Low-volume circuit versus high-volume periodized resistance training in women

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ABSTRACT

MARX, J. O., N. A. RATAMESS, B. C. NINDL, L. A. GOTSHALK, J. S. VOLEK, K. DOHI, J. A. BUSH, A. L. GÓMEZ, S. A. MAZZETTI, S. J. FLECK, K. HÄKKINEN, R. U. NEWTON, and W. J. KRAEMER. Low-volume circuit versus high-volume periodized resistance training in women. *Med. Sci. Sports Exerc.*, Vol. 33, No. 4, 2001, pp. 635–643. **Purpose:** The purpose of this investigation was to determine the long-term training adaptations associated with low-volume circuit-type versus periodized high-volume resistance training programs in women. **Methods:** 34 healthy, untrained women were randomly placed into one of the following groups: low-volume, single-set circuit (SSC; $N = 12$); periodized high-volume multiple-set (MS; $N = 12$); or nonexercising control (CON) group ($N = 10$). The SSC group performed one set of 8-12 repetitions to muscular failure 3 $d \cdot wk^{-1}$. The MS group performed two to four sets of 3-15 repetitions with periodized volume and intensity 4 $d \cdot wk^{-1}$. Muscular strength, power, speed, endurance, anthropometry, and resting hormonal concentrations were determined pretraining (T1), after 12 wk (T2), and after 24 wk of training (T3). **Results:** 1-RM bench press and leg press, and upper and lower body local muscular endurance increased significantly ($P \leq 0.05$) at T2 for both groups, but only MS showed a significant increase at T3. Muscular power and speed increased significantly at T2 and T3 only for MS. Increases in testosterone were observed for both groups at T2 but only MS showed a significant increase at T3. Cortisol decreased from T1 to T2 and from T2 to T3 in MS. Insulin-like growth factor-1 increased significantly at T3 for SSC and at T2 and T3 for MS. No changes were observed for growth hormone in any of the training groups. **Conclusion:** Significant improvements in muscular performance may be attained with either a low-volume single-set program or a high-volume, periodized multiple-set program during the first 12 wk of training in untrained women. However, dramatically different training adaptations are associated with specific domains of training program design which contrast in speed of movement, exercise choices and use of variation (periodization) in the intensity and volume of exercise. **Key Words:** STRENGTH TRAINING, TRAINING VOLUME, TESTOSTERONE, CORTISOL, GROWTH HORMONE, IGF-1

Resistance training is becoming an important component of women's health/fitness programs. Nevertheless, our factual understanding of the training adaptations consequent to long-term resistance training programs (e.g., 24 wk or longer) are limited. Furthermore, direct comparisons of different types of "total-body" resistance training programs commonly used by women are also scant. Over the past 10 years, the concept of periodization of training has gained greater popularity in the health and fitness arena as it allows for variation in the training stimulus (i.e., different workouts with different intensities and volumes of exercise) and planned recovery periods to prevent overtraining. Although a review of the recent literature on periodization of training supports this concept (7), further investigation has been deemed necessary, especially over longer periods of training and in women, where there is a paucity of data. Thus, a distinct need exists for long-term training studies examining various resistance training programs in women.

Periodization of training allows for changes in the intensity (e.g., heavy, moderate and light resistance) as well as changes in the volume of exercise (i.e., sets × repetitions), which theoretically keeps the exercise stimulus effective (7). Conversely, many types of single-set circuit weight training programs are of lower volume with a specific intensity range (e.g., 8–12 RM). Several studies have indicated superior performance increases when periodized programs were compared with nonperiodized programs (7,12,14,17). Yet no data exist in healthy, young women. Thus, more dramatic variation in training intensity and volume of exercise may be vital for long-term adaptations in muscular fitness.

One particular aspect of training volume, which has unfortunately captured interest, has been the number of sets performed per exercise. There has been considerable debate surrounding this variable as to the efficacy of performing either single- or multiple-set (i.e., 3–6) programs. However, it should be noted that not every exercise in a resistance training program has to be performed using the same

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number of sets. However, over the past 25 years, popular equipment and training philosophies have many times prompted the sole use of this approach. Short-term, single-set programs have produced significant increases in muscular strength in both men and women (2,15,27), as have multiple-set nonperiodized programs (11,13,20,29–32). In direct comparison, several studies have reported similar strength increases between single- and multiple-set programs (2,15,24,27–29), whereas several studies have reported nonperiodized three-set programs superior to one set (1,34,36) in untrained subjects. A recent study by Haas et al. (10) reported similar strength increases in recreationally trained, middle-aged men and women between single and multiple sets. Thus, the evidence indicates that both single- and multiple-set programs are effective for increasing muscular strength in untrained individuals during the initial 7–12 wk of training. However, many key elements missing in most comparative studies are a combination of program design domain factors, such as the lack of periodization in the higher volume program, machine versus free weight exercises, and larger intensity ranges over which variation can take place. It has been postulated that adaptations to different resistance training programs take longer to manifest themselves, especially when subjects are untrained (7). Few long-term training studies exist examining the effects of single- versus multiple-set periodized resistance training programs, especially in women. In resistance-trained men, higher-volume periodized resistance training has been shown to be superior to low-volume single set programs for improvements in muscular strength, power, hypertrophy, and local muscular endurance (17,22). Therefore, evidence indicates similar short-term improvements with both single- and multiple-set programs in untrained individuals but superior improvements with multiple-set programs over long-term training periods in resistance-trained individuals. Thus, we hypothesized that no significant differences would be observed with short-term training but greater magnitudes of training adaptations would be demonstrated with long-term training, in favor of a program utilizing periodization and a higher volume of work.

If periodized, higher-volume resistance training impacts performance gains as hypothesized, we also theorized that underlying hormonal mechanisms may reflect these adaptational differences. Endocrine mechanisms are involved with a variety of resistance training adaptations including alterations in the quantity and quality of muscle fiber proteins (32). With acute exercise-induced increases of anabolic and catabolic hormones observed during the recovery period after a resistance exercise workout (13,18,19,21), such changes are thought to be part of the myriad of mediating mechanisms for adaptations in target tissues (e.g., muscle fibers, immune cells, etc.) consequent to training. Hormonal signals derived from the physiological cues created by the acute exercise demands lead to signal transduction at the level of the nucleus to alter phenotypic expression and ultimately performance-based capabilities. Thus, we hypothesized that the higher volume resistance training program would result in a greater number of basal changes in resting anabolic and catabolic hormones, than in the lower volume program. Although differences in the hormonal profile have not been observed when comparing elite lifters to untrained subjects, such a study design did not allow for the prospective study of these hormonal changes as used in the current investigation (33).

The purpose of this investigation was to determine the training adaptations associated with low-volume circuit-type weight training versus periodized high-volume resistance training program on muscular performances in women. A secondary purpose was to examine the underlying changes in basal anabolic/catabolic hormones to gain insights into some of the underlying physiological mechanisms of adaptation.

METHODS

Experimental Approach to the Problem

In this study, we wanted to address the question of how commonly used high-volume versus low-volume resistance training programs impact measures of muscular performance with long-term training in untrained, healthy women. To answer this question, we chose two distinctly different training programs that are naturally different in their training volume due to inherent program differences alone. Furthermore, they were programs that could be generalized to many other programs of high- and low-volume genres commonly used today. Experimentally, an almost unlimited number of factors (e.g., load range, volume, exercise choice, speed of movement, etc.) could be partialed out by various research designs but such studies would never allow one to see the more realistic effects of a composite domain of contributors to the adaptational effects. Therefore, we decided to make the comparison between two broad program designs made up of a specific set of clustered variables to determine the adaptational variations which may exist between two dramatically different program domains. To examine a long-term training scenario, 24 wk of training was used under carefully monitored and controlled conditions. To examine the anabolic and catabolic hormonal adaptations to the respective training programs, resting serum testosterone, cortisol, insulin-like growth factor-1, and growth hormone concentrations were evaluated within the context of the early follicular phase of the menstrual cycle of each woman.

Subjects

From a pool of about 50 women, 34 active but untrained, young, healthy women met the experimental screening criteria and volunteered to participate in this study. Each woman was randomly assigned to one of three groups: a low-volume, single-set circuit (SSC) resistance training group ($N = 12$); a high-volume, periodized multiple-set (MS) resistance training group ($N = 12$); or a nonexercising control (CON) group ($N = 10$). Subjects were matched for physical characteristics and performance before the start of the study and then were randomly placed into one of the

TABLE 1. Initial characteristics of the experimental groups before training.

	SSC (N = 12)	MS (N = 12)	CON (N = 10)
Age (yr)	23.2 ± 4.5	22.6 ± 3.7	22.2 ± 5.7
Height (cm)	166.1 ± 5.4	165.4 ± 4.4	165.7 ± 5.7
Body mass (kg)	55.4 ± 6.5	57.6 ± 6.8	55.6 ± 5.7
% Body fat	25.5 ± 3.6	26.5 ± 4.7	26.6 ± 3.2

CON, control group; SSC, single set circuit group; MS, multiple-set group.

three experimental groups (two training groups and one control group). Subject characteristics can be seen in Table 1. In this study, two of the control subjects had to terminate participation from the study due to schedule problems (e.g., job, school) unrelated to the study protocol. In addition, all of the subjects were nonsmokers, were not taking any medication, and had no previous experience with resistance exercise. The women had no medical or endocrine disorders that would confound the findings of his investigation. All women were determined to be eumenorrheic according to methods previously described (5). Each subject had had regular 28- to 32-d menstrual cycles throughout the previous year, and none had used oral contraceptives or intrauterine devices within the past year. Each subject was informed of the potential risks associated with the investigation and signed an informed consent document approved by the Institutional Review Board for use of human subjects in research and in accordance with the policies outlined by the American College of Sports Medicine. A physician performed all of the medical screening. A minimum of 2 wk was used for the familiarization period to allow subjects to accustom themselves to the testing procedures and exercise equipment before initial data collection. Special care was taken in this preliminary phase of the study to remove all learning effects typically leading to inflated training related gains in performance. Testing was conducted on three occasions: before the initiation of training (T1), after 12 wk of training (T2), and after 24 wk of training (T3). Stability of testing was substantiated by test-retest intraclass correlations, which showed Rs $\geq$ 0.95 for the experimental tests used in this investigation.

Testing Procedures

Body composition. Body density was determined via a standard hydrostatic weighing technique (computer interfaced with a load cell with residual volume determined using an oxygen dilution method). These methods have been previously described in detail (6).

Assessments of Muscular Performance

Upper and lower body muscular strength was measured using the one-repetition maximum (1 RM) bench press and leg press exercises on Universal™ weight machines by using methods previously described (18). Briefly, a warm-up of 5–10 repetitions at 40–60% of perceived maximum was performed followed by 3–5 repetitions with 60–80% of the perceived maximum. Three to four subsequent attempts were then made to determine the 1 RM for each exercise. Three- to 5-min rest periods were used in between lifts to ensure optimal recovery.

Upper and lower body muscular endurance was assessed by measuring the maximal number of repetitions performed for both the bench press and leg press exercises using Universal™ weight machines. A load was selected which corresponded to 80% of subjects' 1 RM. Each subject was instructed to perform each exercise to momentary muscular exhaustion. The total number of repetitions performed was recorded. Any repetitions not performed in a full range of motion were not counted. In addition, local muscular endurance of the abdominal muscles was measured using the 1-min sit-up test.

The Wingate anaerobic power test was performed on a cycle ergometer (Monark Ergometer Model 818E, Monark AB, Varberg, Sweden) anchored to the floor and modified to permit the instantaneous application of an opposing force of 0.736 $N \cdot kg^{-1}$ body mass. Seat height was adjusted such that the knees were slightly bent (approximately 10°) when the pedal of the same side was at its lowest position during a revolution. Subjects performed a 2-min warm-up using a self-selected resistance and cadence followed by 1 min of rest. Subsequently, subjects were instructed to pedal as rapidly as possible (i.e., about 120 rpm) with maximal effort against the inertial resistance of the flywheel while resistance was applied to initiate the test. Subjects were required to remain seated throughout the 30-s bout, and verbal encouragement was provided during the test. Flywheel revolutions were monitored and recorded for each of six 5-s segments via an electromagnetic detection system with printer interface (Miniprinter Model No. MM2481/5S1, Keltron Corporation, Waltham, MA). Power output was calculated using the number of flywheel revolutions and the opposing force. Peak power was determined as the highest 5-s segment average power output. An additional power determination was made using a countermovement vertical jump was performed using an AMTI force plate (American Medical Technology, Inc., Newton, MA) interfaced with a computer, and customized software was used to calculate peak power. Maximal speed was assessed using the 40-yard sprint test with electronic timing. The lowest time out of three trials was recorded.

Assessments of Resting Hormone Concentrations

All subjects refrained from any vigorous activity for 48 h before the targeted onset of menses for that month in order to reduce confounding activity before blood sampling. Venous blood samples were obtained from subjects in a semirecumbent position during the early follicular phase (2–4 d) of the menstrual cycle (5) in the early morning period (8–10 a.m.) at T1, T2, and T3 to reduce any possible effects of diurnal variations on hormonal concentrations. Prior menstrual histories were obtained on each women over the past 6 months during the familiarization phase in order to determine approximate starting dates for all of the women. Due to the fact that each subject had a personal trainer, we could involve staggered starts over a 14- to 17-d starting period to accommodate follicular phase variations and blood sampling in these women. The training program started after the first follicular phase, and therefore we had only minor 1- or 3-d variations on each targeted month for blood sampling. The venous blood samples were obtained from a superficial arm vein on the radial aspect of the arm by using 20-gauge needle and syringe with a specialized Vacutainer set-up. Before obtaining a resting blood sample, a 20-min equilibration period was utilized. All blood samples were processed, centrifuged for 15 min at 3000 × *g*, serum harvested, and stored at −120°C until analyzed.

Serum testosterone, human growth hormone (GH), insulin-like growth factor-1 (IGF-1), and cortisol concentrations were determined in duplicate in blinded analyses using standard radioimmunoassay (RIA) techniques. Determinations of the different concentrations for the various RIAs were attained with the use of a Beckman 5500 gamma counter and on-line data reduction system. Total serum testosterone was measured with ^{125}I solid-phase RIA (Diagnostic Products Corp., Los Angeles, CA) with a detection limit of 0.38 nmol·L^{-1}. Intra- and inter-assay variances were calculated to be < 3.0 and < 5.1%, respectively. Serum GH was measured using a ^{125}I liquid-phase RIA with double-antibody technique (Cambridge Medical Diagnostics, Billerica, MA) with a limit detection of 0.24 μg·L^{-1}. Intra- and inter-assay variances were calculated to be < 2.6 and < 3.2%, respectively. Total serum IGF-1 was measured with ^{125}I double-antibody disequilibrium RIA with a preliminary octadecasilyl-silica column extraction procedure (Inc-Star Corp, Stillwater, MN), the limit detection being < 2.0 nmol·L^{-1}. Intra- and inter-assay variances were calculated to be < 3.7 and < 5.0% respectively. Serum cortisol concentrations were assayed with a solid-phase ^{125}I RIA technique (Diagnostic Products Corp.). The intra- and inter-assay variances were < 3.1 and < 7.1%, respectively.

Training Programs

We utilized two distinctly different training programs that inherently had very different composite domains of program variables (i.e., days per week, number of total sets, exercise choices, speed of movement, total work, and volume of exercise etc.). The workouts were individually supervised by a group of certified personal trainers with several years of professional experience in training both the general public and collegiate athletes and were professionally certified (i.e., ACSM-Certified Health and Fitness Instructor and NSCA-Certified Strength and Conditioning Specialist). Each subject had a personal trainer present at all training sessions to supervise training and answer questions and provide spotting, verbal encouragement, motivation, and advice concerning the progression of training loads. The SSC group trained on three alternate days per week. The workouts consisted of performing a single set of each exercise in a slow, controlled manner with a 1- to 2-min rest period between exercises. Each set consisted of 8–12 repetitions (at a pace of 2 s up and 4 s down) performed to momentary muscular failure. The resistance was increased during the subsequent training session if a subject could perform 12 or more repetitions for a set without assistance. Subjects alternated between two different training circuits using the same exercise order (see Table 2). The use of two circuits was used to minimize boredom and staleness over the 24-wk training period so as to create some variation in exercise choice.

TABLE 2. Exercises performed by the single-set circuit-type training group.

Circuit A	Circuit B
Leg press	Knee extension
Bench press	Chest fly
Leg curl	Leg curl
Seated row	Lateral raise
Standing calf raise	Seated calf raise
Arm curl	Triceps pushdown
Sit-up	Back extension
Pullover	Upright row
Military press	Rotator cuff exercises
Hip abduction/adduction	Lat pulldown

The MS group trained 4 d·wk^{-1} performing 2–4 sets per exercise. A frequency of 4 d·wk^{-1} was chosen to allow greater variation in program design and higher volume of work (17). On Monday and Thursday, the intensity varied between either heavy (3–5 RM), moderate (8–10 RM) or light (12–15 RM) loads. On Tuesday and Friday, subjects trained using moderate loads (8–10 RM). Each set was performed until the targeted number of repetitions was performed. If more repetitions than the target zone could be performed, the resistance was increased for the next set or training session. The velocities of movement were related to the intensity of the exercise and the movement being trained but encompassed explosive movement speeds when loads were submaximal and exercises appropriate (e.g., hang cleans vs bench press). The rest periods in between sets were 1–2 min on moderate and light days and 3–4 min on heavy days. The exercises performed and order are listed in Table 3. The control group (CON) only performed their normal recreational activities and did not perform any type of resistance training throughout the study period. No training-related injuries were observed in any of the groups over the study period. Make up workouts were allowed on weekends (<3% of total workouts). Thus, each subject in the study completed 100% of the workouts for the 6-month training period.

TABLE 3. Exercises performed by the periodized, high-volume multiple-set group.

Monday/Thursday	Tuesday/Friday
Hang clean	Upright row
Squat	Dumbbell military press
Bench press	Arm curl
Push press	Triceps pushdown
Leg curl	Lat pulldown
Sit-up	Seated row
Rotator cuff exercises	Sit-up
	Side bend
	Lateral hip flexion
	Leg curl
	Calf raise
	Lunge

Statistical Analyses

A two-way analysis of variance (ANOVA) with repeated measures (groups × time) was used to analyze the data. Tukey's *post hoc* analyses to determine pairwise differences were performed when significant *F*-values resulted. Statistical power was determined to be from 0.78 to 0.80 for the sample sizes used at the 0.05 alpha level (nQuery Advisor® software, Statistical Solutions, Saugus, MA). Significance was defined as $P \leq 0.05$.

RESULTS

No significant differences in body mass were observed for any group during the 6-month training period. A significant decrease in percent body fat was observed at T2 for SSC and MS. However, only MS showed further reduction in body fat at T3. There was a significant difference between groups as MS showed a three-fold decrease compared with SSC at T3. In addition, a significant increase in lean body mass was only observed in MS at T2. No other changes in lean body mass were observed for any group (see Table 4).

TABLE 4. Anthropometric and performance changes over six months of training (mean ± SD).

	SSC (N = 12)	MS (N = 12)	CON (N = 10)
Body fat (%)			
T1	25.5 ± 3.6	26.5 ± 4.7	26.6 ± 3.2
T2	23.7 ± 3.5^{a}	22.5 ± 3.7^{a}	26.4 ± 2.8
T3	23.0 ± 3.6^{a}	19.8 ± 3.8^{a,b,c}	26.3 ± 2.6
Fat-free mass (kg)			
T1	41.3 ± 5.1	42.3 ± 5.3	40.6 ± 4.2
T2	42.3 ± 4.7	44.4 ± 5.6^{a}	41.7 ± 3.9
T3	42.3 ± 5.0	45.6 ± 6.3^{a,c}	39.9 ± 4.4
Bench press (kg)			
T1	22.1 ± 1.6	21.8 ± 1.6	22.9 ± 4.3
T2	24.8 ± 1.5^{a}	26.9 ± 1.4^{a,c}	23.3 ± 3.5
T3	24.8 ± 1.6^{a}	32.0 ± 2.7^{a,b,c}	23.1 ± 3.8
Leg press (kg)			
T1	95.6 ± 7.8	95.5 ± 6.5	95.9 ± 6.6
T2	103.6 ± 7.8^{a}	115.5 ± 7.5^{a,c}	95.9 ± 5.9
T3	106.3 ± 7.8^{a}	126.0 ± 6.3^{a,b,c}	95.7 ± 6.5
Bench press reps (80% 1RM)			
T1	9.6 ± 0.8	9.5 ± 0.5	10.0 ± 0.9
T2	9.8 ± 0.8	10.8 ± 0.6^{a,c}	9.8 ± 0.9
T3	10.6 ± 1.4^{a}	11.8 ± 1.2^{a,b,c}	9.6 ± 0.7
Leg press reps (80% 1RM)			
T1	11.2 ± 1.3	11.3 ± 1.7	11.7 ± 1.5
T2	13.0 ± 1.5^{a}	15.2 ± 1.7^{a,c}	11.4 ± 1.3
T3	13.3 ± 1.4^{a}	18.6 ± 2.2^{a,b,c}	11.7 ± 0.9
Wingate peak power (W)			
T1	601.0 ± 43.3	593.2 ± 60.3	608.5 ± 34.7
T2	605.5 ± 50.2	674.2 ± 64.4^{a,c}	614.3 ± 30.7
T3	624.2 ± 64.4	754.8 ± 64.0^{a,b,c}	613.5 ± 28.2
Sit-ups in 1 min			
T1	40.3 ± 3.8	40.2 ± 2.6	36.7 ± 2.1
T2	43.6 ± 3.0^{a}	50.5 ± 4.1^{a,c}	37.3 ± 1.4
T3	45.7 ± 4.2^{a}	57.1 ± 2.9^{a,b,c}	37.1 ± 3.1
Vertical jump power (W)			
T1	2135.5 ± 107.7	2159.7 ± 166.8	2071.7 ± 183.1
T2	2328.0 ± 88.7^{a}	2674.8 ± 88.7^{a,c}	2129.7 ± 214.0
T3	2356.0 ± 93.2^{a}	3018.1 ± 131.7^{a,b,c}	2098.4 ± 182.6
40-yard dash (s)			
T1	5.90 ± 0.25	5.97 ± 0.18	5.88 ± 0.35
T2	5.93 ± 0.31	5.77 ± 0.19^{a,c}	5.89 ± 0.38
T3	5.86 ± 0.31	5.59 ± 0.14^{a,b,c}	5.90 ± 0.37

T1, pretraining; T2, 12 wk training; T3, 24 wk training.
[a] $P \leq 0.05$ from corresponding preexercise time point T1.
[b] $P \leq 0.05$ from corresponding time point T2.
[c] $P \leq 0.05$ difference from corresponding SSC and CON groups.
CON, control group; SSC, single-set group; MS, multiple-set group.

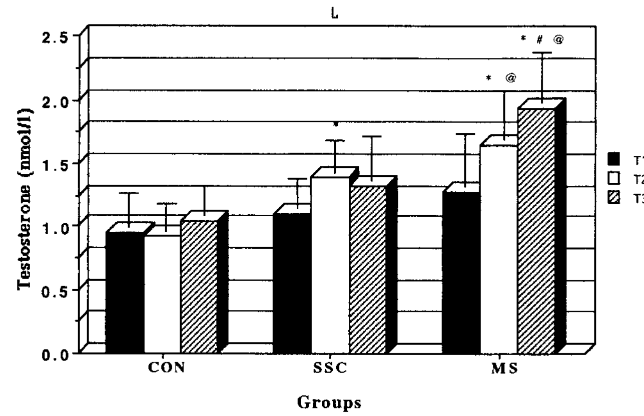

FIGURE 1—The effects of low- and high-volume resistance training on resting serum testosterone concentrations in women. * $P \leq 0.05$ from corresponding preexercise time point T1. # $P \leq 0.05$ from corresponding time point T2. @ $P \leq 0.05$ between groups.

Muscular performance data are presented in Table 4. Both bench press and leg press 1 RM increased significantly at T2 in SSC and MS. However, only MS showed a significant increase from T2 to T3 for the bench press and leg press 1 RM. The increases observed for both exercises at T2 and T3 were significantly greater for MS. The number of repetitions performed with 80% of 1 RM for the bench press increased significantly at T2 only for the MS group. Both SSC and MS showed a significant increase at T3 compared with T1, but only MS showed a significant increase from T2 to T3. For the leg press, both SSC and MS increased at T2 and T3 compared with T1. However, only MS increased from T2 to T3. The increases observed at T2 and T3 for both exercises were significantly greater in MS. A significant increase was observed for the number of sit-ups performed in 1 min at T2 and T3 compared to T1 for SSC and MS but only MS showed a significant increase from T2 to T3. Both increases were significantly greater for MS than SSC (42 vs 13%, respectively). Lower body power assessed by the Wingate test increased only for MS at T2 and T3. Lower body power assessed by the vertical jump increased in SSC and MS at T2 and T3 compared with T1, but only MS showed a significant increase from T2 to T3. Both increases at T2 and T3 were significantly greater for MS. Only the MS group significantly improved 40-yard dash time at T2 and T3. No significant differences for any variable were observed in the CON group over the training period.

Resting serum hormonal data are presented in Figures 1–5. Serum testosterone concentrations increased significantly in SSC and MS at T2 compared with T1. The MS group showed a significant increase in testosterone concentrations at T3 compared with T1 and T2. Serum cortisol concentrations significantly decreased in MS at T2 and T3 compared to T1. In addition, serum cortisol decreased significantly at T3 compared with T2. No differences were observed in SSC. The testosterone/cortisol ratio followed the pattern of responses expected from the testosterone and cortisol changes. SSC increased significantly at T2

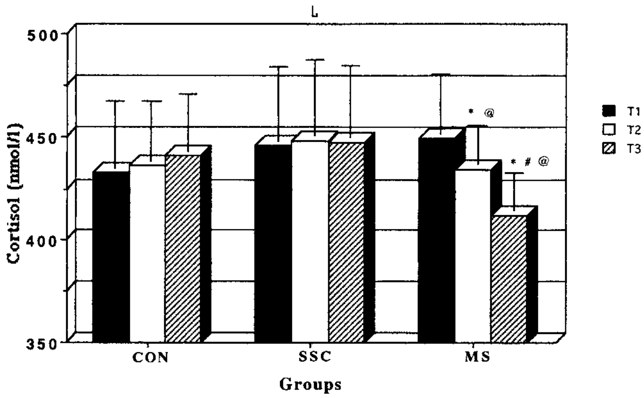

FIGURE 2—The effects of low- and high-volume resistance training on resting serum cortisol concentrations in women. * $P \leq 0.05$ from corresponding preexercise time point T1. # $P \leq 0.05$ from corresponding time point T2. @ $P \leq 0.05$ between groups.

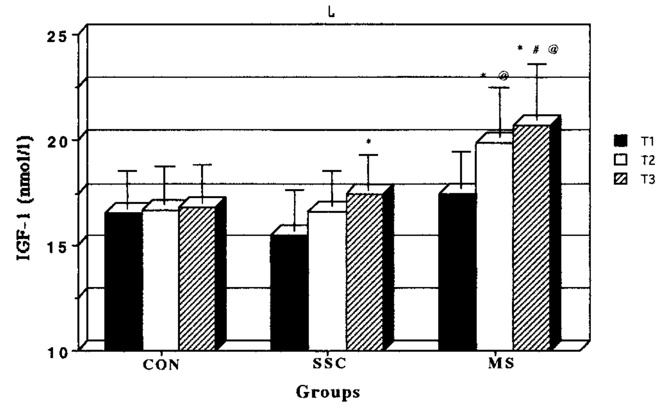

FIGURE 4—The effects of low- and high-volume resistance training on resting serum IGF-1 concentrations in women. * $P \leq 0.05$ from corresponding preexercise time point T1. # $P \leq 0.05$ from corresponding time point T2. @ $P \leq 0.05$ between groups.

compared with T1, whereas the MS group significantly increased at T2 and T3, and the values were significantly higher than both SSC and CON. Serum IGF-1 increased significantly in SSC at T3 compared with T1 and in MS at T2 and T3 compared with T1. No significant differences in serum GH were observed in either training group at any time point. In addition, no significant hormonal differences were observed in the CON group at any time point.

DISCUSSION

We had hypothesized that periodized resistance training would continue to create an effective exercise stimulus that would result in a higher magnitude of change in muscular performance over a long-term training period. Essentially, this was the primary finding of this investigation. The MS group demonstrated greater: increases in upper and lower body maximal strength, increases in muscular power and speed, and increases in high-intensity local muscular endurance compared with the SSC training group. In addition, higher volumes of training mediated several underlying physiological changes related to increases in lean body mass, decreases in percent body fat, increases in resting serum testosterone and IGF-1 concentrations, and decreases in resting serum cortisol concentrations when compared with a low-volume, single-set circuit-type program in previously untrained women.

Studies attempting to compare higher-volume, multiple-set and low-volume, single-set resistance training programs have typically ranged from 8 to 14 wk in duration (2,10,25,27–29). Such training durations may not allow adequate time for separation of training adaptations related to muscle strength performance (7). In the present study, increases in the bench press and leg press 1 RM strength were greater in magnitude, especially over the last 3 months of training. This finding underscores the importance of long-term training studies to partial out adaptational differences between resistance training programs. In addition, these data show that low-volume, single-set circuit training programs are effective in the maintenance of strength. The greater muscle strength increases observed in the higher volume group may have been mediated by the greater increases in fat-free mass.

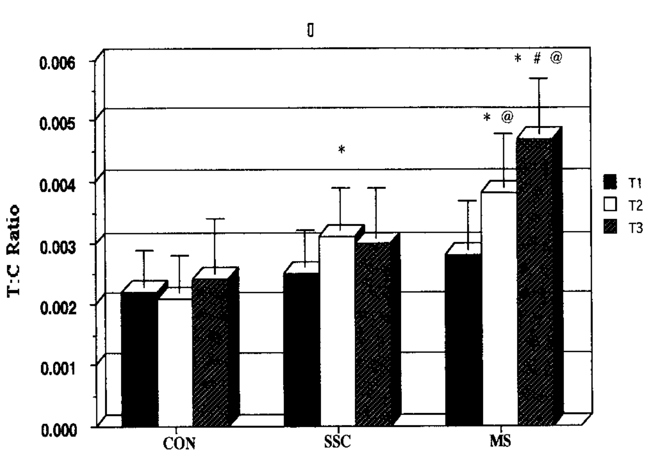

FIGURE 3—The effects of low- and high-volume resistance training on resting testosterone/cortisol ratio (T/C) in women. * $P \leq 0.05$ from corresponding preexercise time point T1. # $P \leq 0.05$ from corresponding time point T2. @ $P \leq 0.05$ between groups.

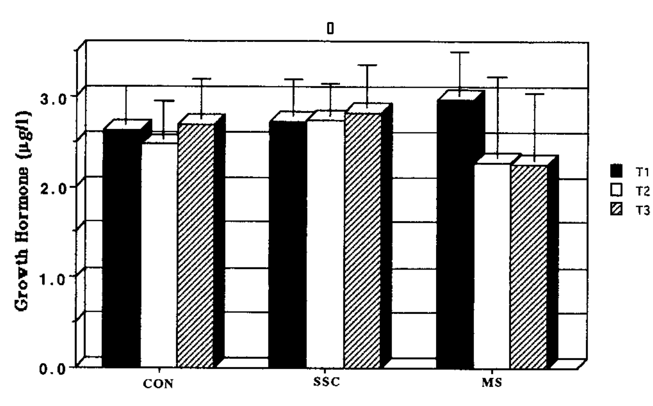

FIGURE 5—The effects of low- and high-volume resistance training on resting serum growth hormone concentrations in women. No significant differences were observed in any group.

Remarkable differences were observed between the two different training groups in lower body power (determined by the Wingate test), vertical jump, and sprint speed development. For example, at T3 the MS group increased power by 34% (approximate average increase in both VJ and Wingate tests), whereas SSC only increased power by 7% (see Table 4). The experimental differences in volume, exercise selection (i.e., hang clean, squat in the MS group), intensity, and velocity of movements used in the two different training programs most likely influenced these findings (35). Kraemer (17) and Stone et al. (34) have both reported significantly greater increases in muscular power when high-volume, higher velocity exercise movements (e.g., hang cleans) were used in training programs. Further support for this hypothesis was observed in a study by Ostrowski et al. (26), who did not utilize any higher velocity training movements and reported an insignificant decrease for the vertical jump after 10 wk of low-volume, single-set resistance training. In the present study, the MS group performed their repetitions with moderate-to-explosive contraction velocities over a range of training loads. Conversely, the SSC group performed each repetition in a slow and controlled manner (e.g., a 2-s concentric phase and a 4-s eccentric phase). In addition, the load range only spanned one set of 8–12 repetitions performed to momentary muscular failure (27,29). Higher velocities of resistance exercise have been reported to be more effective for increasing muscular power (3). Therefore, training solely with relatively slow movements appears to have limited power development in the SSC group. Lastly, proper exercise selection is important for increasing power and speed development. Multiple-joint closed-kinetic chain exercises are typically regarded as the most effective for increasing both upper and lower body power (17,35). Concomitantly, the inclusion of such closed-kinetic movements (i.e., hang clean, squats) in a training program appears to have the greatest amount of transfer specificity to sprint speed.

This study utilized a leg press and bench press with 80% of 1 RM to operationally define local muscular endurance. Our data showed that the higher volume MS group increased local muscular endurance (at relatively high intensity) to a greater extent than the lower volume SSC group. The higher number of repetitions performed in the MS group was probably mediated by the higher number of repetitions performed in a workout and over the course of the training program. In general, the SSC group increased by a combined average of 14%, whereas the MS group increased by a combined average of 42% for these two exercises (see Table 4). The number of sit-ups performed in one min also increased to a significantly greater extent in MS (i.e., MS = 42%; SSC = 13%). These findings support previous studies in men comparing high-volume versus low-volume, single-set training programs (17,24). McGee et al. (24) reported both cycle endurance and the maximal number of repetitions performed with 60 kg for the squat were significantly greater in the multiple-set group (19 and 73%, respectively) compared with the single-set group (12 and 46%, respectively). Therefore, our data support the hypothesis that periodized high-volume multiple-set protocols improve local muscular endurance to a greater extent than a low-volume, single-set programs.

In this study, several hormones were examined in order to gain insights into the potential underlying mechanism(s) that may, in part, be responsible for higher level muscular performance adaptations. Testosterone is a well known potent androgenic-anabolic hormone in both men and women. Few changes in testosterone have typically been observed in women (4). Nevertheless, even small increases as a part of a physiological adaptation strategy may be important to anabolic changes in a woman's neuromuscular system. The resting hormone concentrations measured in this investigation were carefully phased into their menstrual cycle, which allowed greater sensitivity for determined changes with training. The results of the present study showed small but significant increases in resting serum testosterone concentrations for both training groups. However, this increase was greater for the MS group over the 6-month training period. Stoessel et al. (33) reported no differences in resting serum testosterone concentrations between untrained and highly competitive women weightlifters. However, menstrual phase was not accounted for in their study and cross-sectional designs cannot determine the time course of changes. Staron et al. (32) reported no significant differences in serum testosterone concentrations over the first 8 wk (i.e., 16 workouts used in this study over 8 wk) of resistance training in women, indicating that, different from the men in the study, acute homeostatic adaptations may not be engaged with just 16 workouts. In addition, Häkkinen et al. (13) reported no statistically different changes in resting serum testosterone after 16 wk of power training, but, again, menstrual phase was not accounted for potentially masking the small but significant alterations in serum testosterone with training. Although the mechanism(s) involved with the chronic increases in serum testosterone remain speculative in women, it appears to be highly individual and a large contribution has been shown to be derived from adrenal sources (19).

Serum cortisol concentrations have been reported to increase during an acute bout of resistance exercise in women (4,18,19). Cortisol plays several regulatory roles in metabolism and negatively impacts protein metabolism when attempting to conserve glycogen stores. In the present study, resting serum cortisol concentrations significantly decreased at T2 and T3 only in the MS group. An increase in resting serum testosterone or decrease in resting serum cortisol may indicate tissue anabolism. The testosterone:cortisol ratio has been used as a marker of anabolic status (13,14). Resting serum concentrations of cortisol in women have shown no difference after 16 wk of power training (13) and have shown decreases after 8 wk of high-volume resistance training (21). The data from the current study show that the MS group had a distinct advantage for this theoretical predominant anabolic environment compared to SSC and CON. In men, reductions in serum cortisol have been shown with 3 months of heavy resistance training alone (20). Conversely, significant increases were observed when the resistance training program was combined with a high-intensity endurance training program potentially reflecting a potential overtraining phenomenon as a mediating factor in cortisol's adaptational pattern (20). A decrease in resting serum cortisol may be important for a reduction in catabolism of muscle proteins and support hypertrophic accretion of protein by a reduction in protein degradation. This may be especially important in Type I muscle fibers which rely on reduced degradation of protein as a primary mechanism for muscle hypertrophy (8).

Long-term studies investigating changes in the resting serum GH concentrations in women during resistance training have been few. Staron et al. (32) reported no significant differences after 8 wk of resistance training. Our data also indicate no significant differences in either the SSC or MS groups after 6 months of training. These data indicate that immunoreactive GH may be responsive to resistance exercise stress. Alternatively, several factors might explain a lack of change in the resting 22-kDa immunoreactive GH. First, the 22-kDa GH has been the primary variant measured and its response is very pulsatile (37). Typically, reductions in resting GH concentrations have been observed to decrease in response to endurance training. The data from the current investigation indicates a potentially different physiological mechanism of adaptation when compared to endurance training results (endurance vs resistance training) (37). In addition, there is growing body of evidence that relates to the dichotomy of molecular weight variants of GH that are measured via immunoassay and bioassay (23). The response of bioassay GH in the previous training studies remains unknown, but the possibility of alterations in other molecular weight variants with resistance exercise and training requires further study.

Insulin-like growth factor-1 (IGF-1) is a 7.5-kDa polypeptide that exerts significant anabolic effects on skeletal muscle (16). IGF-1 is not typically regulated in a purely endocrine manner and autocrine mechanisms are thought to play significant roles in mediating its effects on skeletal muscle (9). In the present study, resting serum IGF-1 increased significantly at T3 compared with T1 for the SSC group but again increased to a significantly greater extent at all time points for the MS group. Long-term (i.e., 6 months) increases in resting serum concentrations of IGF-1 have been reported previously in women undergoing high-volume training (16). Interestingly, the increase in resting IGF-1 concentrations in the present study occurred in the absence of any observed changes in immunoreactive GH. This may be more representative of the total influence of a composite GH response over the 24-h d. It is possible that the changes in other GH factors (pulse amplitude, magnitude, frequency etc.) may provide alternative hypotheses for a change in IGF-1 with no changes in a single sample of GH (37). In addition, although no changes in immunoreactive GH were observed, no data exist as to the influence of higher molecular weight GHs on IGF-1 secretion.

In summary, a high-volume, periodized multiple-set resistance training program was superior to a low-volume, single-set program for improving muscular performances in previously untrained women. The results of the present study support previous findings (7,17,22,34,36) in men where high-volume, periodized multiple-set resistance training programs were superior to low-volume single-set programs for increasing muscular strength. Nevertheless, several prior studies have been too short in duration to effectively distinguish significant differences between inherently diverse resistance training programs using different volumes of exercise. In addition, the intensity exposure of the low circuit volume program was in the standard range of 8–12 RM, whereas the higher volume periodized resistance training program had workouts which spanned higher intensity range (e.g., 3–5 RM) used with the periodized program. This heavier component may well have provided additional stimuli for changes observed in this program, thus pointing out a potential limitation in using only the 8–12 RM loading range. Thus, the program differences reflect inherent differences in choices in variables popularly used today in resistance training. Comparisons of such different training programs allow for practical use and understanding of the applied context validity. Interestingly, to date, no study has reported superior performance enhancement using single-set programs. Increases in muscular strength, local muscular endurance, anaerobic power, and speed were all greater for MS versus the SSC training group. In addition, resting serum testosterone and IGF-1 increased to a greater extent in the MS group, whereas resting serum cortisol decreased to a greater extent in the MS group indicating a more anabolic environment. These hormonal differences may help explain the mechanisms that contributed to the greater increases in lean body mass and decrease in percent body fat observed in the MS group. We had hypothesized that the volume of exercise associated with training variation (i.e., periodization) plays a crucial role in the modulation of the exercise stress and recovery patterns ultimately leading to greater adaptations. This study, in part, supports this hypothesis but more research delineating the specific contribution of variation under different training conditions remains for future research (7). Therefore, these results indicate that training volume is a significant variable associated with resistance training over longer periods of training in women. It appears that the variation of volume and intensity of a resistance training program is vital for improvements in muscular performance beyond those of the initial stage of training.

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