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Effects of Resistance, Endurance and Concurrent Training on Women

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Abstract: To determine whether endurance and resistance training concurrently performed produces different performance as compared with each type of training alone. 36 female volunteers were randomly assigned to one of three groups: endurance training (ET, $N = 12$); resistance training (RT, $N = 12$); and concurrent training (CT, $N = 12$). The following measurements were made on all subjects before and after 8 weeks of training: weight, percent body fat, one-repetition maximum (1RM) leg press, 1RM bench press, vertical jump height and calculated jump power. Results revealed that weight and lean body mass (LBM) significantly ($p<0.05$) increased in the RT and CT groups ($f > 0.05$). Percent body fat was significantly increased in the ET and CT groups. Improvements in 1RM leg press and bench press were significant ($p<0.05$) in all groups, but were more obviously significantly ($p<0.05$) in the ET and CT compared to the RT group. Jump power significantly ($p<0.05$) improved only in all groups and in vertical jump height. In conclusions, concurrent training performed by young, healthy women interferes with strength development.

Key words: Resistance · Endurance Concurrent Training · Women

INTRODUCTION

The specificity of training principle states that the nature of tissue adaptation after training is dependent on the specific type of training practiced [1-3]. As a corollary to this principle, combining two types of training (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 [4]. 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 fibbers and a possible reduction of muscle mitochondrial and capillary density [1,2,5,6].

In 1980, Hickson *et al.* [7] were the first to proved 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 concurrently performed (concurrent training). Studies published subsequently, employing various resistance- and endurance-training protocols, are inconclusive; some [8-13] supported these earlier findings and others [5,8, 13 -21] disproved them. By comparison, interference with aerobic adaptations when resistance and endurance training are undertaken together has rarely been reported [22]. Reasons for conflicting findings are not presently known, but it is likely that different employed methodologies 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.

MATERIALS AND METHODS

Subjects: Thirty-six untrained women were recruited on a volunteer basis from the Zagazig University to serve as subjects for this study. Untrained was operationally

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Table 1: Subject characteristics by group before training.

		Age (year)		Height (cm)		Weight (kg)	
Group	N	Mean	SD	Mean	SD	Mean	SD
ET	12	20.51	1.217	172.455	1.391	84.909	0.791
RT	12	20.56	1.001	176.462	1.439	81.846	0.758
CT	12	20.61	1.060	176.750	1.349	83.750	0.664

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 18-20 years. Anticipating no more than a moderate effect size, we chose 5% as an acceptable comparison wise Type I error rate. Setting the desired power to 0.8, a value acceptable by most researchers,. 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-12); and concurrent training (CT, N-12). Characteristics of subjects in the three groups are presented in table 1. Subjects were informed of all possible risks involved in the study. 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, one-repetition maximum (1RM) leg press, 1RM barbell bench press and vertical jump height (detailed procedures to follow). All pre- and post training testing procedures were completed within one week periods, spaced 8 weeks apart. One day of rest and recovery was scheduled between each day of testing. Percent body fat was measured on the first testing day. Vertical jump height and 1RM strength assessments were completed on the second day of testing.

Mid training testing was conducted during week 5 of the study. All dependent variable measurements were repeated during mid testing. During this week, testing was conducted on 2 days separated by at least 48 hours. Percent body fat completed on day, 1RM leg press, 1RM bench press and vertical jump height were all tested on day 2.

Demographic Measurements, Body Composition: Subject height and weight were measured to the nearest centimetre 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 [23]. Percent body fat was estimated from body density, by the formula developed by Brozek [24].

Brozek formula: $BF = (4.57/\rho - 4.142) \times 100$, ρ is the body density in kg/L

Strength Measurements: 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 [1]. The warm-up consisted of 5 min of cycling, 5 min of stretching and four light sets of each exercise. During pre- and mid training 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 Sergent vertical jump test. 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 flat footed 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 [2].

Training Program: Members of each group took part in a training program that lasted 9 weeks, with one additional week (week 5) used for mid training 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 times per week) every odd-numbered week, (3 times per week) every even-numbered week. This training frequency was chosen to ensure that the total number of resistance workouts over the course of 8 weeks 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 [25, 26]. The exercises included an abdominal crunch in addition to those previously listed. 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 5) 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) per week. 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 [27]. Training sessions lasted between 20 and 35 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 [25]. Resting and maximum heart rates were reassessed during week 5 (mid training testing) to adjust the endurance-training prescription for weeks 6 to 8. A more detailed description of the progression of the endurance-training program is presented in table 2.

The CT group trained (5) times per week. 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 the same number of endurance and resistance workouts over the course of the study as the ET and RT subjects, respectively.

Data Analysis: A one-way analysis of variance with repeated measures was used to analyze pre-, mid- and post training values within each group for all dependent variables. L.S.D. tests were employed for post analyses of significant ANOVA results. The magnitude of changes for all dependent variables produced by training in the three groups (between-group comparisons) were compared using a one-way analysis of variance on the delta scores, calculated by subtracting pre training values from post training values for each variable. Once again, L.S.D. tests were employed for post analyses of significant ANOVA results. As previously mentioned, the acceptable Type comparison wise error rate was set at 5%.

RESULTS

Strength Measurements: In the ET, RT and CT groups, 1RM leg press was significantly ($p<0.05$) increased across all time points: pre- to mid training, mid to post training and pre- to post training (Table 3). The average increases in 1RM leg press from pre- to post training in the RT and CT groups were significantly ($p<0.05$) greater than the RT group average. The average increases in 1RM leg press in the ET and CT groups were significantly ($p<0.05$) different from one another. The average 1RM bench press improved from pre- to post training in the ET group. By comparison, 1RM bench press average values were significantly ($p<0.05$) higher at all training periods in the RT and CT groups: pre- to mid training, mid- to post training and pre- to post training (Table 3). Between group analyses showed the pre- to post training increase in 1RM bench press to be significantly ($p<0.05$) higher in ET and CT groups compared with the RT group.

Table 2: Resistance and endurance training program progression for all groups.

Week	1 &d 2	3 & 4	6 & 7	8 &9
Resistance Training	1 warm-up set of 10 reps at 50% 1RM Workout: 3 sets 10 reps at 75% 1RM	1 warm-up set of 10 reps at 50% 1RM Workout: 3 sets 8 reps at 80% 1RM	1 warm-up set of 10 reps at 50% 1RM Workout: 3 sets 6 reps at 85% 1RM	1 warm-up set of 10 reps at 50% 1RM Workout: 3 sets 10 reps at 75% 1RM
Endurance Training	Muscle warm-up and stretching Workout: 20 minutes at 65% of HRR	Muscle warm-up and stretching Workout: 25 minutes at 70% of HRR	Muscle warm-up and stretching Workout: 30 minutes at 75% of HRR	Muscle warm-up and stretching Workout: 35 minutes at 80% of HRR

Mid-training testing conducted during week (5).

Power Measurements: within-group and between group changes in vertical jump height were significant (p<0.05). Furthermore, significant (p<0.05) changes in average jump power were found in the ET and CT subjects (Table 3, 4). Increases in jump power were significant (p<0.05) from pre- to mid training, mid- to post training and pre to post training in the ET group. When jump power was indexed on body weight, within-group changes were significant (p<0.05), between-group analyses revealed that, in spite of the relatively greater improvement in average jump power in the RT compared to the CT group; this difference was not statistically significant. However, the average increase that occurred in the RT group was significantly (p<0.05) greater than the respective increase in the ET group. ET and CT between-group differences in average jump power were significant.

Demographic Measurements: In the ET group the average change in body weight after training was significant (p<0.05), the average body weight in the RT group was significantly (p<0.05) elevated above pre training levels at both the mid- and post training time points. Mid- and post training values in the RT group were significantly (p<0.05) different from each other. Body weight increased significantly (p<0.05) from pre- to post training in the CT group (Table 5, 6). Between-group

Table 3: Indication variances between training groups in muscle power and strength.

Variable	Source of Variation	SS	df	MS	F
Vertical jump (cm) ET	Between Groups	17.6805	2	8.84027	14.913*
	Within Groups	19.5625	33	0.59280	
Vertical jump (cm) RT	Between Groups	8	2	4	3.3*
	Within Groups	40	33	1.2121	
Vertical jump (cm) CT	Between Groups	8.72222	2	4.36111	4.65498*
	Within Groups	30.9167	33	0.93686	
Jump power (W) ET	Between Groups	248	2	124	66*
	Within Groups	62	33	1.87878	
Jump power (W) RT	Between Groups	728	2	364	375.375*
	Within Groups	32	33	0.96969	
Jump power (W) CT	Between Groups	56	2	28	17.7692*
	Within Groups	52	33	1.57575	
1RM leg press (kg) ET	Between Groups	1672.67	2	836.333	1075.28*
	Within Groups	28	36	0.77777	
1RM leg press (kg) RT	Between Groups	1152.66	2	576.333	471.545*
	Within Groups	44	36	1.22222	
1RM leg press (kg) CT	Between Groups	2608.67	2	1304.33	1020.78*
	Within Groups	46	36	1.27777	
1RM bench press (kg) ET	Between Groups	488	2	244	191.714*
	Within Groups	42	33	1.27272	
1RM bench press (kg) RT	Between Groups	1184	2	592	271.333*
	Within Groups	72	33	2.18181	
1RM bench press (kg) CT	Between Groups	1944	2	972	422.052*
	Within Groups	76	33	2.30303	

* Significantly different at f <.05 =3.284918

Values are given as ET, endurance trained; RT, resistance trained; CT, concurrent trained, * Indicates the between-group change, calculated as the Post training minus the pre training value, was significantly different from that in the other two groups (*f* < 0.05)

Table 4:L.S.D. between the three measurements in three training groups

Variable	Average	Pre	Mid	Post	L S D
Vertical jump (cm) ET	34.08333				0.642
	35.08333	1.000			
	35.79167	1.708	0.708		
Vertical jump (cm) RT	29				0.918
	30	1.000			
	30	1.000	0.000		
Vertical jump (cm) CT	30.083				0.807
	29	1.083			
	30	0.083	-1.000		

Table 4: Continue

Variable	Average	Pre	Mid	Post	L S D
Jump power (W) ET	901				1.143
	906	-5.000			
	907	-6.000	-1.000		
Jump power (W) RT	730				0.821
	736	6.000			
	741	11.000	5.000		
Jump power (W) CT	930				1.046
	931	1.000			
	933	3.000	2.000		
1RM leg press (kg) ET	115				0.735
	122	7			
	131	16	9		
1RM leg press (kg) RT	110				0.922
	119	9			
	123	13	4		
1RM leg press (kg) CT	116				0.942
	125	9			
	136	20	11		
1RM bench press (kg) ET	35				0.94
	39	4			
	44	9	5		
1RM bench press (kg) RT	33				1.231
	41	8			
	47	14	6		
1RM bench press (kg) CT	31				0.94
	40	9			
	49	18	9		

Table 5: Indication variances between training groups in Demographic and body composition.

Variable	Source of Variation	SS	df	MS	F
Body weight (kg) ET	Between Groups	11.18	2	5.59	3.39536*
	Within Groups	54.33	33	1.64636	
Body weight (kg) RT	Between Groups	36.56	2	18.28	27.0754*
	Within Groups	22.28	33	0.67515	
Body weight (kg) CT	Between Groups	11.76	2	5.88	6.27961*
	Within Groups	30.9	33	0.93636	
% body fat ET	Between Groups	10.32	2	5.16	5.52498*
	Within Groups	30.82	33	0.93393	
% body fat RT	Between Groups	2.48	2	1.24	2.37907
	Within Groups	17.2	33	0.52121	
% body fat CT	Between Groups	10.64	2	5.32	5.96331*
	Within Groups	29.44	33	0.89212	
Lean body mass (kg) ET	Between Groups	22.32	2	11.16	13.431*
	Within Groups	27.42	33	0.83091	
Lean body mass (kg) RT	Between Groups	38	2	19	44.1549*
	Within Groups	14.2	33	0.43030	
Lean body mass (kg) CT	Between Groups	40.88	2	20.44	39.3535*
	Within Groups	17.14	33	0.51939	
	Within Groups		33		

* Significantly different at p <.05 =3.284918

Values are given as ET, endurance trained; RT, resistance trained; CT, concurrent trained, * Indicates the between-group change, calculated as the Post training minus the pre training value, was significantly different from that in the other two groups ($f < 0.05$).

Table 6: L.S.D. between the three measurements in three training groups

Variable	Average	Pre	Mid	Post	L S D
Body weight (kg) ET	88.15				1.07
	87.3	0.850			
	86.8	1.350	0.500		
Body weight (kg) RT	72.8				0.685
	74.5	1.7			
	75.2	2.4	0.7		
Body weight (kg) CT	91.6				0.807
	92.3	0.7			
	93	1.4	0.7		
% body fat ET	20.5				0.806
	19.7	0.800			
	19.2	1.300	0.500		
% body fat RT	15.9				0.602
	15.4	0.5			
	15.3	0.6	0.1		
% body fat CT	91.6				0.807
	92.3	0.7			
	93	1.4	0.7		
Lean body mass (kg) ET	67.7				0.76
	69.2	1.5			
	69.5	1.8	0.3		
Lean body mass (kg) RT	61.8				0.547
	63.3	1.5			
	64.3	2.5	1		
Lean body mass (kg) CT	73.6				0.601
	75.5	1.9			
	76.1	2.5	0.6		

analysis showed that the change in body weight in the RT group was significantly ($p<0.05$) different than the weight change in the ET and CT groups. The change in weight for the RT and CT subjects significantly ($p<0.05$) differ.

Body Composition Measurements: There were significant ($p<0.05$) changes in percent body fat were found in the RT group. In the CT group, percent body fat increased significantly ($p<0.05$) from pre- to mid training, with no further reduction from mid to post training. Between groups comparisons for changes in percent body fat were significant ($p<0.05$). Lean body mass (LBM) significantly ($p<0.05$) increased from pre- to post training measurement periods in the RT and CT subjects (Tables 5, 6). Between-group analysis showed that the average gain in LBM for the RT subjects was significantly ($p<0.05$) greater than that of the ET and CT subjects.

DISCUSSION

This study was designed to test the specificity of training principle as applied to two types of exercise modalities commonly recommended promoting the health and physical fitness of healthy young adults. Our goal was to characterize 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, than concurrent training. Contrary to our hypothesis for muscle strength, subjects in the ET and CT groups made similar gains in maximum leg-press, both of which were significantly greater than respective gains made by subjects in the RT group. The improvements seen in the 1RM leg press measures after training by our ET and CT subjects were similar to, or greater than, those previously reported in studies employing the same or similar testing procedures (e.g. 1RM squat) [5,17,18,20]. In agreement with Kraemer *et al.* [13] reported interference in the strength development in their concurrent training group. Hickson *et al.* [7]. However, our findings are in general disagreement with those of McCarthy *et al.* [18], who reported no interference in strength gains and comparable improvements in 1RM squat performance between their endurance and concurrent-trained subjects, the first to report interference in strength development with concurrent training, required subjects in the resistance-training group to train (5) days per week and those in the endurance-training and concurrent-training groups to train (6) days per week. Hence, the workout volumes were not balanced in this study. Hennessy *et al.* [12], 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 inter study 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 RT subjects in our study showed a substantial increase in 1RM leg press strength, this was significantly less than the gains realized by the ET and CT subjects.

It was concluded that concurrent training performed by young, healthy women interferes with strength development.

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