

Concurrent resistance and endurance training influence basal metabolic rate in nondieting individuals

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Dolezal, Brett A., and Jeffrey A. Potteiger. Concurrent resistance and endurance training influence basal metabolic rate in nondieting individuals. *J. Appl. Physiol.* 85(2): 695–700, 1998.—Thirty physically active healthy men (20.1 ± 1.6 yr) were randomly assigned to participate for 10 wk in one of the following training groups: endurance trained (ET; 3 days/wk jogging and/or running), resistance trained (RT; 3 days/wk resistance training), or combined endurance and resistance trained (CT). Before and after training, basal metabolic rate (BMR), percent body fat (BF), maximal aerobic power, and one-repetition maximum for bench press and parallel squat were determined for each subject. Urinary urea nitrogen was determined pre-, mid-, and posttraining. BMR increased significantly from pre- to posttraining for RT ($7,613 \pm 968$ to $8,090 \pm 951$ kJ/day) and CT ($7,455 \pm 964$ to $7,802 \pm 981$ kJ/day) but not for ET ($7,231 \pm 554$ to $7,029 \pm 666$ kJ/day). BF for CT (12.2 ± 3.5 to $8.7 \pm 1.7\%$) was significantly reduced compared with RT (15.4 ± 2.7 to $14.0 \pm 2.7\%$) and ET (11.8 ± 2.9 to $9.5 \pm 1.7\%$). Maximal aerobic power increased significantly for ET (13%) but not RT (–0.2%) or CT (7%), whereas the improvements in one-repetition maximum bench press and parallel squat were greater in RT (24 and 23%, respectively) compared with CT (19 and 12%, respectively). Urinary urea nitrogen loss was greater in ET (14.6 ± 0.9 g/24 h) than in RT (11.7 ± 1.0 g/24 h) and CT (11.5 ± 1.0 g/24 h) at the end of 10 wk of training. These data indicate that, although RT alone will increase BMR and muscular strength, and ET alone will increase aerobic power and decrease BF, CT will provide all of these benefits but to a lesser magnitude than RT and ET after 10 wk of training.

metabolism; exercise; energy expenditure; urinary urea nitrogen; weight loss

WHEN ENERGY EXPENDITURE exceeds energy intake, a negative energy balance exists and body mass is reduced. The energy expenditure side of the energy balance equation, especially those factors affecting a person's basal metabolic rate (BMR), has been given considerable attention in the literature. Given that BMR represents the largest percentage of an individual's daily energy expenditure (~60–75% of total energy expenditure), many researchers have been interested in identifying interventions that may potentiate an increase in BMR (26) and resting metabolic rate (RMR) to facilitate weight loss (14). Typically, endurance exercise has been used for altering body composition because of its ability to increase energy expenditure and fat utilization. However, the results of previous studies examining the effects of endurance training on BMR and RMR are equivocal. The results of some investigations have shown increases in RMR (1, 4, 30), whereas the results of other studies indicate that BMR is unaltered (26) or RMR is decreased slightly (28) by endurance training.

Many factors have been shown to influence metabolic rate. The strongest correlation exists between an individual's fat-free mass (FFM) and BMR. It has been proposed that increases in lean body mass will increase BMR, thus increasing total energy expenditure (19). Fat mass (FM) and total body mass (TM) are generally reduced with endurance exercise; however, this reduction contributes minimally to gains in lean body mass (29). Much of the research centering on increases in lean body mass have used resistance training as the exercise modality. The potential influence on BMR and body composition that resistance and endurance exercise may offer to individuals warrants further investigation.

Recently, concurrent resistance and endurance exercise has received much attention as a form of training. Many of the past investigations have examined similar variables including maximal aerobic power ($\dot{V}O_{2\max}$), isotonic and isokinetic strength, and body composition. Moreover, they have demonstrated that the impact of concurrent training appears to be more detrimental to potential strength gains (5, 8, 9, 13, 18, 23) and not aerobic power (2, 5, 8, 9, 13, 15, 16, 22, 23). Additionally, after concurrent resistance and endurance training, investigators have noted positive changes in body composition including decreases in FM and body fat (BF) percent and increases in FFM. To our knowledge, no studies exist that have addressed the influence of concurrent resistance and endurance training on BMR in nondieting individuals. Many individuals participate in concurrent resistance- and endurance-training programs, yet limited information is known about the effect of this type of training on metabolic rate. Therefore, the purpose of this study was to examine the influence of concurrent resistance and endurance training on BMR, body composition, $\dot{V}O_{2\max}$, muscular strength, and urinary urea nitrogen excretion.

METHODS

Subjects. Thirty physically active men (20.1 ± 1.6 yr) participated in the study. All methods and procedures were approved by the University Committee for Human Experimentation. Subjects read and signed the subject consent form and medical history questionnaire before beginning the study. Inclusionary criteria were 1) training for at least 3 days/wk for at least 1 yr, 2) $\dot{V}O_{2\max} \geq 40$ ml·kg⁻¹·min⁻¹, and 3) BF between 9 and 20%. Subjects were randomly assigned to one of three experimental groups: an endurance-trained group (ET, $n = 10$), a resistance-trained group (RT, $n = 10$), and a combined endurance- and resistance-trained group (CT, $n = 10$). During the initial visit to the laboratory, subjects were familiarized with the equipment and experimental procedures. Subjects then completed the following tests in a 24-h period before and after the 10-wk training period.

Table 1. Basal metabolic rate before and after 10 wk of training

Basal Metabolic Rate	Pretraining			Posttraining		
	Resistance	Endurance	Concurrent	Resistance	Endurance	Concurrent
kJ/day	7,613.3 ± 968.7	7,231.2 ± 554.1	7,454.9 ± 964.2	8,090.8 ± 951.2*†	7,029.7 ± 666.4*	7,801.8 ± 980.6*†
kJ · kg TM ⁻¹ · h ⁻¹	4.12 ± 0.21	4.07 ± 0.19	4.28 ± 0.32	4.28 ± 0.24*	4.10 ± 0.21	4.44 ± 0.33*
kJ · kg FFM ⁻¹ · h ⁻¹	4.87 ± 0.19	4.62 ± 0.21	4.88 ± 0.40	5.01 ± 0.26†	4.53 ± 0.24	4.87 ± 0.37

Results are means ± SD. TM, total body mass; FFM, fat-free mass. *Significantly different from pretraining for same group, $P < 0.05$; †significantly different from endurance, $P < 0.05$.

BMR. Indirect calorimetry was used to measure BMR. All subjects had 8 h of sleep, did not perform any exercise for 48 h before each session, and did not eat or consume any liquids, except water, for 12 h before testing. Each subject was transported by motor vehicle to the testing site to ensure minimal activity before BMR determination. All BMR measurements were performed between 0600 and 0800.

After entering the laboratory, subjects rested in a supine position for 30 min. A Hans Rudolph flow-by face mask (Kansas City, MO) was positioned on the subject. Oxygen uptake was monitored continuously for 20 min by a Sensor-Medics 2900 Metabolic Measurement cart. The system was calibrated before testing by using gases of known concentration, whereas the flowmeter was calibrated by using a 3-liter syringe. During the test, the room was darkened, and noise was kept to a minimum. The subjects were instructed to remain awake, quiet, and motionless before and throughout the entire 20-min period. The average of the last 15 min of the measurement period was used as the measure of BMR.

Body composition analysis. Hydrostatic weighing was performed to determine body density. To determine TM, the subjects, wearing only a swimsuit, were weighed on a calibrated digital scale. Five measures of underwater weight were collected with the average of the last three measures used as the mean value for analysis. Residual lung volume was measured by using a percentage of total lung capacity (21). The Siri equation (25) was used to calculate percent BF, with FFM and FM calculated accordingly.

$\dot{V}O_{2max}$. Subjects completed a graded exercise test to exhaustion on a motor-driven treadmill. The test began with a 4-min warm-up period followed by an increase of speed or grade every 2 min until a treadmill grade of 10% was achieved. Thereafter, only the treadmill speed was increased until each subject reached volitional exhaustion. Expired air was measured continuously for oxygen and carbon dioxide concentrations by using a calibrated SensorMedics 2900 Metabolic Measurement cart. $\dot{V}O_{2max}$ was defined as that point at which 1) the oxygen consumption reached a plateau (change of <2.0 ml · kg⁻¹ · min⁻¹) with an increase in workload and 2) the respiratory exchange ratio was ≥ 1.10 .

Determination of maximal strength. Subjects underwent strength testing for the determination of the one-repetition maximum (1-RM) by using Olympic-style free weights. Each subject was tested for 1-RM on the bench press and parallel squat by using previously described methods (27).

Urinary urea nitrogen analysis. During pre-, mid-, and posttesting, and at least 24 h after their last exercise bout, each subject was required to make a 24-h urine collection and to preserve the collections in a refrigerator until delivery to the laboratory. Urine volume was recorded, and aliquots of each day's urine sample were stored at -70°C until analysis for urea nitrogen with the use of Sigma Chemical kit no. 640B (St. Louis, MO). All samples were analyzed in duplicate by using standard spectrophotometric techniques, with the average of the duplicate values used in statistical analysis.

Three-day nutritional intake. Each subject completed a 3-day dietary diary before testing, during week 5, and during week 10 of the training period. Subjects were provided with examples of food samples, written guidelines, and a record booklet for keeping track of food intake. Recording days were randomly assigned; however, the recalls always included 1 weekend day and 2 weekdays. The Nutritionist III software program (N-Squared Computing, Salem, OR) was used to analyze dietary composition for daily total caloric intake and the percentage of energy nutrients.

Training program. After completing all pretesting, each subject participated for 10 wk in ET, RT, or CT. Subjects trained 3 days/wk on alternate days. Individual training programs were designed to produce marked improvements in either strength or aerobic power. All training was periodically monitored by an investigator.

Each subject in the ET group participated in a jogging and/or running program. Subjects gradually increased exercise duration and intensity so that a training goal was reached every 2 wk. At weeks 1–2, subjects exercised for 25 min at 65% of age-derived maximum heart rate (HR_{max}), at weeks 3–6 for 35 min at 65–75% of HR_{max} , and at weeks 7–10 for 40 min at 75–85% of HR_{max} . A telemetric heart-rate monitor (Polar) was available to all subjects to accurately determine exercise intensity. Subjects were instructed to palpate the radial artery for determination of heart rate when telemetry units were unavailable.

Subjects in RT performed resistance training using a combination of Olympic free weights and Universal machines. The program was divided into upper-body exercises (performed on Monday), lower-body exercises (performed on Wednesday), and both upper- and lower-body exercises (performed on Friday). The resistance-training program involved

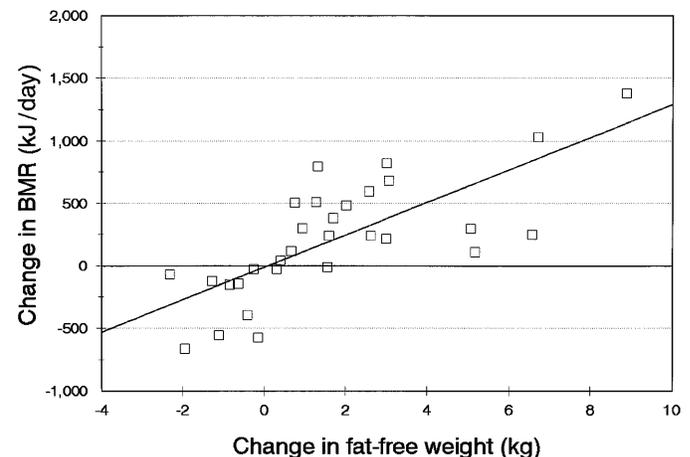


Fig. 1. Relationship shown between change in fat-free mass and change in basal metabolic rate (BMR) after 10 wk of resistance, endurance, or concurrent training for $n = 30$ subjects.

Table 2. Body composition values before and after 10 wk of training

	Pretraining			Posttraining		
	Resistance	Endurance	Concurrent	Resistance	Endurance	Concurrent
TM, kg	76.9 ± 7.4	74.0 ± 5.2	72.8 ± 7.6	78.5 ± 7.4	71.5 ± 5.0*‡	73.4 ± 9.4
BF, %	15.4 ± 2.7	11.8 ± 2.9‡	12.2 ± 3.5	14.0 ± 2.7*	9.5 ± 1.7*	8.7 ± 1.7*‡
FFM, kg	65.0 ± 6.7	65.2 ± 2.9	63.7 ± 6.9	67.3 ± 7.1*†	64.6 ± 3.8	66.9 ± 7.8*†
FM, kg	11.9 ± 2.3	8.8 ± 2.7	9.1 ± 3.7	11.1 ± 2.1	6.8 ± 1.6*	6.5 ± 1.9*‡

Results are means ± SD. BF, body fat; FM, fat mass. *Significantly different from pretraining for same group, $P < 0.05$; †significantly different from endurance, $P < 0.05$; ‡significantly different from resistance, $P < 0.05$.

all major muscle groups and included the following exercises: bench press, lat pulldown, shoulder press, bicep curl, tricep pushdown, back squat, leg extension, leg curl, clean pulls, incline dumbbell press, leg press, seated row, and upright row. During the first 2 wk of the program, subjects performed 10–15 repetitions per set, with three sets per exercise. The resistance was established so that the subject became fatigued at 10–15 repetitions. Fatigue was defined as the point at which the exercise could not be executed correctly through its full range of motion. During the final 8 wk, exercises were performed with the resistance established for each set so that failure to lift the weight occurred at 10–12 repetitions on the first set, 8–10 repetitions on the second set, and 4–8 repetitions on the third set.

Subjects in the CT group participated in a summation of the exact same endurance- and resistance-training programs outlined above. For CT, endurance and resistance training were performed on the same days of the week, with resistance training always completed first.

Statistical analysis. The magnitude of changes for each dependent variable produced by training in the three groups was compared by using a one-way ANOVA on the difference (posttest minus pretest) scores. Post hoc Tukey honestly significant difference comparisons were performed when significant F -ratios were found. Urinary urea nitrogen and dietary intake were analyzed by a repeated-measures ANOVA. Within-group differences from baseline to week 10 were analyzed for all variables by using Student's t -test. A Pearson correlational analysis between changes in body composition and RMR was performed. Significance was set at $P \leq 0.05$. All values are reported as means ± SD.

RESULTS

The BMR results for the pre- and posttraining measurement periods are presented in Table 1. Pretraining values for BMR (in kJ/day, $\text{kJ} \cdot \text{kg} \text{ TM}^{-1} \cdot \text{h}^{-1}$, and $\text{kJ} \cdot \text{kg} \text{ FFM}^{-1} \cdot \text{h}^{-1}$) were not significantly different among groups. The RT and CT groups showed significant increases in BMR (expressed in kJ/day and $\text{kJ} \cdot \text{kg} \text{ TM}^{-1} \cdot \text{h}^{-1}$) from baseline to week 10, compared with ET, whereas the ET group significantly decreased in BMR

(expressed in kJ/day) from baseline to week 10. A significant correlation was observed between the changes in BMR (expressed in kJ/day) and FFM and is presented in Fig. 1 ($r = 0.74$, $P < 0.01$).

The body composition results for the pre- and post-training measurements are presented in Table 2. All groups showed significant decreases in BF from baseline to week 10. Comparison among groups showed a significantly greater decrease for BF and FM for the CT group ($-3.5 \pm 1.8\%$ and -2.6 ± 1.8 kg, respectively) than for the RT and ET groups (RT: $-1.4 \pm 0.1\%$ and -0.8 ± 0.2 kg, ET: $-2.3 \pm 1.2\%$ and -2.0 ± 1.1 kg, respectively). Both the ET and CT groups showed significant decreases in FM from baseline to week 10. The RT and CT groups significantly increased in FFM from baseline to week 10 (by 2.7 ± 0.4 kg and 3.2 ± 0.9 kg, respectively) and were significantly higher compared with the ET group (-1.4 ± 0.9 kg) at week 10.

The $\text{VO}_{2\text{max}}$ and 1-RM results for the pre- and post-training measurement periods are presented in Table 3. The ET group significantly improved in $\text{VO}_{2\text{max}}$ from baseline to week 10 (by 13%), and, although $\text{VO}_{2\text{max}}$ increased in the CT group (by 7%) after training, this value was not statistically significant from baseline. Both the RT and CT groups significantly increased strength from baseline to week 10. For the 1-RM squat, significant increases in both the RT (23%) and CT (19%) groups occurred, whereas the ET group did not change (-0.7%). For the 1-RM bench press, the RT group significantly increased the most (24%), and the CT group improved to a lesser degree (12%), whereas the ET group did not change (-0.4%).

Figure 2 illustrates the urinary urea nitrogen for the pre-, mid-, and posttraining measurements in each group. No significant differences in RT and CT groups from pre- to mid- and from mid- to posttraining were observed. The ET group did show a significant increase in urinary urea nitrogen from pre- to mid- and from

Table 3. One-repetition maximum and maximal aerobic power values before and after 10 wk of training

	Pretraining			Posttraining		
	Resistance	Endurance	Concurrent	Resistance	Endurance	Concurrent
1-RM bench press, kg	76.1 ± 15.7	67.1 ± 11.8	83.2 ± 22.0	94.3 ± 15.3*†§	66.8 ± 12.0	92.9 ± 21.5*†
1-RM squat, kg	94.4 ± 22.3	84.6 ± 10.2	100.2 ± 22.8	116.1 ± 22.4*†	84.0 ± 11.2	118.9 ± 21.0*†
$\dot{\text{V}}\text{O}_{2\text{max}}$, $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$	50.4 ± 4.0	50.7 ± 5.8	52.3 ± 4.4	50.5 ± 4.5	57.1 ± 5.0*‡	55.8 ± 5.2

Results are means ± SD. 1-RM, one-repetition maximum; $\dot{\text{V}}\text{O}_{2\text{max}}$, maximal aerobic power. *Significantly different from pretraining for same group, $P < 0.05$; †significantly different from endurance, $P < 0.05$; ‡significantly different from resistance, $P < 0.05$; §significantly different from concurrent, $P < 0.05$.

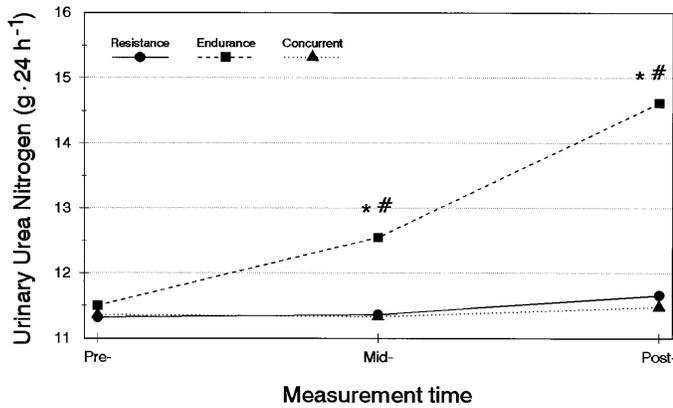


Fig. 2. Urinary urea nitrogen values pre-, mid-, and posttraining. Subjects participated in resistance, endurance, or concurrent exercise training for 10 wk. *Significantly different from pretraining ($P < 0.001$); #significantly different from resistance- and concurrent-training groups ($P < 0.001$).

mid- to posttraining. Both the mid- and posttraining urinary urea nitrogen measurements for the ET group were significantly higher than for the RT and CT groups.

Results from the 3-day dietary diary are illustrated in Table 4. There were no significant changes in each group's normal dietary patterns among measurement periods (pre- to mid- and mid- to posttraining).

DISCUSSION

BMR and body composition. This study is believed to be the first to examine the influence of concurrent resistance and endurance training on BMR in individuals on an ad libitum diet. The results of this study indicate that absolute BMR (kJ/day) and BMR expressed as $\text{kJ} \cdot \text{kg} \text{ TM}^{-1} \cdot \text{h}^{-1}$ increased significantly over the 10-wk training period for RT and CT groups; however, the differences between the two groups were not significant. The ET group significantly decreased absolute BMR (kJ/day) over the 10-wk training period. Figure 3 represents the change values in BMR (kJ/day) among the groups.

Table 4. Nutritional intake before and after 10 wk of training

	Energy Intake, kJ/day	Carbohydrates, %	Fat, %	Protein, %
Pretraining				
Resistance	10,542.6 \pm 2,738.6	54.1 \pm 6.6	24.9 \pm 7.2	21.1 \pm 6.8
Endurance	11,750.9 \pm 767.3	59.9 \pm 7.3	21.4 \pm 2.2	18.5 \pm 7.3
Concurrent	11,619.9 \pm 2,237.3	58.2 \pm 7.5	24.2 \pm 7.7	17.7 \pm 4.3
Midtraining				
Resistance	10,856.6 \pm 2,719.6	54.0 \pm 7.5	25.5 \pm 7.1	20.3 \pm 6.3
Endurance	11,857.9 \pm 1,087.5	61.6 \pm 7.1	20.4 \pm 2.4	17.7 \pm 7.0
Concurrent	11,241.1 \pm 1,923.9	57.7 \pm 6.3	24.4 \pm 6.3	18.3 \pm 4.1
Posttraining				
Resistance	10,794.7 \pm 2,592.1	53.6 \pm 6.5	23.9 \pm 4.5	22.5 \pm 3.6
Endurance	11,946.8 \pm 1,113.7	61.0 \pm 6.9	19.8 \pm 2.7	19.1 \pm 5.4
Concurrent	11,660.5 \pm 1,893.2	58.3 \pm 5.6	23.4 \pm 5.5	18.3 \pm 3.1

Results are means \pm SD. No significant differences among or within the groups were found.

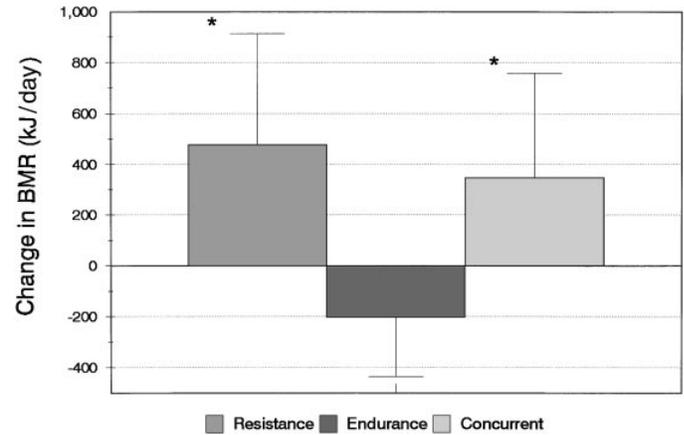


Fig. 3. Change in BMR (kJ/day) for resistance, endurance, and concurrent exercise training groups. *Significantly different from endurance-training group ($P < 0.001$).

We were only able to identify one study in which individuals were measured for RMR while concurrently training for 12 wk. Whatley et al. (30) concluded that a large volume of endurance exercise in combination with resistance training added to a very-low-energy diet may improve body mass and BF losses in obese females. Nonetheless, Whatley et al. were unable to ascertain that combined endurance and resistance training exerted a positive effect on RMR and preserved FFM. In our study, concurrently training for 10 wk induced favorable body mass changes as well as increases in BMR, both of which may aid in weight management.

A strong relationship was found between the changes in FFM and BMR during the 10 wk of training. When all three groups were collapsed together, a significant correlation existed between the changes in pre- to posttraining values for FFM and BMR ($r = 0.74$, $P < 0.01$). These findings are in agreement with reports that FFM has been shown to be the major intrinsic determinant of BMR (3, 26, 29). Pratley et al. (21) found that resistance training in healthy older men increased BMR, and this was accompanied by an increase in FFM. The intense, periodized resistance training completed by the RT and CT groups in our study most likely promoted skeletal muscle hypertrophy, which elevated BMR by increasing the total amount of metabolically active tissue (i.e., FFM). It has been demonstrated that, whereas the increase in BMR with resistance training can be accounted for by concomitant increases in FFM, elevations in BMR found with endurance training appear to be partially mediated by an increase in the rate of activity per kilogram of tissue (29). However, in this study, when BMR was normalized to FFM ($\text{kJ} \cdot \text{kg} \text{ FFM}^{-1} \cdot \text{h}^{-1}$), there were no significant improvements in BMR for any of the three groups, and in fact there was a slight, nonsignificant decrease found in the ET group. This finding is not consistent with many of the theories that have been proposed as to the mechanism of exercise-induced increases in BMR per FFM. Those theories include increases in the concentration of metabolic hormones (e.g., cortisol, catecholamines, and thyroid hormone), increased activity of various enzymatic

reactions and shuttle systems, increased substrate flux, repair of exercise-induced trauma, and increased protein synthesis (1, 19).

We speculate that the absolute increases in BMR (kJ/day) found in the RT and CT groups and the decrease in BMR found in the ET group may simply reflect gains and losses in FFM, respectively. Even though there was a nonsignificant decline in FFM for the ET group over the 10-wk study, we believe that the decline in BMR could still have been attributed to losses in FFM. This was evidenced by the ET group's elevation in urinary urea nitrogen over the 10-wk study (Fig. 2). Fluctuations in FFM can be followed by the measurement of changes in urinary urea nitrogen. Because urea is the major nitrogen-containing metabolic product of protein catabolism in humans, as FFM is degraded there is a release of nitrogen-derived ammonia that causes urinary urea nitrogen to become elevated (24). Although urinary urea nitrogen levels did not significantly increase after consecutive days of jogging, Kolkhorst et al. (14) noted that overall nitrogen balance decreased after exercise, inferring a greater breakdown of FFM. In a clinical study of recovering coronary artery bypass graft surgery patients, Shaw et al. (24) showed increases in urinary urea nitrogen accompanying the loss of FFM after the initial days of bed rest. Similarly, elevated urinary urea nitrogen levels in the ET group in our study were consistent with a nonsignificant loss of FFM; and we believe that this decrease in FFM could have partially explained the concomitant decrease in BMR.

With respect to other body compositional changes, all three groups decreased BF over the 10 wk of training, and only the ET and CT groups reduced FM. Melby et al. (17) speculated that strenuous resistive exercise could be beneficial in weight control, not only because of the direct caloric cost of the exercise and acute residual elevation of BMR, but also because of greater postexercise fat oxidation. Although our RT group did show a nonsignificant decrease in FM over the 10 wk, when endurance training was combined (the CT group), the drop in FM and BF became significant. This larger weight loss may have been due to a greater amount of work (e.g., resistance and endurance training compared with resistance training alone), and, similar to what Whatley et al. (30) hypothesized in their study, the additional energy cost of exercise may have been met by an increase in fat oxidation.

Muscular strength and aerobic power. The results of the present study and those of others (2, 5, 8–13, 15, 16, 18, 22, 23) indicate that concurrently training for strength and endurance induces increases in muscular strength and aerobic power. However, the increases in aerobic power and muscular strength of those subjects performing concurrent training were of lesser magnitude than those induced by endurance and resistance training alone, respectively. Additionally, performance of only endurance training did not increase muscular strength, whereas resistance training improved muscular strength but not aerobic power.

Whereas researchers have proposed that simultaneous training appears to compromise strength improvement more so than endurance improvement when both modes of training engage the same muscle groups (5, 8, 13, 18, 23), it was interesting to find that in this study the reverse was true. That is, the improvement in $\dot{V}O_{2\max}$ was compromised more than the improvements in lower-body strength for the CT group. The attenuated improvements found in $\dot{V}O_{2\max}$ of the CT group, when compared with endurance training alone, could be explained by interferences found in strength-training adaptations, which may include muscle fiber hypertrophy and increases in contractile proteins with associated decreases in capillary and mitochondrial volume densities (2, 9, 16, 22). Conversely, the theory that endurance training may impede strength development by promoting increases in capillary density, mitochondrial volume density, oxidative enzyme activity, and decreases in muscle fiber size (2, 9, 16, 22) was not consistent with our data.

In summary, the findings of this study show that 10 wk of concurrent resistance and endurance training have beneficial effects on energy expenditure and weight loss. Whereas single-mode training, such as endurance or resistance training, has been shown extensively to increase aerobic capacity and muscular strength, respectively, in this study concurrent training was shown to increase both of these traits together, although to a lesser magnitude. Moreover, whereas resistance training alone induced an increase in FFM with a concomitant increase in RMR, and endurance training alone induced losses in BF and FM, concurrent training shared all of these benefits, thereby providing for the most effective exercise program strategy when weight loss is desired.

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REFERENCES

1. **Ballor, D. L., and E. T. Poehlman.** Resting metabolic rate and coronary-heart-disease risk factors in aerobically and resistance-trained women. *Am. J. Clin. Nutr.* 56: 968–974, 1992.
2. **Bell, G. J., S. R. Petersen, J. Wessel, K. Bagnall, and H. A. Quinney.** Physiological adaptations to concurrent endurance training and low velocity resistance training. *Int. J. Sports Med.* 12: 384–390, 1991.
3. **Bogardus, C., S. Lillioja, E. Ravussin, W. Abbott, J. K. Zawadzki, A. Young, W. C. Knowler, R. Jacobowitz, and P. P. Moll.** Familial dependence of the resting metabolic rate. *N. Engl. J. Med.* 315: 96–100, 1986.
4. **Broeder, C. E., K. A. Burrhus, L. S. Svanevik, and J. H. Wilmore.** The effects of either high-intensity resistance or endurance training on resting metabolic rate. *Am. J. Clin. Nutr.* 55: 802–810, 1992.
5. **Dudley, G. A., and R. Djamil.** Incompatibility of endurance and strength training modes of exercise. *J. Appl. Physiol.* 59: 1446–1451, 1985.

6. **Dudley, G. A., and S. J. Fleck.** Strength and endurance training: are they mutually exclusive? *Sports Med.* 4: 79–85, 1987.
7. **Fleck, S. J., and W. J. Kraemer.** Resistance training: physiological responses and adaptations. *Physician Sportsmed.* 16: 108–124, 1988.
8. **Hennesy, L. C., and A. W. S. Watson.** The interference effects of training for strength and endurance simultaneously. *J. Strength Cond. Res.* 8: 12–19, 1994.
9. **Hickson, R. C.** Interference of strength development by simultaneously training for strength and endurance. *Eur. J. Appl. Physiol.* 45: 255–269, 1980.
10. **Hickson, R. C., B. A. Dvorak, E. M. Gorostiga, T. T. Kurowski, and C. Foster.** Potential for strength and endurance training to amplify endurance performance. *J. Appl. Physiol.* 65: 2285–2290, 1988.
11. **Hickson, R. C., M. A. Rosenkoetter, and M. M. Brown.** Strength training effects on aerobic power and short term endurance. *Med. Sci. Sports Exerc.* 12: 336–339, 1980.
12. **Hortobagyi, T., F. I. Katch, and P. F. LaChance.** Effects of simultaneous training for strength and endurance on upper and lower body strength and running performance. *J. Sports Med. Phys. Fitness* 31: 20–30, 1991.
13. **Hunter, G., R. Demment, and D. Miller.** Development of strength and maximum oxygen uptake during simultaneous training for strength and endurance. *J. Sports Med. Phys. Fitness* 27: 269–275, 1987.
14. **Kolkhorst, F. W., B. R. Londeree, and T. R. Thomas.** Effects of consecutive exercise days of jogging or cycling on the resting metabolic rate and nitrogen balance. *J. Sports Med. Phys. Fitness* 34: 343–350, 1994.
15. **Kraemer, W. J., J. F. Patton, S. E. Gordon, E. A. Haraman, M. R. Deschenes, K. Reynolds, R. U. Newton, N. T. Triplett, and J. E. Dziados.** Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J. Appl. Physiol.* 78: 976–989, 1995.
16. **McCarthy, J. P., J. C. Agre, B. K. Graf, M. A. Pozniak, and A. C. Vailas.** Compatibility of adaptive responses with combining strength and endurance training. *Med. Sci. Sports Exerc.* 27: 429–436, 1995.
17. **Melby, C., 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.
18. **Nelson, G. A., D. A. Arnell, S. F. Loy, L. J. Silvester, and R. K. Conlee.** Consequences of combining strength and endurance training regimens. *Phys. Ther.* 70: 287–294, 1990.
19. **Poehlman, E. T.** A review: exercise and its influence on resting energy metabolism in man. *Med. Sci. Sports Exerc.* 21: 515–525, 1989.
20. **Pollock, M. L., L. Garzarella, and J. E. Graves.** The measurement of body composition. In: *Physiological Assessment of Human Fitness*, edited by P. J. Maud and C. Foster. Champaign, IL: Human Kinetics, 1995, p. 167–204.
21. **Pratley, R., B. Nicklas, M. Rubin, J. Miller, A. Smith, M. Smith, B. Hurley, and A. Goldberg.** Strength training increases resting metabolic rate and norepinephrine levels in healthy 50- to 65-yr-old men. *J. Appl. Physiol.* 76: 133–137, 1994.
22. **Sale, D. G., I. Jacobs, J. D. MacDougall, and S. Garner.** Comparison of two regimens of concurrent strength and endurance training. *Med. Sci. Sports Exerc.* 22: 348–356, 1990.
23. **Sale, D. G., J. D. MacDougall, I. Jacobs, and S. Garner.** Interaction between concurrent strength and endurance training. *J. Appl. Physiol.* 68: 260–270, 1990.
24. **Shaw, D. K., D. T. Deutsch, P. M. Schall, and R. J. Bowling.** Physical activity and lean body mass loss following coronary artery bypass graft surgery. *J. Sports Med. Phys. Fitness* 31: 67–74, 1991.
25. **Siri, W. E.** Body composition from fluid spaces and density. In: *Techniques for Measuring Body Composition*, edited by J. Brozek and A. Henschel. Washington, DC: National Academy of Sciences, 1961, p. 223–244.
26. **Sjodin, A. M., A. H. Forslund, K. R. Westerterp, A. B. Andersson, J. M. Forslund, and L. M. Hambræus.** The influence of physical activity on BMR. *Med. Sci. Sports Exerc.* 28: 85–91, 1996.
27. **Stone, M. H., K. Pierce, R. Goosen, G. D. Wilson, D. Blessing, R. Rozenek, and J. Chromiak.** Heart rate and lactate levels during weight training exercise in trained and untrained men. *Physician Sportsmed.* 15: 97–105, 1987.
28. **Thompson, J. L., M. M. Manore, and J. R. Thomas.** Effects of diet and diet-plus-exercise programs on resting metabolic rate: a meta-analysis. *Int. J. Sport Nutr.* 6: 41–61, 1996.
29. **Weinsier, R. L., Y. Schutz, and D. Bracco.** Reexamination of the relationship of resting metabolic rate to fat-free mass and to the metabolically active components of fat-free mass in humans. *Am. J. Clin. Nutr.* 55: 790–794, 1992.
30. **Whatley, J. E., W. J. Gillespie, J. Honig, M. J. Walsh, A. L. Blackburn, and G. L. Blackburn.** Does the amount of endurance exercise in combination with weight training and a very-low-energy diet affect resting metabolic rate and body composition? *Am. J. Clin. Nutr.* 59: 1088–1092, 1994.