *Eur J Appl Physiol* 2013; 113(6):1441–1447.
17. Buchfuhrer MJ, Hansen JE, Robinson TE et al. Optimizing the exercise protocol for cardiopulmonary assessment. *J Appl Physiol* 1983; 55(5):1558–1564.
18. Howley ET, Bassett Jr DR, Welch HG. Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc* 1995; 27(9):1292–1301.
19. Jones AM, Doust JH. A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *J Sports Sci* 1996; 14(4):321–327.
20. Swain DP. Energy cost calculations for exercise prescription: an update. *Sports Med* 2000; 30(1):17–22.
21. Cunha FA, Midgley AW, Monteiro WD et al. The relationship between oxygen uptake reserve and heart rate reserve is affected by intensity and duration during aerobic exercise at constant work rate. *Appl Physiol Nutr Metab* 2011; 36(6):839–847.
22. Grafen A, Hails R. *Modern statistics for the life sciences: learn how to analyse your own data*, Oxford, Oxford University Press, 2002.
23. Jakicic JM, Wing RR, Butler BA et al. Prescribing exercise in multiple short bouts versus one continuous bout: effects on adherence, cardiorespiratory fitness, and weight loss in overweight women. *Int J Obes Relat Metab Disord* 1995; 19(12):893–901.
24. Swain DP, Franklin BA. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. *Am J Cardiol* 2006; 97(1):141–147.
25. Gaesser GA, Brooks GA. Metabolic bases of excess post-exercise oxygen consumption: a review. *Med Sci Sports Exerc* 1984; 16(1):29–43.
26. Scott CB, Littlefield ND, Chason JD et al. Differences in oxygen uptake but equivalent energy expenditure between a brief bout of cycling and running. *Nutr Metab (Lond)* 2006; 3:1.