Effects of Resistance, Endurance, and Concurrent Exercise on Training Outcomes in Men

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ABSTRACT

GLOWACKI, S. P., S. E. MARTIN, A. MAURER, W. BAEK, J. S. GREEN, and S. F. CROUSE. Effects of Resistance, Endurance, and Concurrent Exercise on Training Outcomes in Men. Med. Sci. Sports Exerc., Vol. 36, No. 12, pp. 2119–2127, 2004. The specificity of training principle predicts that combining resistance and endurance training (concurrent training) could interfere with the maximum development of strength and endurance capacity that results from either type of training alone. Purpose: To determine whether endurance and resistance training performed concurrently produces different performance and physiologic responses compared with each type of training alone. Methods: Untrained male volunteers were randomly assigned to one of three groups: endurance training (ET, N = 12); resistance training (RT, N = 13); and concurrent training (CT, N = 16). The following measurements were made on all subjects before and after 12 wk of training: weight, percent body fat, peak oxygen consumption (VO\textsubscript{2peak}), isokinetic peak torque and average power produced during single-leg flexion and extension at 60 and 180°·s\textsuperscript{-1}, one-repetition maximum (1RM) leg press, 1RM bench press, vertical jump height, and calculated jump power. Results: Weight and lean body mass (LBM) increased significantly in the RT and CT groups (P < 0.05). Percent body fat was significantly decreased in the ET and CT groups. VO\textsubscript{2peak} was significantly improved only in the ET group. Peak torque during flexion and extension at 180°·s\textsuperscript{-1} increased in the RT group. Improvements in 1RM leg press and bench press were significant in all groups, but were significantly greater in the RT and CT compared to the ET group. Jump power improved significantly only in the RT group, and no group showed a significant change in vertical jump height. Conclusions: Concurrent training performed by young, healthy men does not interfere with strength development, but may hinder development of maximal aerobic capacity. Key Words: MUSCLE POWER, ISOKINETIC, STRENGTH, AEROBIC, WEIGHT LIFTING, SPECIFICITY

The specificity of training principle states that the nature of tissue adaptation after training is dependent on the specific type of training practiced (4,9,29). As a corollary to this principle, combining two types of training (e.g., resistance and endurance training) may interfere with the training response induced by either type of training alone. Reasonable physiologic and metabolic evidence exists to support this principle. Adaptations to resistance and endurance training are generally different, and at times opposed to each other (31). Resistance training has little effect on aerobic capacity, but results in increased muscle force production, glycolytic enzyme activity, and intramuscular ATP/phosphocreatine stores, along with hypertrophy of muscle fibers and a possible reduction of muscle mitochondrial and capillary density (4,9,17,31). In contrast, endurance training induces increases in mitochondrial and capillary density, intramuscular myoglobin, enzymes of the TCA cycle and electron transport chain, and maximal aerobic capacity (4,9,31). In addition, a decrease in muscle fiber size may accompany endurance training, a change that could negatively impact muscle strength and power (25,30,31).

In 1980, Hickson et al. (21) first provided evidence for the existence of an “interference phenomenon” between resistance and endurance training by demonstrating that strength gains were hindered when the two types of training were performed concurrently (concurrent training). Studies published subsequently, employing various resistance- and endurance-training protocols, are inconclusive; some (7,8,12,13,20,25) support these earlier findings, and others (1,5,6,7,17,22,26,27,30,33) refute them. By comparison, interference with aerobic adaptations when resistance and endurance training are undertaken together has rarely been reported (28). Reasons for conflicting findings are not presently known, but it is likely that different methodologies employed in various studies have contributed to confusion of published results. For example, methods in published studies, such as modality of resistance training, modality and duration of endurance training, sequencing and timing of concurrent training sessions, volume of training, training status of
subjects before training, subject gender, and types of performance and physiological testing employed to measure the dependent variables, vary in important dimensions. In addition, in many studies, the volume of resistance and endurance training performed by the subjects trained concurrently was not balanced by an equivalent volume performed by subjects engaged singularly in endurance or resistance training.

The relevance of an interference phenomenon, when it exists, for optimal sport performance is self-evident. Training practices, related to the performance of the sport, should be designed to maximize the adaptive response most closely related to the performance of the sport, and training factors that detract from that primary objective should generally be avoided (or at least relegated to specific periods in a training cycle). However, conflicting findings evident in the current literature question the conditions in which training interference can occur, and to what extent it might impede training progress, especially in the nonathletic population. In many of the studies previously cited, the training modalities, intensities, frequencies, and volumes employed were not those most commonly recommended for general health and fitness, and often the subject sample was not representative of the general population. This gap in knowledge is significant because leading authorities, such as the American College of Sports Medicine (ACSM) (2), now recommend concurrent training practices for the physical fitness and health of the general population. Thus, the purpose of our study in young, healthy men was to compare and contrast the effects of endurance, resistance, and concurrent training balanced for training volume, modeled after ACSM recommendations for exercise training for physical fitness and health (2). Based on the specificity of the training principle and previous research, we hypothesized that gains in muscle strength/power and aerobic capacity would be less after concurrent training than respective gains after resistance or endurance training performed singularly. The results of this study provide new information of immediate usefulness for exercise practitioners when recommending exercise training for health and fitness to young, healthy men.

**METHODS**

**Subjects.** Forty-five untrained men were recruited on a volunteer basis from the Texas A&M University population to serve as subjects for this study. Untrained was operationally defined for this study as not having participated regularly in either endurance or resistance training for at least 3 months. The acceptable age range for recruitment purposes was 18–40 yr. A statistical power analysis using methods described by Hays (19) was employed to ensure an adequate subject number in each experimental group. Anticipating no more than a moderate effect size, we chose 5% as an acceptable comparisonwise Type I error rate. Setting the desired power to 0.8, a value acceptable by most researchers (24), it was determined that a minimum of 10 subjects would be needed in each experimental group. The subjects were randomly assigned to one of three groups, with the number of subjects completing the study as follows: endurance training (ET, N = 12); resistance training (RT, N = 13); and concurrent training (CT, N = 16). Characteristics of subjects in the three groups are presented in Table 1. Four subjects failed to complete the study, three due to injury and one for unknown reasons. Subjects were informed of all possible risks involved in the study, and signed an informed consent approved by Texas A&M University’s Institutional Review Board for Use of Human Subjects in Research. Subjects also completed a general health history questionnaire before the start of pretesting. These questionnaires were reviewed by the investigators to rule out any contraindications to exercise testing and training.

**Experimental design.** All subjects, regardless of group assignment, were tested before and after training for each of the following dependent variables: body weight, percent body fat, peak oxygen consumption (VO_{2peak}), isokinetic peak torque production and average power during knee extension and flexion at 60 and 180°·s\(^{-1}\), one-repetition maximum (1RM) leg press, 1RM barbell bench press, and vertical jump height (detailed procedures to follow). All pre- and posttraining testing procedures were completed within 1-wk periods, spaced 13 wk apart. One day of rest and recovery was scheduled between each day of testing. Percent body fat and VO_{2peak} were measured on the first testing day. All isokinetic testing was conducted on day 2. Vertical jump height and 1RM strength assessments were completed on the third day of testing.

Midtraining testing was conducted during week 7 of the study. All dependent variable measurements, except isokinetic measurements, were repeated during midtesting. During this week, testing was conducted on 2 d separated by at least 48 h. Percent body fat and VO_{2peak} measurements were completed on day 1. 1RM leg press, 1RM bench press, and vertical jump height were all tested on day 2.

**Demographic measurements, body composition, and aerobic capacity measurements.** Subject height and weight were measured to the nearest centimeter and tenth of a kilogram, respectively. Body weight was measured weekly during training. Body density was measured using the hydrostatic weighing technique at estimated residual volume (16,32). Percent body fat was estimated from body density by the formula developed by Brozek (10). VO_{2peak} was determined for each subject by indirect, open-circuit calorimetry (Medical Graphics® CPX/D) during treadmill exercise to volitional exhaustion, according to the protocol developed by Bruce et al. (11). Two out of three of the following criteria were used to determine VO_{2peak}: a plateau of oxygen consumption (defined as a rise of less than 0.3 ml·kg\(^{-1}\)·min\(^{-1}\) during the last 30 s of exercise at submaximal levels), a heart rate within 10 beats·min\(^{-1}\) of age-predicted maximum, and a respiratory exchange ratio of 1.05.

### Table 1. Subject characteristics by group before training.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET</td>
<td>12</td>
<td>25 ± 5</td>
<td>178 ± 8</td>
<td>87.9 ± 16.6</td>
</tr>
<tr>
<td>RT</td>
<td>13</td>
<td>23 ± 3</td>
<td>175 ± 6</td>
<td>72.8 ± 11.9*</td>
</tr>
<tr>
<td>CT</td>
<td>16</td>
<td>22 ± 2</td>
<td>182 ± 6</td>
<td>91.6 ± 17.1</td>
</tr>
</tbody>
</table>

Values are given as mean ± SD. ET, endurance trained; RT, resistance trained; CT, concurrent trained. Body weight was significantly lower in the RT group compared to the other two groups. * P < 0.05.
than 2 mL·kg\(^{-1}\)·min\(^{-1}\) during final min of test), a respiratory exchange ratio of greater than 1.15, and a heart rate within 10 beats of the age-predicted maximum (220 – subject’s age) (29). The metabolic cart was calibrated before and after each maximal test using gases of known oxygen and carbon dioxide concentrations. Resting and maximal exercise heart rate measurements were taken during \(V_O^2\) peak testing through the use of Polar® heart rate monitors.

**Isokinetic and strength measurements.** Peak torque production and average power were tested using a Biodex\textsuperscript{®} isokinetic knee extension/flexion device at speeds of 60 and 180°·s\(^{-1}\). Subjects performed a set of 3 and 15 repetitions at the two speeds, respectively. The set of 3 at 60°·s\(^{-1}\) always preceded the faster set of 15. Peak torque and average power were recorded for both speeds, as well as for both flexion and extension. 1RM for leg press and barbell bench press were determined by the maximum weight the subject could successfully lift one time with proper technique after completion of a standardized warm-up (4). The warm-up consisted of 5 min of cycling, 5 min of stretching, and four light sets of each exercise. During pre- and midtraining testing, the subjects in the RT and CT groups were required to perform a 1RM test in all of the exercises that were incorporated into the resistance-training program. The exercises included leg press, leg curl, standing calf raise, barbell bench press, lat pull-down, dumbbell military press, and barbell curl.

**Power measurements.** Vertical jump height was measured using a jump-and-touch testing method with a Vertec vertical jump device (Sports Imports\textsuperscript{®}, Columbus, OH). The standing reach of the subject’s dominant hand was measured as the maximum height the subject could reach while standing flatfooted. Subjects were instructed to stand flatfooted before jumping, and no step was allowed before the execution of the jump. Subjects were allowed three maximal jumps. Vertical jump height was determined by the difference between the subject’s highest jump touch and the subject’s standing reach. Jump power was then calculated using the Lewis formula (9).

**Training program.** Members of each group took part in a training program that lasted 12 wk, with one additional week (week 7) used for midtraining retesting. All training sessions were supervised by trained exercise instructors, and careful records were kept of each subject’s workout performance and physiologic response. The RT group completed a series of standard resistance-training exercises 2× wk\(^{-1}\) every odd-numbered week, and 3× wk\(^{-1}\) every even-numbered week. This training frequency was chosen to ensure that the total number of resistance workouts over the course of the 12-wk training program would be equivalent to the number performed by subjects in the CT group. The resistance-training program consisted of individualized daily workouts of 3 sets of 6–10 repetitions on 8 exercises designed to train all the major muscle groups of the body, and generally patterned after recommendations by ACSM (2,3). The exercises included an abdominal crunch in addition to those previously listed (see isokinetic and strength measurements). A percentage of each subject’s 1RM for each exercise was used to determine the intensity each week. The intensity and number of repetitions performed for each exercise were progressively changed biweekly, and were adjusted for new 1RM measured at the midpoint (week 7) of the training. A more detailed description of the progression of the resistance-training program is presented in Table 2.

The ET group was trained by running on an indoor treadmill or outdoors on a running surface 2–3× wk\(^{-1}\). This group followed the same pattern as the RT group by training twice on odd numbered weeks and three times on even numbered weeks. Thus, the total number of endurance workouts performed by subjects in the ET group was equivalent to the number performed by those in the CT group. The running intensity was determined by a percentage of heart rate reserve (HRR) calculated according to Karvonen (23). Training sessions lasted between 20 and 40 min, and exercise heart rates were continuously monitored using Polar® heart rate monitors. The intensity and/or duration of each session were increased biweekly as training progressed. The training program was designed to conform in principle to that recommended by ACSM (2). Resting and maximum heart rates were reassessed during week 7 (midtraining testing) to adjust the endurance-training prescription for weeks 8 to 13. A more detailed description of the progression of the endurance-training program is presented in Table 2.

The CT group trained 5× wk\(^{-1}\). Every odd-numbered week, this group performed the RT program three times, and the ET program twice. Every even-numbered week, the CT group performed the ET program three times, and the RT program twice. Thus, the subjects in the CT group completed

| TABLE 2. Resistance and endurance training program progression for all groups. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Week #** | **1 & 2** | **3 & 4** | **5 & 6** | **8 & 9** | **10 & 11** | **12 & 13** |
| **Resistance Training** | 1 warm-up set of 10 reps at 50% 1RM | 1 warm-up set of 10 reps at 50% 1RM | 1 warm-up set of 10 reps at 50% 1RM | 1 warm-up set of 10 reps at 50% 1RM | 1 warm-up set of 10 reps at 50% 1RM | 1 warm-up set of 10 reps at 50% 1RM |
| | Workout: 3 sets 10 reps at 75% 1RM | Workout: 3 sets 8 reps at 85% 1RM | Workout: 3 sets 10 reps at 75% 1RM | Workout: 3 sets 8 reps at 80% 1RM | Workout: 3 sets 8 reps at 80% 1RM | Workout: 3 sets 6 reps at 85% 1RM |
| **Endurance Training** | Muscle warm-up & stretching | Muscle warm-up & stretching | Muscle warm-up & stretching | Muscle warm-up & stretching | Muscle warm-up & stretching | Muscle warm-up & stretching |
| | Workout: 20 minutes at 65% of HRR | Workout: 25 minutes at 70% of HRR | Workout: 30 minutes at 75% of HRR | Workout: 35 minutes at 75% of HRR | Workout: 40 minutes at 75% of HRR | Workout: 40 minutes at 80% of HRR |

Mid-training testing conducted during week 7.
TABLE 3. Demographic, body composition, and aerobic capacity results.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pre</th>
<th>Mid</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>ET</td>
<td>87.9 ± 16.6</td>
<td>87.3 ± 15.7</td>
<td>86.8 ± 15.0*</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>72.8 ± 11.9a</td>
<td>74.5 ± 11.5b</td>
<td>75.2 ± 11.2b</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>91.6 ± 17.1a</td>
<td>92.3 ± 15.7a</td>
<td>93.0 ± 15.6a</td>
</tr>
<tr>
<td>VO2peak (L·min⁻¹)</td>
<td>ET</td>
<td>3.52 ± 0.67a</td>
<td>3.74 ± 0.67b</td>
<td>3.81 ± 0.60b</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>3.23 ± 0.47</td>
<td>3.23 ± 0.35</td>
<td>3.35 ± 0.36</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>3.97 ± 0.61</td>
<td>4.03 ± 0.46</td>
<td>4.08 ± 0.48</td>
</tr>
<tr>
<td>VO2peak (mL·kg⁻¹·min⁻¹)</td>
<td>ET</td>
<td>40.8 ± 9.0a</td>
<td>43.4 ± 8.2b</td>
<td>44.3 ± 7.0b</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>44.7 ± 5.1</td>
<td>43.9 ± 4.2</td>
<td>44.9 ± 4.6</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>44.0 ± 7.2</td>
<td>44.3 ± 6.1</td>
<td>44.6 ± 8.8</td>
</tr>
<tr>
<td>% body fat</td>
<td>ET</td>
<td>20.5 ± 9.7*</td>
<td>19.7 ± 8.8*</td>
<td>19.1 ± 8.7*</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>15.9 ± 4.6</td>
<td>15.4 ± 5.0</td>
<td>15.3 ± 5.4</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>18.3 ± 9.0a</td>
<td>17.0 ± 8.9b</td>
<td>17.0 ± 9.0b</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>ET</td>
<td>68.7 ± 9.5</td>
<td>69.2 ± 9.3</td>
<td>69.5 ± 9.3a</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>61.8 ± 8.7*</td>
<td>63.3 ± 8.5*</td>
<td>64.3 ± 8.5*</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>73.6 ± 8.7*</td>
<td>75.5 ± 8.2*</td>
<td>76.1 ± 7.9*</td>
</tr>
</tbody>
</table>

Values are given as mean ± SD. ET, endurance trained; RT, resistance trained; CT, concurrent trained; Pre, pretraining; Mid, mid-training retest at week 7; Post, posttraining. Within-group means across training periods with the same superscripted letter are not significantly different (P > 0.05). * Indicates the between-group change, calculated as the posttraining minus the pretraining value, was significantly different from that in the other two groups (P < 0.05).

RESULTS

Demographic measurements. In the ET group the average change in body weight after training was not significant, although there was a trend toward weight loss (−1.2%). In contrast, the average body weight in the RT group was significantly elevated above pretraining levels at both the mid- (+2.0%) and posttraining (+3.3%) time points. Mid- and posttraining values in the RT group were not significantly different from each other. Body weight increased significantly from pre- to posttraining (+1.5%) in the CT group (Table 3). Between-group analysis showed that the change in body weight in the ET group (−1.2%) was significantly different than the weight changes in the RT (+3.3%) and CT (+1.5%) groups. The change in weight for the RT and CT subjects did not differ significantly (Fig. 1).

Body composition and aerobic capacity measurements. The average VO2peak, whether expressed in absolute terms or indexed on body weight, was significantly higher in the ET group at both mid- (+6%) and posttraining (+8%) time points, compared with pretraining values (Table 3). However, mid- and posttraining values were not significantly different from one another. Only modest and nonsignificant increases in VO2peak values were noted from pretraining to posttraining in the RT (3.7%) or CT (2.8%) groups. In this sample of subjects, the between-group comparisons for changes in VO2peak did not reach statistical significance. In spite of the lack of statistical significance between groups, the more than twofold greater improvement in VO2peak in the ET group is noteworthy, and may be considered to be of functional importance. With respect to body composition, a significant decrease in percent body fat was found from pre- to posttraining (−1.5%) in the ET group (Table 3). No differences were found between pre- and midtraining values or between mid- and posttraining values. No significant change in percent body fat was found in the RT group. In the CT group, percent body fat decreased significantly from pre- to midtraining (−1.3%), with no further reduction from mid- to posttraining. Between-group comparisons for changes in percent body fat were not significant. Lean body mass (LBM) increased significantly from pre- to posttraining measurement periods only in the RT (+4.1%) and CT (+3.4%) subjects (Table 3). Between-group analysis showed that the average gain in...
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ever, the average increase that occurred in the RT group was significantly greater than the respective increase in the ET group (+0.4%). ET and CT between-group differences in average jump power were not significant (Fig. 5).

DISCUSSION

This study was designed to test the specificity of training principle as applied to two types of exercise modalities commonly recommended to promote the health and physical fitness of healthy young adults. Our goal was to characterize the physiologic and performance adaptations which result from endurance and resistance training performed singularly and concurrently. Based on the specificity of training principle and published research, we hypothesized that resistance and endurance training performed singularly would produce greater gains in muscle strength/power and aerobic capacity, respectively, than concurrent training.

Contrary to our hypothesis for muscle strength, subjects in the RT and CT groups made similar gains in maximum leg-press and bench-press strength, both of which were significantly greater than respective gains made by subjects in the ET group. The improvements seen in the 1RM leg-press measures after training by our RT (+40.8%) and CT (+39.4%) subjects were similar to, or greater than, those previously reported in studies employing the same or similar testing procedures (e.g., 1RM squat) (17,22,26,30). Our findings are in general agreement with those of McCarthy et al. (26), who reported no interference in strength gains and comparable improvements in 1RM squat performance between their resistance- (+23%) and concurrent-trained (+22%) subjects. In contrast, Kraemer et al. (25) reported interference in the strength development in their concurrent-training group, as well as leg-press gains substantially lower than those found in our investigation. However, the subjects in the Kraemer et al. (25) investigation were physically active members of the U.S. Army, and all subjects were required to train 4 d·wk⁻¹. The concurrently trained subjects of the Kraemer et al. investigation performed both the endurance and resistance workouts on the same day, with endurance preceding resistance training by 5–6 h (25). Hickson et al. (21), the first to report interference in strength development with concurrent training, required subjects in the resistance-training group to train 5 d·wk⁻¹, and those in the endurance-training and concurrent-training groups to train 6 d·wk⁻¹. Hence, the workout volumes were not balanced in this study. Hennessy et al. (20), who also reported compromised strength gains with concurrent training, studied subjects who were competitive rugby players with resistance training experience. Thus, between-study variability exists in the subjects’ initial strength levels, as well as in duration, intensity, type, and volume of resistance and endurance training employed. Clearly, such interstudy methodological differences could at least partially explain the variations in results found in the published literature with respect to the interference phenomenon.

The specificity of training principle would not predict an increase in strength with endurance training equivalent to that obtained with resistance training alone. Our data generally support this principle. While the ET subjects in our study showed a substantial increase in average 1RM leg-press strength (+20.4%), this was significantly less than the gains realized by the RT (+40.8%) and CT (+39.4%) subjects. Others have reported comparable gains in leg strength in formerly untrained subjects after completing a 12-wk endurance-training program similar to ours (18). Published results in older individuals are also comparable.
Wood et al. (33) reported a significant increase in 5RM leg extension (+24.1%) and leg curl (+29.0%) in formerly untrained, older subjects (aged 68 yr) after endurance training. Moreover, endurance training performed at a relatively high intensity appears to confer no greater strength benefit. Sale et al. (30) reported that endurance training consisting of repetitive 3-min exercise bouts at 90–100% VO2peak improved 1RM leg press 20.3%, an improvement not greater than that realized after exercise at more moderate intensities. Thus, regardless of the intensity, endurance training may promote a 20–25% improvement in leg-press or leg-extension strength in previously untrained subjects.

Like 1RM leg press, the average increase in 1RM bench press in our RT (+30.5%) and CT (+21.2%) subjects was similar in magnitude to increases reported by previous investigators (20,22,25,26). Although the increase in 1RM bench press in our RT subjects was over 9% greater than the increase in the CT subjects, the between-group difference was not statistically significant. Comparatively, only a modest increase in 1RM bench press was found in our ET subjects (+7.52%). Since little force overload is placed on the upper-body musculature during lower-body endurance training (i.e., running), no great improvement in upper-body strength after run training would be anticipated. However, modest increases are not without precedent in the literature. Wood et al. (33) reported a nonsignificant, yet notable increase (+15.3%) in chest-press 5RM in a group of endurance-trained older adults. Furthermore, Hass et al. (18) reported significant increases in 1RM chest press and seated row after 12 wk of an endurance-training protocol similar to that used in our investigation.

Significant gains in average absolute jump power (expressed in watts) were found only in our RT group (Table 4). This is consistent with reports from other studies in which significant increases in anaerobic power occurred only in subjects who were resistance trained (13,17,20,22,25,26). Using the Wingate power test, a more dynamic measure of leg power, Kraemer et al. (25) reported power gains in their resistance-trained subjects to be significantly greater than gains in their concurrent-trained and endurance-trained subjects. To our knowledge, we are the first to report the effects of concurrent training on vertical jump power. The only significant between-group change in jump power in our investigation was between the RT and ET groups (Fig. 5). This finding would again be predicted by the specificity of training principle, since endurance training is not typically associated with an increase in anaerobic power (4,5,9,20,25,26). Interestingly, when jump power was indexed on body weight (W·kg−1), no significant improvements were found in any group (Table 4). Taken together with the relatively greater gains in body weight and LBM in the RT group, and assuming that much of this gain was an increase in muscle tissue, these findings suggest that the increase in absolute jump power is likely related to the increase in muscle mass induced by resistance training.

No significant change in vertical jump height, often considered representative of lower-body power, was found in any of the three training groups. However, a trend toward an increase in the ET and RT subjects existed. Our findings are in disagreement with the previously published literature showing that resistance training alone resulted in significant increases in vertical jump (20,22,26). In two of these previous investigations, it was reported that the subjects who performed concurrent training failed to improve vertical jump height, whereas those in the resistance-training-only group improved significantly (20,22). In contrast, McCarthy et al. (26) found similar improvements in vertical jump height in concurrent- and resistance-trained subjects. Other research has shown endurance training alone to cause decreases in vertical jump height (14,31). The divergent findings involving vertical jump are difficult to explain, but are likely attributable to varying methodologies among study training protocols.

Our data show that traditional resistance training alone may improve some measures of isokinetic leg power (+10 to +11%), but combining endurance training with resistance training prevents parallel improvements. Indeed, even ET alone produced a modest 5.3% posttraining increase in peak torque during extension at 180°·s−1, while CT did not. Furthermore, between-group comparisons demonstrated that RT resulted in significantly greater gains in peak torque during flexion (180°·s−1) than either ET or CT. These data support the hypothesis that CT might attenuate isokinetic power gains compared with RT alone. Our findings partially corroborate those of Dudley and Djamil (13), who reported that while subjects in the CT and RT groups demonstrated similar improvements in peak torque production at low velocities (0–96.3°·s−1), the torque improvements at higher velocities (96.3–240°·s−1) were comparatively greater in subjects of the RT group. Likewise, in our investigation the RT and CT groups showed similar changes in leg-press strength and peak low-velocity torque, but differed in jump power and peak high-velocity torque. Dudley and Djamil (13) speculated that changes in neural factors were responsible for the decreased ability of the concurrent subjects to rapidly produce force. More recent research does not support this neural activation hypothesis. McCarthy et al. (27) applied EMG analysis to show that the amount of neural activation at any given isokinetic torque was the same after either resistance training alone or concurrent training. Thus, additional research will be necessary to explain the basis for this training and power production interference phenomenon.

The absence of any other substantial isokinetic changes within or between groups in our investigation could be due to the fact that the resistance training program used was isotonic in nature, not isokinetic. This, again, is consistent with the specificity of training principle. In several other investigations, significant torque gains by the isokinetic resistance-trained and concurrent-trained subjects have been reported at all testing velocities (1,28). The results of these investigations are difficult to compare with those reported in the present investigation, since the training protocols were qualitatively different.

As noted previously, the principle of training specificity predicts that endurance training alone should produce a greater increase in VO2peak than resistance or concurrent training. Our data supports this principle, showing a signif-
significant increase (+8.25%) in VO$_{2\text{peak}}$ with endurance training, but not with resistance or concurrent training. This increase was less than the 15 to 20% increase after endurance training reported by others (21,26). The smaller change found in our investigation could be partly due to the lower total volume of training performed by our subjects. We designed our study so that the frequency and volume of endurance training would be balanced between the ET and CT groups. Hence, our ET subjects alternated between 3 d·wk$^{-1}$ and 2 d·wk$^{-1}$ frequencies of training sessions over the 12-wk training program, for a total of 30 workout sessions. Research has shown that when the total number of training sessions per week conducted over a 20-wk period is increased from 1 to 3, and from 3 to 5, there is a corresponding increase in the magnitude of gain in VO$_{2\text{peak}}$ (15).

The absence of any change in VO$_{2\text{peak}}$ in our CT subjects was unexpected, and conflicts with the majority of the concurrent-training literature. Improvements in VO$_{2\text{peak}}$ in individuals trained aerobically and concurrently have been reported in most published studies (1,8,12,13,17,20,21,22,25,26,30). Only Nelson et al. (28) have shown concurrent training to inhibit aerobic adaptations. The subjects in the concurrent-training group in their investigation showed a significant increase in VO$_{2\text{peak}}$ after the first 10 wk of training (+6.2%), but no change after training an additional 10 wk. By comparison, VO$_{2\text{peak}}$ improved 9 and 16.8% after 10 and 20 wk of training, respectively, in subjects who were endurance trained. The authors speculated that a dilution of mitochondrial volume caused by resistance-training–induced hypertrophy in the CT subjects might be responsible for the training interference. In support of this contention, the activity of the mitochondrial oxidative enzyme citrate synthase increased only in the endurance-trained subjects (28). Although we have no corroborating muscle enzyme evidence from our study, the fact that strength improvements, reduced body fat, and gains in LBM occurred in our CT and RT subjects strongly suggests that these two types of training produced muscle hypertrophy. Thus, it is possible that mitochondrial dilution occurred in our CT and RT subjects, an adaptation which could at least partially explain the negligible improvements in VO$_{2\text{peak}}$ measured in these two groups of subjects.

It is also conceivable that the relatively higher pretraining VO$_{2\text{peak}}$ of our CT subjects (Table 3) that was present in spite of randomizing group assignment might have blunted their endurance-training response. Although we cannot rule out this possibility, we believe it an unlikely explanation for our findings. Even assuming that the CT subjects were initially closer to their heritable endurance limit, their pretraining VO$_{2\text{peak}}$ expressed relative to body weight (44 mL·kg$^{-1}$·min$^{-1}$) was just average for young, healthy men (44–50 mL·kg$^{-1}$·min$^{-1}$) (4). Furthermore, the average VO$_{2\text{peak}}$ indexed for LBM actually decreased slightly in the CT (−0.28 mL·kg$^{-1}$ · LBM·min$^{-1}$) and RT (−0.17 mL·kg$^{-1}$ · LBM·min$^{-1}$) compared to the ET (+3.64 mL·kg$^{-1}$ · LBM·min$^{-1}$) subjects. Interestingly, with respect to endurance capacity, the CT subjects mirrored the RT subjects, essentially showing no significant improvement in VO$_{2\text{peak}}$ after 12 wk of training. Thus, outside of an interference phenomenon, we believe it is improbable that a measurable improvement in VO$_{2\text{peak}}$ would not be found in CT subjects after 12 wk of endurance training, which was matched in volume to that of the ET group.

The principle of training specificity would predict no, or at best minimal, improvement in VO$_{2\text{peak}}$ with traditional resistance training. Our data confirm this principle in that no increase in VO$_{2\text{peak}}$ was found in our RT group. Other researchers have similarly reported no change in VO$_{2\text{peak}}$ with resistance training (31). As previously stated, resistance training induces adaptations (e.g., muscle hypertrophy and consequent decreases in mitochondrial volume) that could hinder improvements in aerobic performance (28,30). Although we have no data to explain the mechanism, our findings demonstrate once again that traditional resistance training by young, healthy men is ineffective for developing aerobic capacity.

The body weight change (−1.1 kg) was not significant in our ET subjects, yet a significant decrease in percent body fat was found from pre- to posttraining. These findings suggest some increase in LBM, and are in agreement with other investigations that have used running as the mode of endurance training (20,21,22). By comparison, the RT subjects in our study showed a significant increase in body weight, a nonsignificant decrease in percent body fat, and a resultant significant increase in LBM, all findings well supported in the published literature (4,9,20,21). Parallel changes in body composition occurred in the subjects in the CT group, with the exception of a significant decrease in percent body fat. Others have reported either a decrease or no change in body weight, accompanied by a decrease in body fat with concurrent training programs (20,21,22,26). Not unlike our findings with respect to endurance capacity, the CT subjects in our study showed body composition adaptations that were comparatively similar to those found in the RT group.

In conclusion, we studied young, healthy men to determine the effects of prescribing endurance, resistance, and concurrent exercise consistent with the recommendations of the ACSM to improve health and fitness (2). Our findings do not support the existence of an “interference phenomenon” between concurrent resistance and endurance training with respect to strength gains. When young, healthy men perform equal volumes of resistance training in a training program either of resistance training only or of concurrent resistance and endurance training, similar strength gains and changes in body composition can be expected. The effects of concurrent training on the development of muscle power are less clear, but our findings suggest that when resistance training is performed singularly, it is superior to concurrent training when the goal is to improve muscle power. Finally, our data show that concurrent resistance and endurance training may interfere with the improvements in aerobic capacity that can be expected when healthy young men engage in an equal volume of endurance training alone. These findings have important implications for professionals designing exercise programs to improve health and fitness in the general population.
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