Effect of weight training exercise and treadmill exercise on post-exercise oxygen consumption

BURLESON, MAX A. JR; O'BRYANT, HAROLD S.; STONE, MICHAEL H.; COLLINS, MITCHELL A.; TRIPLETT-McBRIDE, TRAVIS

Medicine & Science in Sports & Exercise: April 1998 - Volume 30 - Issue 4 - p 518-522
Basic Sciences: Original Investigations

Abstract **Author Information** **Article Outline**

To compare the effect of weight training (WT) and treadmill (TM) exercise on postexercise oxygen consumption ($\dot{V}O_2$), 15 males (mean ± SD) age = 22.7 ± 1.6 yr; height = 175.0 ± 6.2 cm; mass = 82.0± 14.3 kg) performed a 27-min bout of WT and a 27-min bout of TM exercise at matched rates of $\dot{V}O_2$. WT consisted of performing two circuits of eight exercises at 60% of each subject's one repetition maximum with a work/rest ratio of 45 s/60 s. Approximately 5 d after WT each subject walked or jogged on the TM at a pace that elicited an average $\dot{V}O_2$ matched with his mean value during WT. $\dot{V}O_2$ was measured continuously during exercise and the first 30 min into recovery and at 60 and 90 min into recovery. $\dot{V}O_2$ during WT (1.58 $L \cdot min^{-1}$) and TM exercise (1.55 $L \cdot min^{-1}$) were not significantly($P > 0.05$) different; thus the two activities were matched for $\dot{V}O_2$. Total oxygen consumption during the first 30 min of recovery was significantly higher ($P < 0.05$) as a result of WT (19.0 L) compared with that during TM exercise (12.7 L). However, $\dot{V}O_2$ values at 60 (0.32 vs 0.29 $L \cdot min^{-1}$), and 90 min (0.33 vs 0.30 $L \cdot min^{-1}$) were not significantly different ($P > 0.05$) between WT and TM exercise, respectively. The results suggest that, during the first 30 min following exercise, WT elicits a greater elevated postexercise $\dot{V}O_2$ than TM exercise when the two activities are performed at matched $\dot{V}O_2$ and equal durations. Therefore, total energy expenditure as a consequence of WT will be underestimated if based on exercise $\dot{V}O_2$ only.

Exercise Physiology Lab, Department of Health, Leisure, and Exercise Science Appalachian State University, Boone, NC 28608

Submitted for publication March 1997.

Accepted for publication August 1997.

Postexercise recovery energy consumption can be an important consideration for many reasons, including its possible effect on body mass and body composition and its effect upon subsequent exercise. Several studies have examined the effects of steady-state exercise on recovery oxygen consumption[2,3,7,11,24,25]. Generally, these studies suggest that intensity of training may have a somewhat greater effect upon recovery energy expenditure than does the duration of exercise[21]. Higher intensities of exercise likely disturb homeostasis to a greater degree than lower intensity exercise, resulting in more energy being used for recovery. This suggests that anaerobic exercise, because of the high exercise intensities involved, would require more energy and perhaps a longer duration for recovery. Weight training is a commonly used form of high intensity anaerobic training among athletes and the general public. It is possible that weight training can disturb homeostasis sufficiently to markedly increase postexercise oxygen consumption and energy requirements for recovery. Few studies have attempted to examine the total energy expenditure or duration of recovery from weight training[11,21-23] or compared recovery variables as a result of weight training with those as a result of other forms of exercise [11]. The purpose of the present study was to compare the duration and total energy requirement during recovery as a result of a typical circuit weight training session and steady-state aerobic exercise on a treadmill when exercise was performed for the same duration at matched $\dot{V}O_2$.

METHODS

Fifteen males, aged 20 to 26 yr, who had a minimum of 6 months previous weight training experience and were familiar with the exercises used in the experiment, volunteered to participate in the study. Subject demographics are presented in Table 1. Before participation each subject signed an informed consent and responded to a physical activity and medical history questionnaire.

Variable	Mean	SD
Age (yr)	22.7	±1.6
Height (cm)	165.0	±6.2
Body mass (kg)	82.0	±14.3
Body fat (%)	13.1	±7.6
Maximal oxygen consumption (L·min⁻¹)	3.57	±0.61
Maximal heart rate (beats·min⁻¹)	199.0	±7.0

TABLE 1

Maximal oxygen uptake ($\dot{V}O_{2max}$) and maximal heart rate were determined using a grade-incremented treadmill test [1]. Following a 5-min warm-up on the treadmill (Quinton model ST206, Seattle, WA), each subject walked for 2 min at 3 mph, 0% grade. At the end of each 2-min interval the treadmill speed was increased by 0.5 mph until the subject reached 7 mph. At 7 mph the speed was held constant and the treadmill grade was increased by 2% each 2-min interval. The subject was asked to exercise until volitional exhaustion. The small increments in work rate during the early stages of the maximal treadmill test were necessary to identify the appropriate speed setting to match with the $\dot{V}O_2$ values measured during the weight training session.

Expired air was collected and analyzed minute-by-minute using a Beckman metabolic measurement cart (SensorMedics, Anaheim, CA) equipped with an OM-11 oxygen analyzer and an LB-2 carbon dioxide analyzer. The analyzers were calibrated using 100% nitrogen and a standard gas previously analyzed using a micro-Scholander chemical gas analyzer (Otto Hebel Instruments, Swarthmore, PA). Heart rates were measured using a Hewlett-Packard Pagewriter electrocardiograph (Hewlett Packard Medical Products, Andover, MA). $\dot{V}O_{2max}$ was identified as the highest $\dot{V}O_2$ measured during the test if the subject achieved at least one of the following criteria: 1) a plateau or decrease in $\dot{V}O_2$ with an increase in work rate evidenced by a rise less than 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$ [28], or 2) a respiratory exchange ratio greater than 1.1 and a heart rate within one SD of agepredicted maximum. All subjects met one or both of these criteria during the first test.

Maximum strength (1 RM) was assessed for five exercises: parallel squat, bench press, one arm dumbbell row, bent-arm pullover, and latissimus dorsi pulldown. All one-repetition maximums were assessed using free weights following the procedure outlined by Stone and O'Bryant[26]. Briefly, maximum strength measures consisted of a warm-up with light weights followed by incremental increases in single attempts until failure, the last completed single was taken as the 1 RM. Reliability in our laboratory for 1 RM measures has been consistently $r \geq 0.9$.

The physiological responses to exercise were measured before, during, and after the 27-min bouts of weight training exercise and treadmill exercise. To facilitate the matching of $\dot{V}O_2$, the weight training session always preceded the treadmill session, and the sessions were separated by a minimum of 5 d. The subjects underwent 30 min of supine rest in a comfortable environment to ensure that a resting metabolic state existed before exercise. Following this 30-min rest period, three separate 5-min resting expired air samples were collected from each subject. These samples were used to establish a resting (baseline) metabolic rate. After rest each subject performed the 27-min bout of exercise during which expired air samples were collected continuously. Upon termination of exercise, each subject resumed the supine resting position and expired air was collected continuously for first 30 min into recovery. Between 30 and 60 min of recovery, expired air was collected for 5 min during every other 5-min interval. For the last 30 min of recovery, expired air was collected for 15 min during every other 15-min interval (seeFig. 1). All expired air samples were collected in meteorological balloons and analyzed using the OM-11 oxygen analyzer and LB-2 carbon dioxide analyzer described above. Gas volumes were measured using a S-301 Pneumoscan spirometer (K. L. Engineering Co., Sylman, CA), and gas temperature was measured using a telethermometer. Meteorological balloons were used for gas collection because of the low resting and recovery ventilations and to facilitate relocation for laboratory analysis. Heart rates were monitored during all gas collection times. Blood samples were taken via venipuncture immediately before and immediately after exercise for determination of lactate levels using the Sigma enzymatic method 826-UV (Sigma Chemical Co., St. Louis, MO). Ratings of perceived exertion were measured at each 4-min interval during exercise using the scale described by Borg[5].

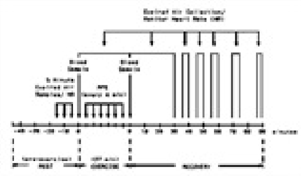

Figure 1-Testing schematic

The weight training session consisted of performing two circuits of eight exercises: parallel squat, bench press, Roman chair sit-ups, one arm dumbbell row, bent-arm pull-over, pull-ups, back hyperextension, and the latissimus dorsi pulldown. The equipment consisted of standard Olympic barbells, dumbbells, benches, and lat-pulldown machine. All exercises were performed at 60% of each subject's one-repetition maximum, except for sit-ups (25 repetitions), pull-ups (10 repetitions), and back hyperextensions (10 repetitions) where body weight served as the resistance. Each exercise was performed for as many repetitions as possible (except for the three described above) during a 45-s exercise period which was followed by 60 s of rest. Typically 8-12 repetitions were completed per set; sets were not typically performed to failure. The volume load (repetitions × mass lifted) ranged between 3000 and 6000 kg. Circuit weight training was chosen as the mode of resistance training because it is a commonly used method of effecting changes in various aspects of “fitness,” such as body composition including decreases in percent body fat and loses in total fat[12,26].

The treadmill session consisted of walking or jogging on the treadmill at a pace that elicited the same level of $\dot{V}O_2$ as each subject's average $\dot{V}O_2$ during the weight training session (approximately 45% of $\dot{V}O_{2max}$). The appropriate treadmill speed was extrapolated from the results of the maximal treadmill test. The treadmill speed necessary to elicit a matched rate of $\dot{V}O_2$ was between 3.5 and 5.0 mph.

The pre-exercise data were analyzed using a 2 × 3 (Treatment × Time) ANOVA with repeated measures. All other data were analyzed using paired*t*-tests. The alpha level was set at 0.05. A Bonferroni adjustment was used to control for alpha level inflation.

RESULTS

The three mean resting pre-exercise $\dot{V}O_2$ samples were not significantly different for either weight training or treadmill; therefore, the average of the three values was used as a resting baseline. In addition, the resting baselines for weight training and treadmill exercise were not significantly different (Table 2).

Variable	Mode of Exercise: Weight Training Exercise	Mode of Exercise: Treadmill Exercise	t Value
Resting $\dot{V}O_2$ (L·min^{-1})	0.295 (0.192)	0.309 (0.018)	−0.55
Exercise $\dot{V}O_2$ (L·min^{-1})	1.582 (0.084)	1.548 (0.073)	0.30
Total oxygen consumed during 30 min of recovery (L)	19.0	12.7	5.04*
$\dot{V}O_2$ at 30 min (L·min^{-1}) into recovery	0.414 (0.016)	0.351 (0.027)	1.97
$\dot{V}O_2$ at 60 min (L·min^{-1}) into recovery	0.321 (0.020)	0.294 (0.025)	0.86
$\dot{V}O_2$ at 90 min (L·min^{-1}) into recovery	0.328 (0.019)	0.298 (0.025)	0.93

*p < .05.

TABLE 2

The mean (± SEM) rates of $\dot{V}O_2$ during exercise (rest periods + exercise) are presented in Table 2. $\dot{V}O_2$ during weight training and treadmill exercise was 1.58 and 1.55 L·min^{-1} which was 44.3 and 43.4% of treadmill determined $\dot{V}O_{2max}$, respectively. There was no significant difference between the rates of $\dot{V}O_2$ during each mode of exercise; therefore, we assumed that the rates of $\dot{V}O_2$ were matched. The corresponding energy expenditures were 7.9 and 7.7 kcal·min^{-1} during the weight training and treadmill exercise, respectively. As illustrated inTable 3, weight training elicited significantly greater heart rate, ventilation, respiratory exchange ratio, lactate concentration, and rating of perceived exertion than treadmill exercise, even though the $\dot{V}O_2$ was equal. Average heart rate during exercise was 70.4 and 55.3% of treadmill determined heart rate maximum for weight training and treadmill exercise, respectively.

Variable	Mode of Exercise: Weight Training Exercise	Mode of Exercise: Treadmill Exercise	t Value
Heart rate (beats·min^{-1})	146.0 (4.0)	110.0 (3.0)	8.00*
Ventilation (L·min^{-1})	54.7 (3.3)	37.3 (1.9)	4.51*
Respiratory exchange ratio	0.92 (0.01)	0.77 (0.01)	8.70*
Blood lactate (Mmol·L^{-1})	9.5 (0.6)	0.8 (0.2)	12.77*
Rating of perceived exertion	12.8 (0.3)	8.6 (0.4)	5.82*

*P < .05.

TABLE 3

Mean (± SEM) total oxygen consumption during the first 30 min of recovery and $\dot{V}O_2$ at minute 30, 60, and 90 after exercise are presented in Table 2. Total oxygen consumed during the first 30 min after weight training exercise (19.0 L) was significantly($P < 0.05$) greater than after treadmill exercise (12.7 L). If adjusted for the resting $\dot{V}O_2$, this reflects almost a three-fold greater elevated postexercise $\dot{V}O_2$ following weight training compared with that after treadmill exercise. $\dot{V}O_2$ values at 30, 60, and 90 min were not significantly different between the two activities. Compared with baseline values, $\dot{V}O_2$ for the treadmill recovery was not significantly different at 30, 60, or 90 min; however, the weight training recovery $\dot{V}O_2$ was significantly elevated at 30 and 90 min.

DISCUSSION

The results of this study indicate that more energy can be required for recovery from weight training than typical steady-state exercise when the exercise sessions are matched for duration and oxygen consumption. This suggests that weight training exercise increases the energy required for recovery compared with low intensity aerobic exercise, agreeing with the observations of other researchers [6,11,24]. The reasons for this difference are not completely understood.

One possibility concerns the intensity of exercise. Low intensity exercise(30-60% of max $\dot{V}O_2$), such as that used in the present study, generally produces a relatively small total recovery energy consumption[21]. Increasing the duration of low intensity exercise(i.e., more total work) appears to result in linear increases in total recovery energy [2,3,21]. However, increasing the intensity of exercise (i.e., power output) may increase recovery energy consumption exponentially [3,21]. Thus, one possible factor contributing to the difference, in total energy consumed among types of exercise during recovery may be related to the exercise intensity.

A factor related to exercise intensity is the size of the O_2 deficit. Moderate correlations have been established between the O_2 deficit and recovery $\dot{V}O_2$ [4,16]. Oxygen uptake may not account for all the energy required during non-steady-state intermittent anaerobic exercise. Although in the present study the two types of exercise were equated for oxygen consumption and duration, they were not equated for ATP consumption. Thus, it is possible that intermittent anaerobic exercise results in a relatively large oxygen deficit which could influence the recovery $\dot{V}O_2$.

Another possibility for the differences in recovery energy relates to changes in homeostasis resulting from the physiological response to exercise. Factors affecting postexercise recovery include elevated body temperature, additional cardiorespiratory work, phosphogen resynthesis, resynthesis of glycogen from lactate (≤ 20% of the lactate produced), resaturation of tissue water, resaturation of venous blood, resaturation of blood in the skeletal muscle, resaturation of myoglobin, redistribution of ions within tissue compartments, tissue repair, and residual effects of hormones[8-10,14,15,29]. Anaerobic exercise, particularly resistance training, can disturb homeostasis to a greater degree than steady-state aerobic exercise[17,27]. In the present study a greater homeostatic disturbance was indicated by the greater exercise ventilation, heart rate, and lactate concentrations resulting from the weight training session compared with those in the treadmill session.

In isolated muscle in which nervous and hormonal influences were removed, recovery from a series of maximum tetanic contractions indicated that the largest total recovery oxygen consumption possible is ≤ 4.0 L·20 kg^{-1} of muscle [30]. Assuming, in man, that during exercise 20 kg of muscle can be activated, then recovery requiring more than 4.0 L of oxygen could not be accounted for as a result of exercise energy demands alone [30]. This suggests that the increased recovery oxygen consumption noted with high intensity exercise results from factors in addition to energy repletion. While many factors contribute to recovery from weight training exercise, two factors in particular may be related to the increased energy consumption relative to those observed as a result of typical aerobic exercise [30]. First, studies of weight training exercise indicate that hormonal perturbations, particularly for catecholamines, cortisol, and growth hormone, can be substantial[13,19,20] especially if the repetitions per set are high (>5) and the rest periods between sets are ≤ 1 min[18]. Residual effects of hormones could have a major effect on recovery energy consumption as a result of weight training exercise. Second, it is also possible that tissue damage and the stimulus for tissue hypertrophy resulting from weight training may be sufficient to contribute to the increased total energy required to recover.

The use of resistance training for body weight management is controversial[21]. Although weight training can elevate recovery energy consumption beyond that of typical aerobic exercise, it may not be substantial enough to significantly alter body mass or composition. In the present study, approximately 95 kcal were consumed in 30 min of recovery from weight training exercise and 64 kcal from treadmill exercise. Neither of these values is likely to make a substantial impact on body mass even if training takes place several times per week. However, the weight training protocol used in this study resulted in neither a high relative intensity of training (≤ 60%) nor a high volume of work (volume load < 6000 kg).

Volume of weight training (i.e., total work accomplished) may be an important factor influencing recovery from weight training [21]. The accumulative effect of higher volumes of weight training on recovery may be sufficient to affect body mass and composition.

In summary, the results of this study indicate that weight training can produce a larger recovery oxygen (energy) consumption than steady-state aerobic exercise (walking 3-5 $m \cdot h^{-1}$). This effect likely results from the higher intensity of weight training exercise and from physiological responses resulting from the exercise which persist into recovery.

The authors wish to thank Dr. Hugh Welch for his assistance (and patience) in the preparation of this manuscript. We also wish to thank Tim Smith and Kevin Allran for their assistance in data collection.

Current address for Mitchell A. Collins: Department of Health and Physical Education, Kennesaw State College, Marietta, GA 30061.

Address for correspondence: Dr. Michael Stone, Department of Health, Leisure, and Exercise Science, Appalachian State University, Boone, NC 28608

REFERENCES

1. Åstrand, P. O. and K. Rodahl. *Textbook of Work Physiology*. New York: McGraw-Hill, 1970, pp. 343-372.
2. Bahr, R., J. Ingnes, O. Vaage, O. M. Sejersted, and E. A. Newsholme. Effect of duration of exercise on excess postexercise oxygen consumption. *J. Appl. Physiol.* 62:485-490, 1987.
3. Bahr, R. and O. M. Sejersted. Effect of intensity of exercise on excess postexercise oxygen consumption. *Metabolism* 40:836-841, 1991.
4. Berg, W. E. Individual differences in respiratory gas exchange during recovery from moderate exercise. *Am. J. Physiol.* 149:507-530, 1947.
5. Borg, G. Perceived exertion as an indicator of somatic stress. *Scand J. Rehab. Med.* 2:92-98, 1970.
6. Burhus, K. A., J. L. Lettunich, M. L. Casey, and J. H. Wilmore. The effects of two different types of resistance exercise on postexercise oxygen consumption. *Med. Sci. Sports Exerc.* 24:S76, 1992.
7. Brehm, G. A. and B. Gutin. Recovery energy expenditure for steady state exercise in runners and nonexercisers. *Med. Sci. Sports Exerc.* 18:205-210, 1986.
8. Brooks, G. A., K. E. Brauner, and R. G. Cassens. Glycogen synthesis and metabolism of lactic acid after exercise. *Am. J. Physiol.* 224:1162-1186, 1973,.
9. Brooks, G. A. K. J. Kittleman, J. A. Faulkner, and R. E. Beyer. Temperature, skeletal muscle mitochondrial functions and oxygen debt.*Am. J. Physiol.* 220:1053-1068, 1971.
10. Claremont, A. D., F. Nagle, W. D. Reddan, and G. A. Brooks. Comparison of metabolic, temperature, heart rate and ventilatory responses to exercise at extreme ambient temperatures (0°C and 35°C).*Med. Sci. Sports* 7:150-154, 1975.
11. Elliot, D. L., L. Goldberg, and K. S. Kuehl. Effect of resistance training on excess post-exercise oxygen consumption. *J. Appl. Sports Sci. Res.* 6:77-81, 1992.
12. Fleck, S. J. and W. J. Kraemer. *Designing Resistance Training Programs*, Champaign, IL: Human Kinetics, 1987.
13. Fry, A. C., W. J. Kraemer, M. H. Stone, et al. Endocrine responses to over-reaching before and after one year of weightlifting training. *Can. J. Appl. Physiol.* 19:400-410, 1994.
14. Gaesser, G. A. and G. A. Brooks. Metabolic basis of excess post-exercise oxygen consumption: a review. *Med. Sci. Sports Exerc.* 16: 29-43, 1984.
15. Gladden, L. B., W. Stainsby, and B. MacIntosh. Norepinephrine increase canine skeletal muscle $\dot{V}O_2$ during recovery. *Med. Sci. Sports Exerc.* 14:471-476, 1982.
16. Henry, F. M. Aerobic oxygen consumption and alactic debt in muscular work. *J. Appl. Physiol.* 3:427-450, 1957.
17. Kindermann, W., A. Schnabel, W. M. Schmitt, et al. Catecholamines, growth hormone, cortisol, insulin and sex hormones in anaerobic and aerobic exercise. *Eur. J. Appl. Physiol.* 49:389-399, 1982.
18. Kraemer, W. J., L. Marchitelli, D. McCurry, et al. Hormonal and growth factor responses to heavy resistance exercise. *J. Appl. Physiol.* 69:1442-1450, 1990.
19. Kraemer, W. J., A. C. Fry, B. J. Warren, et al. Acute hormonal responses in elite junior weightlifters. *Int. J. Sports Med.* 13:103-109, 1992.
20. McMillan, J., M. H. Stone, J. Sartain, et al. The 20-hr hormonal response to a single session of weight training. *J. Strength Cond. Res.* 7:9-21, 1993.

21. Melby, C. L., C. Scholl, G. Edwards, and R. Bullough. Effect of acute resistance exercise on postexercise energy expenditure and resting metabolic rate. *J. Appl. Physiol.* 75:1847-1853, 1993.
22. Melby, C. L., T. Ticknell, and W. D. Schmidt. Energy expenditure following a bout of nonsteady state resistance exercise. *J. Sports Med. Phys. Fitness* 32:128-135, 1992.
23. Murphy, E. and R. Schwarzkopf. Effects of standard set and circuit weight training on excess post-exercise oxygen consumption.*J. Appl. Sport Sci. Res.* 6:88-91, 1992.
24. Scholl, C. G., R. C. Bullough, and C. L. Melby. Effect of different modes on postexercise energy expenditure and substrate utilization. *Med. Sci. Sports Exerc.* 25:532, 1993.
25. Sedlock, D. A., J. A. Fissinger, and C. L. Melby. Effect of exercise intensity and duration on postexercise energy expenditure.*Med. Sci. Sports Exerc.* 21:626-666, 1989.
26. Stone, M. and H. O'Bryant. *Weight Training: A Scientific Approach* (rev. ed).Minneapolis: Burgess International Group, Inc., 1987.
27. Stone, M. H., S. J. Fleck, W. J. Kraemer, and N. T. Triplett. Health and performance related adaptations to resistive training.*Sports Med.* 11:210-231, 1991.
28. Taylor, H. L., E. Buskirk, A. and A. Henshel. Maximal oxygen intake as an objective measure of cardiorespiratory performance.*J. Appl. Physiol.* 8:73-80, 1955.
29. Welch, H. G., J. A. Falkner, J. K. Barclay, and G. A. Brooks. Ventilatory response during recovery from muscular work and its relation with O_2 debt. *Med. Sci. Sports* 2:15-19, 1970.
30. Welch, H. G. and W. N. Stainsby. Oxygen debt in contracting dog skeletal muscle *in situ*. *Respir. Physiol.* 3:229-242, 1967.
Keywords:
RESISTANCE EXERCISE; WEIGHT TRAINING; OXYGEN UPTAKE; OXYGEN DEBT