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# Effect of Resistance Training on Excess Post-exercise Oxygen Consumption

Diane L. Elliot, Linn Goldberg and Kerry S. Kuehl
*Human Performance Laboratory; Division of General Medicine, Department of Medicine; Oregon Health Sciences University, Portland, Oregon 97201.*

## ABSTRACT

**Elliot, D.L., Goldberg, L. and K.S. Kuehl. Effect of resistance training on excess post-exercise oxygen consumption. *J. Appl. Sport Sci. Res.* 6(2):77-81. 1992.** — *Post-exercise energy expenditure has not been studied after resistance exercise. In this study, metabolic rate was measured by indirect calorimetry for nine volunteers after 40 minutes of cycling (80 percent of maximal heart rate), 40 minutes of circuit training (50 percent of individuals' maximum lift [1 RM] x 15 repetitions x 4 sets), 40 minutes of heavy resistance lifting (80 to 90 percent of 1 RM x 3-8 repetitions x 3 sets) and a control interval. Weight training included use of eight stations of Universal multi- and uni-station equipment. All forms of exercise increased the metabolic rate immediately after exertion ($p < 0.01$). For circuit and heavy resistance lifting, the increase also was significant 30 minutes after exertion ($p < 0.05$). The absolute total increment in caloric use (mean ± standard deviation) after exertion was comparable among circuit training (49 ± 20 kilocalories), heavy lifting (51 ± 31 kilocalories), and cycling (32 ± 16 kilocalories). However, cycling was less ($p < 0.05$) than both forms of weight training. Our findings suggest that dynamic exertion is not required to augment post-exercise oxygen consumption (EPOC), and that the amount of exercising skeletal mass is an additional variable to consider when relating exercise to EPOC.*

KEY WORDS: recovery energy expenditure, excess post-exercise oxygen consumption (EPOC), metabolic rate, resistive exercise, weight lifting

## INTRODUCTION

Exercise increases caloric expenditure during activity and after exertion. The additional energy use that follows exercise has been termed excess post-exercise oxygen consumption (EPOC) or recovery energy expenditure (15, 17, 20). Although early studies of EPOC indicated a sustained elevation that significantly contributed to caloric expenditure (3, 18), subsequent research suggests that the usual bout of aerobic training results in a metabolic rate elevation that lasts approximately 30 minutes (3, 4, 10, 12). More prolonged (three hours) or high-intensity (above the anaerobic threshold) physical activity may cause a greater increase in caloric expenditure (3, 4, 14).

Published studies of EPOC have been limited to the effects of dynamic activity (cycling, walking, jogging) and no previous investigations have evaluated the effects of resistive exercise. We sought to measure the EPOC generated by: heavy-resistance, priority lifting; low-resistance, circuit-style weight training; and aerobic exercise.

## METHODS

Four men and five women volunteered to participate. All were healthy nonsmokers with stable body weights. None took medications, and each was physically active and experienced in both aerobic exercise and weight training. After obtaining informed consent, body composition was determined by hydrodensitometry (5), with estimation of residual volume from measured vital capacity (25).

Oxygen consumption was measured during incremental cycle ergometry, and resting measurements were used to determine metabolic rates by indirect calorimetry (21, 24). All expired air was collected by an occlusive facial mask with a low-resistance valve. Minute ventilation was measured with a dry rolling seal spirometer and analog potentiometer, and flow was obtained by electronic differentiation of the volume signal. Oxygen concentration was measured with a paramagnetic analyzer, and carbon dioxide was assessed by infrared analysis. Every 20 seconds, volume and concentration values were used to calculate oxygen uptake and carbon dioxide production (Gould 900IV Metabolic Cart; Dayton, Ohio). During exercise, heart rate was observed from continuous electrocardiographic recordings, and blood pressure was measured at each work level by aneroid sphygmomanometry. Each subject's maximal exertion was accompanied by volitional exhaustion, a plateau in heart rate and blood pressure and a respiratory exchange ratio greater than 1:1. Strength was assessed by measuring the one-repetition maximum (1 RM) bench press using free weights and standard technique.

Subjects were randomly assigned to one of four conditions: control; 40 minutes of cycling; 40 minutes of circuit weight training; and 40 minutes of heavy resistance weight lifting. Prior to each condition, resting metabolic rate was determined. All subjects were evaluated at an ambient temperature of 26 degrees centigrade, early in the morning after an overnight fast, and without exercise during the previous day. After acclimation to the setting and equipment, a five-minute equilibration interval was used to visually inspect continuous readings for stability. When stabilized, continuous measurements were made for eight minutes, and the mean value was calculated. Because resting metabolic rate correlates most closely with fat-free body mass (FFM) (19), values were expressed in relation to that variable.

The two-hour control period of supine rest was assessed by obtaining mean measurements during the final 10 minutes of each 30-minute interval. Prior to each form of training, baseline indirect calorimetry was performed. Immediately after exertion, (time zero for post-exertion determinations), subjects rested supine with measurements obtained over 10 minutes, and repeated for the concluding 10 minutes of three consecutive 30-minute intervals (90 minutes of follow-up).

Preliminary weight lifting trials and maximal cycle ergometry were used to assign work levels during exercise. Prior to the study, each subject's strength was assessed on each lift with a 1 RM to determine the weight for each set. The cycling intensity was at a workload and heart rate equivalent to 75 percent of the measured maximal heart rate. Cycling work loads remained constant during exercise, while a trained observer monitored heart rate by palpation every three minutes to confirm the appropriate intensity.

The low-resistance circuit training exercises included eight exercises: bench press, knee extension, leg curl, seated leg press, lat pulldown, military press, seated row and seated chest fly (Centurion Model, Universal multi- and uni-station equipment) (6). For each exercise set, resistance was 50 percent of each individual's maximum lift, for 15 repetitions. Subjects moved from station to station with a maximum rest time of 30 seconds, and repeated the circuit for four sets of each exercise (total workout of 40 minutes). Heart rate was determined by radial artery palpation and recorded before and immediately after each set. Values were averaged to estimate the mean heart rate during the workout.

The heavy-resistance workout was performed with the same eight exercises and equipment, except participants used free weights for the bench press. Weights were 80 to 90 percent of the individual's maximum lifts, and each individual lifted until volitional muscle fatigue (three to eight repetitions); three sets were performed per exercise. Subjects were required to wait a minimum of one minute and a maximum of two minutes between sets. Heart rate was monitored in the manner described for circuit weight training.

Caloric use during cycling was calculated by multiplying the oxygen consumption (ml•min$^{-1}$), which was measured at the intensity during incremental testing, by 40 minutes. During circuit and heavy-resistance workouts, caloric use was quantitated for each subject by directly measuring oxygen consumption for the eight low-resistance and eight high-resistance sets, and multiplying by the number of sets. The details of those determinations have been previously reported (16). Total EPOC was calculated by using each individual's control measurements as baseline. Values of the three exertion modes (immediate, 30-, 60- and 90-minute oxygen consumption) were plotted, and the area under the curve integrated to calculate EPOC.

Data were assessed by analysis of variance for repeated measures. Post-hoc comparisons were by two-tailed t-tests. The level of statistical significance was set at the $p < 0.05$ level.

## RESULTS

Descriptive data for the four male and five female subjects are presented in Table 1. Although men had greater body weights and strength, they were comparable to women in aerobic endurance.

Sequential metabolic rates for the control interval and after each training period are shown in Figure 1. Baseline readings were comparable among the four conditions. Immediately after exertion, the metabolic rate was higher for each exercise mode ($p < 0.01$ for each). After cycling, the post-exercise augmentation was significantly greater

Table 1. Descriptive Data ($\overline{X} \pm SD$)

| | Women (N = 5) | Men (N = 4) |
|---|---|---|
| Age (yr) | 24 ± 2 | 27 ± 3 |
| Height (cm) | 167 ± 8 | 177 ± 2 |
| Weight (kg) | 63 ± 6 | 78 ± 14 |
| Body fat (percent) | 15 ± 3 | 12 ± 7 |
| $\dot{V}O_2$ max (ml•kg•min$^{-1}$) | 48 ± 6 | 45 ± 7 |
| Maxium bench press (kg) | 286 ± 23 | 579 ± 21 |

than baseline only for the initial measurement period. However, after both low-resistance circuit and heavy-resistance training, the increase in metabolic rate remained elevated 30 minutes after exercise ($p < 0.05$ for each).

Total caloric expenditure during training periods differed (Table 2). Cycling and circuit weight training used significantly greater calories ($p < 0.01$) than did heavy-resistance exercise. Likewise, with heavy lifting, heart rate was significantly lower ($p < 0.01$) than the other two forms of exercise. The calculated caloric expenditures per minute during exercise, (excluding weight training rest intervals), were 10.8 kcal•min$^{-1}$, 12.1 kcal•min$^{-1}$ and 27.6 kcal•min$^{-1}$ for cycling, circuit training and heavy lifting, respectively.

The absolute increment in caloric expenditure after exertion was small for each activity (Table 2). Heavy-resistance weight lifting produced a significantly greater EPOC than cycling ($p < 0.05$). Although circuit weight training and cycling were similar in their heart rate response and caloric use during exertion, circuit training resulted in significantly greater ($p < 0.05$) EPOC than cycling.

## DISCUSSION

We found that the two typical forms of weight training, (heavy-resistance and circuit weight lifting), resulted in EPOCs comparable to aerobic exercise. Although differences were observed among the three training modes, their absolute magnitudes were small.

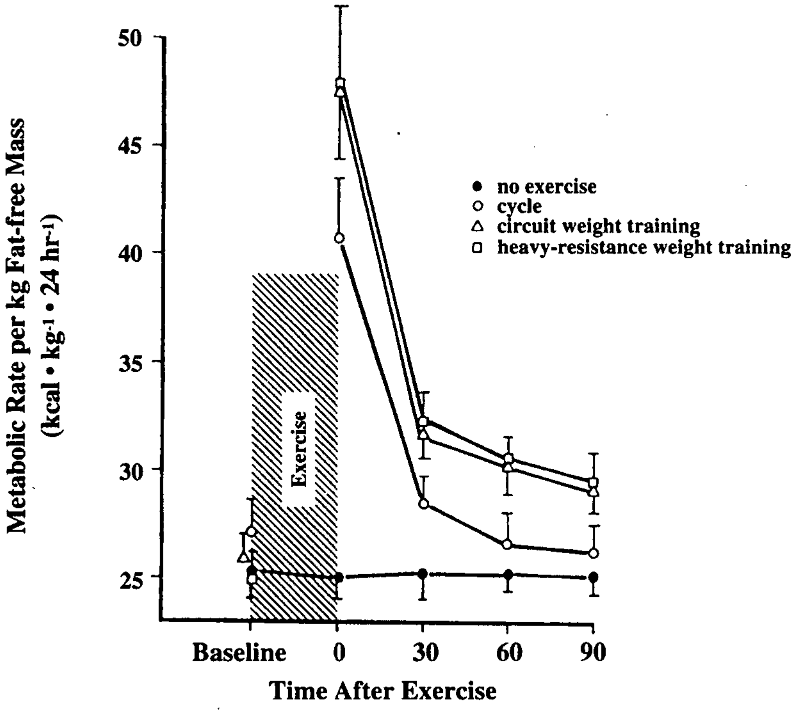

Figure 1. Recovery energy expenditure versus time after exercise for the control condition and the three forms of exertion (data are mean ± SD).

Table 2. Mean Heart Rate and Total Caloric Expenditure During Exercise, and Excess Post-exercise Energy Expenditure ($\bar{X} \pm SD$)

| | Mean Heart Rate (bpm) | Total Caloric Expenditure (kcal) | Excess Post-exercise Energy Expenditure (kcal) |
|---|---|---|---|
| Cycling | 152 ± 5 | 432 ± 95 | 32 ± 16 |
| Circuit lifting | 140 ± 7 | 362 ± 167 | 48 ± 20* |
| Heavy lifting | 115 ± 6*** | 248 ± 129* | 51 ± 31** |

* circuit lifting > cycling ($p < 0.05$)
** heavy lfiting > cycling ($p < 0.05$)
*** heavy lifting < cycling and circuit lifting ($p < 0.01$)

Previously, EPOC has been studied only after dynamic exercise. Although the physiologic processes that result in EPOC have not been clearly defined, potential factors include protein synthesis (13), substrate recycling (16) and increased catecholamine levels after exertion (11). To assess the relationship among training variables and physiologic response, results have been evaluated in regard to exercise intensity, duration and total caloric use. Determining each factor's influence has been difficult, because altering one variable affects the other parameters.

For this study, workout durations were similar among the three conditions. However, indexing intensity for weight training is problematic. Intensity of aerobic exertion is usually determined by percent of maximal heart rate, which correlates with oxygen consumption. The heart rate:intensity relationship is limited in its application to resistance training. As muscle loading increases, the heart and blood pressure responses differ from dynamic exertion. A maximal lift with its isometric component has a predictably lower heart rate and higher systolic blood pressure than maximal dynamic exertion (22, 23). Thus, exertional heart rates were not comparable indicators of overall intensity. An alternative method to compare weight training and dynamic exertions intensity would be the metabolic pathways used. Because heavy weight lifting is a burst activity, using predominantly glycolytic pathways and anaerobic muscle metabolism, it may be considered a more intense form of training, despite a lower heart-rate response.

Total caloric expenditure is another variable that may relate to EPOC. The total caloric expenditure of continuous cycling and low-resistance circuit training were comparable for our subjects, while the least total energy use was during heavy-resistance training. Although values for caloric expenditure during lifting were extrapolations, findings during circuit weight lifting were similar to those observed by other investigators (1, 26), suggesting accurate caloric use estimates.

A final factor to consider when comparing forms of exertion is the amount of exercising skeletal mass. Comparing each subject's exercising muscle mass with his or her EPOC would not allow isolating this variable's effect, because individuals with greater muscle mass also performed more work and had greater caloric expenditure during exercise. Further investigations are needed to define whether exercising mass correlates with EPOC when total work remains constant, and to better define the relationship between EPOC, training indices and physiologic measurements (e.g., catecholamine levels, lactate clearance).

Our findings suggest that muscle mass may be an important variable when relating exertion to EPOC. Unlike total caloric use or heart-rate response, exercising muscle mass unites circuit and heavy-resistance training and may relate to the higher EPOC observed with weight lifting.

## PRACTICAL APPLICATIONS

Exercise is an important component of a weight-reduction program (8). The caloric expenditure during resistance training correlates with the total weight lifted (12). Weight lifting, both low weight, high repetition (circuit style) and high weight, low repetition (strength training), results in additional energy expenditure after exercise. Although the calories used during exertion may be relatively low when initiating a strength-training program, the activity may help preserve or increase skeletal mass during negative caloric balance (2). Thus, weight training may help preserve or increase skeletal mass during negative caloric balance (2). Thus, weight training may have unique advantages for a weight-loss program, and despite a caloric expenditure during exertion that can be less than dynamic conditioning, EPOC are comparable. To maximize caloric expenditure after training, exercise that involves both upper- and lower-body exertion (to involve a greater amount of skeletal mass) may be preferred.

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## REFERENCES

1. Ballor, D.L., Becque, M.D. and V.L. Katch. Metabolic responses during hydraulic resistance exercise. **Med. Sci. Sports Exer.** 19:363-367. 1987.
2. Ballor, D.L., Katch V.L., M.D. Bacque and C.R. Marks. Resistance weight training during caloric restriction enhances lean body weight maintenance. **Am. J. Clin. Nur.** 47:19-25. 1988.
3. Bielinski, R., Schutz, Y. and E. Jequier. Energy metabolism during the post exercise recovery in man. **Am. J. Clin. Nutr.** 42:69-82. 1985.
4. Brehm, B.A. and B. Gutin. Recovery energy expenditure for steady state exercise in runners and non-exercisers. **Med. Sci. Sports Exer.** 18:205-210. 1986.
5. Brozek, J., Grande, F., Anderson, J. and A. Keys. Densitometric analysis of body composition: revision of some quantitative assumptions. **Ann. NY Acad. Sci.** 110:113-140. 1963.
6. Darden, E. **Strength-training Principles: How To Get the Most Out of Your Workout**. Winter Park, FL: Anna Publishing. 1977. p. 27.
7. Edwards, H.T., Thorndike Jr., A. and D.B. Dill. The energy requirements in strenuous muscular exercise. **N. Engl. J. Med.** 213:532-535. 1935.
8. Elliot, D.L., Goldberg, L. and D.E. Girard. Obesity: pathophysiology and practical management. **J. Gen. Intern. Med.** 2:188-198. 1987.
9. Elliot, D.L., Goldberg, L. and K.S. Kuehl. Does aerobic conditioning cause a sustained increase in metabolic rate? **Am. J. Med. Sci.** 296:249-251. 1988.
10. Freedman-Akabas, S., Colt, E., Kisseleft, H.R. and F.X. Pi-Sunyer. Lack of sustained increase in $\dot{V}O_2$ following exercise in fit and unfit subjects. **Am. J. Clin. Nutr.** 41:545-549. 1985.
11. Gladden, L.B., Stainsby, W.N. and B.R. MacIntosh. Norepinephrine increases canine skeletal muscle $\dot{V}O_2$ during recovery. **Med. Sci. Sports Exerc.** 14:471-476. 1982.
12. Kuehl, K.S., Elliot, D.L., Goldberg, L. and D. Frame. Predicting caloric expenditure during multi-station resistance exercise. **J. Appl. Sport Sci. Res.** 4:63-67. 1990.
13. Lemon, P.W.R., Dolny, D.G. and K.E. Yarasheski. Effect of intensity on protein utilization during prolonged exercise. **Med. Sci. Sports Exerc.** 16:151-152. 1984.
14. Maehlum, S., Grandmontagre, M., Newsholme, E.A. and O.M. Sejersted. Magnitude and duration of excess post-exercise oxygen consumption in healthy young subjects. **Metab.** 35:425-429. 1986.
15. Mole, P.A. Impact of energy intake and exercise on resting metabolic rate. **Sports Med.** 10:72-87. 1990.
16. Newsholme, E.A. Substrate cycles: their metabolic, energetic and thermic consequences in man. **Biochemical Society Symposium.** 43:183-205. 1978.
17. Poehlman, E.T. A review: exercise and its influence on resting energy metabolism in man. **Med. Sci. Sports Exerc.** 21:515-525. 1989.
18. Passmore, R. and R.E. Johnson. Some metabolic changes following prolonged moderate exercise. **Metab.** 9:452-456. 1960.
19. Roca, A.M. and H.M. Shezgal. The Harris Benedict equation re-evaluation: resting energy requirements and the body cell mass. **Am. J. Clin. Nutr.** 40:168-182. 1984.
20. Sedlock D.A., Fissinger, J.A. and C.C. Melby. Effect of exercise intensity and duration on post-exercise energy expenditure. **Med. Sci. Sports Exerc.** 21:662-666. 1989.
21. Soares, M.H., Sheela, M.S., Kupad, A.V. et al. The influence of different methods of basal metabolic rate measurements in human subjects. **Am. J. Clin. Nutr.** 50:731-736. 1980.
22. Stone, M.H. and G.D. Wilson. Resistive training and selected effects. **Med. Clin. N. Amer.** 69:109-122. 1985.
23. Stone, M.H., Fleck S.J., Triplett, N.T. and W.J. Kraemer. Health- and performance-related potential of resistance training. **Sports Med.** 11:210-231. 1991.
24. Weir, J.B.V. New methods for calculating metabolic rate with special reference to protein metabolism. **J. Physiol.** 109:1-5. 1949.
25. Wilmore, J. The use of actual, predicted and constant residual volumes in the assessment of body composition by underwater weighing. **Med. Sci.** 1:87-90. 1969.
26. Wilmore, J.H., Parr, R.B., Ward P. et al. Energy cost of circuit weight training. **Med. Sci. Sports.** 10:75-78. 1978.