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Quantitative Analysis of Single- vs. Multiple-Set Programs in Resistance Training

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Abstract. Wolfe, B.L., L.M. LeMura, and P.J. Cole. Quantitative analysis of single- vs. multiple-set programs in resistance training. *J. Strength Cond. Res. 18(1):35–47. 2004.*—The purpose of this study was to examine the existing research on single-set vs. multiple-set resistance training programs. Using the meta-analytic approach, we included studies that met the following criteria in our analysis: (a) at least 6 subjects per group; (b) subject groups consisting of single-set vs. multiple-set resistance training programs; (c) pretest and posttest strength measures; (d) training programs of 6 weeks or more; (e) apparently "healthy" individuals free from orthopedic limitations; and (f) published studies in English-language journals only. Sixteen studies generated 103 effect sizes (ESs) based on a total of 621 subjects, ranging in age from 15–71 years. Across all designs, intervention strategies, and categories, the pretest to posttest ES in muscular strength was ($\bar{\chi}$ = 1.4 ± 1.4; 95% confidence interval, 0.41–3.8; $p < 0.001$). The results of 2 × 2 analysis of variance revealed simple main effects for age, training status (trained vs. untrained), and research design ($p < 0.001$). No significant main effects were found for sex, program duration, and set end point. Significant interactions were found for training status and program duration (6–16 weeks vs. 17–40 weeks) and number of sets performed (single vs. multiple). The data indicated that trained individuals performing multiple sets generated significantly greater increases in strength ($p < 0.001$). For programs with an extended duration, multiple sets were superior to single sets ($p < 0.05$). This quantitative review indicates that single-set programs for an initial short training period in untrained individuals result in similar strength gains as multiple-set programs. However, as progression occurs and higher gains are desired, multiple-set programs are more effective.

Key Words. strength training, training volume, training intensity

Introduction

Resistance training is an effective method for developing musculoskeletal strength and is often prescribed for general fitness, athletic conditioning, rehabilitation, and the prevention of orthopedic or muscular injuries (2–5, 17). The physiological adaptations that result from resistance training include increases in musculoskeletal strength, muscle mass, bone mass, and connective tissue thickness (54, 55). As a part of a broader fitness program, resistance training may reduce the risk of coronary heart disease, non–insulin-dependent diabetes, certain types of cancer, and obesity (by increasing resting metabolism) (20, 28, 38).

The beneficial effects of strength training depend on the manipulation of several factors, including the intensity, frequency, and volume of training. These factors are the product of the number of sets and repetitions completed (18). Strength training guidelines have been developed for healthy adults (4). It is recommended that 8–10 exercises should be performed 2–3 days per week as a starting point and that resistance training programs should be based on individual or specific goals. These recommendations are based on the practical feature of personal time prioritization.

Resistance training has become one of the most popular forms of exercise for developing musculoskeletal fitness and overall health (18). Various individuals with specific goals use resistance training as part of their conditioning program. However, numerous questions have emerged concerning the exercise prescription of various resistance training programs that can produce functional changes in strength.

In many studies, the use of multiple-set programs in resistance training has been shown to produce superior strength gains, power, hypertrophy, athletic performance, and especially local muscular endurance in trained and untrained individuals (6, 29–31, 49) when compared with single-set programs. Fleck and Kraemer (18) suggested that after the neuromuscular system adapts to a strength stimulus, an increase in training volume is needed for additional adaptations to occur. Other frequently cited studies authored by Kraemer and coworkers suggested further that the use of multiple sets is most appropriate for individuals who are trained (7, 30, 31, 48, 49). A clear implication that emerges from this statement is that the use of a single set may be appropriate for those who are beginners or untrained during the initial training period. Indeed, Starkey et al. (52) examined the effect of resistance training volume on strength and muscle thickness in untrained men and women. They found that a single set of high-intensity resistance training was as effective as 3 sets for increasing knee extension and flexion isometric torque and muscle thickness in untrained adults.

Because there are conflicting data among research studies, there are also conflicting opinions in published reviews. A qualitative review by Carpinelli and Otto (10) purported that most studies using multiple sets reported no significant difference in strength increases when compared with single-set programs. A more recent review by Carpinelli (9) suggested further that the 1962 research by Berger (6), which served as "the genesis of the unsubstantiated belief that multiple sets are required for optimal gains in strength," was replete with design and methodological flaws. In contrast, a review authored by Stone et al. (56) reported that a single set to failure did not produce the same effects on strength, power, or high-intensity endurance exercise when compared with multiple-set training programs.

Given the controversy that exists regarding the number of sets necessary to produce functional changes in strength, we conducted a quantitative review of the resistance training literature using the meta-analytic approach. In a meta-analysis, studies are converted to individual data points and are subjected to parametric statistical analyses. This allows researchers to make comparisons on a common research problem that would be difficult or impossible to perform using conventional research paradigms (33). A common methodological conflict in many of the studies in the resistance training literature is related to research design. As an example, many studies were designed to demonstrate program superiority rather than to isolate set number (i.e., single vs. multiple sets). Thus, the purpose of this study was to examine the existing research on resistance training programs and to identify the factor or combination of factors that may affect increases in muscular strength. An additional purpose was to identify areas of potential strengths and weaknesses in the literature and to provide directions for future research on this topic.

Methods

Data Sources

The search for literature was limited to human exercise training studies published in 1962–2002 in which single- vs. multiple-set programs were compared in trained and untrained individuals. Studies were located via computer-generated citation searches of the following databases: Current Contents, Medline, Dissertation Abstracts International, Psychological Abstracts, and Sport Discus. Extensive hand searching and cross-referencing were performed from the bibliographies of previously retrieved studies and from review articles. A sample of the descriptive terms that were used to locate relevant studies in English research journals included resistance training, single sets, multiple sets, and single vs. multiple sets. Most of the relevant articles came from journals that publish studies on resistance training (e.g., *European Journal of Applied Physiology, Medicine and Science in Sports and Exercise, National Strength and Conditioning Association Journal, Journal of Strength and Conditioning,* etc.).

Study Selection

Studies were included if they met the following criteria: (a) at least 6 subjects per group; (b) subject groups consisting of single vs. multiple sets; (c) pretest and posttest strength measures; (d) used resistance training as a mode of training; (e) training programs of 6 weeks or longer; (f) apparently "healthy" individuals (e.g., free from orthopedic limitations); and (g) published studies in English-language journals only.

Data Extraction

The studies in this review were coded according to the following characteristics: (a) exercise program characteristics (length, frequency, duration, mode, and number of sets and repetitions performed); (b) study characteristics (author[s], year, research design, number and type of comparison groups [e.g., single vs. multiple sets], and number of subjects); (c) subject characteristics (age, sex, health status, and fitness status [e.g., trained or untrained]), and (d) primary outcomes (changes in functional strength.) To avoid interobserver bias, the authors of this study independently extracted all data. The authors then met and reviewed each item for accuracy and consistency. Disagreements were resolved by consensus. Several studies met our inclusion criteria but were missing data vital to our analyses (i.e., means and *SD*s); therefore, we contacted the authors to obtain raw data whenever possible.

Statistical Analyses

The primary dependent variable (outcome) in this study was changes in strength for resistance training exercises in studies using single and multiple sets. Subgroup analysis was performed to examine between-group differences. The subgroups were partitioned according to (a) whether the subjects trained until failure vs. general fatigue; (b) program duration (6–16 vs. ≥17 weeks); (c) sex; (d) age (15–25, 37–41, and 47–71 years); (d) the training status of the subjects (trained vs. untrained); (e) the research design (randomized controlled trial [RCT], controlled trial [CT], and no control [NC]); and (f) the impact factor (IF) of the journal in which the study was published (0–2 vs. ≥2.1). Analyses of the dependent variables partitioned by subgroup were performed when the data for each coded characteristic were available; therefore, most studies generated numerous effect sizes (ESs).

The meta-analytic approach was popularized by Glass (19) as a mode of quantitatively integrating findings from various studies. Each study serves as a unit of analysis, and the findings among studies are compared through the calculation of a common metric, the ES. The ES is defined as the difference between the means of the experimental group (ME) and the means of the control group (MC), divided by the control group *SD* (SC). The ES formula is applied as follows:

$$\mathrm{ES} = \frac{\mathrm{ME} - \mathrm{MC}}{\mathrm{SC}}$$

ES Computation and Analysis

The research findings from each study were transformed into the common ES metric that was submitted for further statistical analysis. The purpose of the ES analysis was to allow us to draw conclusions regarding the efficacy of single vs. multiple sets in the existing literature. In the present study, the primary dependent variable of interest used for analysis was muscular strength. For those studies whose research design included a control group, the standard ES formula was applied. When a research design did not include a control group, the pretraining to posttraining changes in functional strength were used to determine the ESs for each study. The pretraining-dependent variables were subtracted from the posttraining-dependent variables to keep the algebraic sign of the ES positive. Thus, a positive ES indicated an improvement in strength following the training period. The differences between the pretraining and posttraining measures for the primary outcomes were divided by a pooled variance. A pooled estimate of the variance provided a more precise estimate of the population variance. The pooled variance weighted for sample size was obtained by using the following formula:

$$\mathrm{Sp} = \sqrt{\frac{S_1{}^2(n1 - 1) + S_2{}^2(n2 - 1)}{n1 + n2 - 2}}$$

for which Sp stands for the pooled *SD*, S_1^2 is the variance for the control group or group 1, S_2^2 is the variance for the experimental group or group 2, nl is the number of subjects in group 1, and n2 is the number of subjects in group 2.

The variance for each ES and a correction for small sample bias were calculated using the procedures developed by Efron and Tibshirani (16). The meta-analytic approach is based on the principle of normally distributed data; however, since this is not always the case, we corrected for bias by bootstrap resampling to generate 95% confidence intervals (CIs) around the mean ES. The estimate generated from this approach is based on the sample itself rather than from a theoretical distribution. This nonparametric method (which is not restricted by large sample assumptions) of estimating the reliability of the original sample estimate is calculated by randomly drawing from the available sample, with replacement (24). Each time an observation is selected for a new sample, each element of the original sample has an equal chance of being selected. If the CI included 0, we concluded that there was no effect of the number of sets on strength. For studies that generated more than 1 ES because of the presence of more than 1 treatment group, the ESs were treated as independent data points but were also combined to determine the impact of ESs on overall results. To obtain a measure of the variability of the data, we examined the heterogeneity of the ESs by identifying the outliers beyond the 10th and 90th percentiles. The authors examined each study represented by an outlier further. If a methodological flaw or physiologic reason existed to explain the variability, the study was precluded from additional analysis. Differences of opinion were resolved through discussion and consensus. In addition, because there is a tendency for studies to be published that generate statistically significant results, we also addressed the issue of publication bias. This was a pertinent concern because the studies included in this review were derived exclusively from research journals. We examined publication bias with the Kendall rank correlation test (r_ϑ). This consisted of correlating observed outcomes (i.e., ES changes muscular strength with sample size).

We used a random-effects model to pool the ES data on changes in muscular strength if heterogeneity was present. The ESs were then averaged across studies to determine treatment effects and were further stratified according to coded characteristics of interest. Analysis of variance (ANOVA)–like procedures and t-tests for meta-analysis were used to determine significant differences in muscular strength. When a statistical difference was found, a Tukey post hoc test was used to determine which means were statistically different from each other. An α level of $p \leq 0.05$ was established a priori to establish the presence of significant differences. Data were analyzed with Sigma Stat software (50).

RESULTS

Study Selection

A total of 39 studies were located and retrieved that addressed the issue of single vs. multiple sets in resistance training programs. From this group of studies, 16 met our criteria for inclusion. The 16 studies generated 103 ESs based on a total of 621 subjects, ranging in age from 15–71 years. Because most investigators reported pretest to posttest strength changes for more than 1 resistance exercise, many studies generated numerous ESs. Reasons for the rejection of studies in this analysis included a lack of or an inability to obtain pretest to posttest strength data, the use of the same subject pool in more than 1 study, cross-sectional rather than longitudinal designs, and short-term response study designs. The time to code each study ranged from 30 minutes to 2.0 hours ($\bar{\chi} = 1.25 \pm 0.20$ hours). An examination of the outliers beyond the 10th and 90th percentiles revealed 4 outliers (34, 37, 46, 48). These outliers remained in the analysis because neither physiological nor methodological reasons were found to exclude them. Additionally, no publication bias was found for ES changes in muscular strength ($p = 0.73$). The average length of training was 6–25 weeks ($\bar{\chi} = 13.88 \pm 72$). A summary of the coded characteristics of exercise prescription reported in the studies is found in Table 1.

Main Effects

Across all designs, intervention strategies, and categories, the ESs ranged from −0.31–10, and the mean pretest to posttest ES in muscular strength was ($\bar{\chi} = 1.4 \pm 0.1.4$; 95% CI, 0.4– 3.8; $p < 0.001$). According to Cohen's categories to classify ESs (<0.41 = small; 0.41–0.70 = moderate; >0.70 = large) (11), the degree to which resistance training produced favorable changes in muscular strength ranged from small to large, with a large, overall effect. The main effects are summarized in Table 2.

Subject Characteristics

All of the subjects were identified as "healthy" because they were free from orthopedic disabilities and comorbidities that might affect their ability to respond to the resistance training programs. A total of 12 studies included male and female subjects who were subjected to statistical analysis for sex differences. A 2×2, 1 between-factor, 1 within-factor ANOVA was performed. The between factor was sex (male and female) and the within factor was number of sets used for resistance training (single and multiple). The analysis of simple main effects revealed that there were neither sex differences nor an interaction between sex and the number of sets performed. A significant difference was found for the different levels of age groups (15–21, 37–41, and 46–71 years); the oldest age group generated significantly higher mean ESs when compared with their younger counterparts ($p < 0.001$). However, there was no significant interaction for age and the number of sets performed; rather, a higher mean ES trend for multiple-set over single-set programs was evident. We also analyzed the effects of training status (trained vs. untrained) and the number of sets performed. Simple main effects analysis revealed that untrained subjects obtained the highest mean increases in muscular strength when compared with trained subjects. A significant interaction was found for trained subjects who performed multiple sets ($p < 0.001$). These data are summarized in Table 3.

Subgroup Analysis

We wanted to determine if the number of sets performed was affected by the length of the resistance training program. Programs that lasted 17–40 weeks did not generate significantly higher mean ESs when compared with those that lasted 6–15 weeks; however, the difference in the mean values for set number was significantly different when allowing for the effects of differences in program duration ($p < 0.005$). Significant interactions were also

TABLE 1. Coded characteristics of the studies: the exercise prescription.*

Study	Strength measures	Until failure	Frequency (d/wk)	Program duration (wk)	Modality	Effect size
Abe et al. (2000) (1)	1RM	Yes	3	12	*Weight machine*	ID
					1 set × 8–12 reps (males)	
					bench press	
					leg extension	
					3 sets × 8–12 reps (males)	
					bench press	
					leg extension	
					1 set × 8–12 reps (females)	
					bench press	
					leg extension	
					3 sets × 8–12 reps (females)	
					bench press	
					leg extension	
Berger (1962) (6)	1RM	Yes	3	12	*Bench press*	ID
					1 set × 2 reps	
					1 set × 6 reps	
					1 set × 10 reps	
					2 sets × 2 reps	
					2 sets × 6 reps	
					2 sets × 10 reps	
					3 sets × 2 reps	
					3 sets × 6 reps	
					3 sets × 10 reps	
Borst et al. (2001) (7)†	1RM	Yes	3	25	*Weight machine*	
					1 set × 8–12 reps	1.4
					3 sets × 8–12 reps	3.33
Coleman (1977) (12)†	1RM	Yes	3	10	*Universal machine*	
					2 sets × 8–10 reps	
					bench press	0.42
					bicep curl	0.87
					lateral pulldown	1.63
					leg press	0.98
					Nautilus machine	
					1 set × 10–12 reps	
					bench press	0.42
					bicep curl	0.81
					lateral pulldown	1.54
					leg press	0.96
Craig and Kang (1994) (13)	1RM	NI	NI	NI	1 × 75% of 1RM	ID
					1 × 90% of 1RM	
					2 × 75% and 90% of 1RM	
De Hoyos et al. (1998) (abstract) (14)	1RM	To fatigue	3	25	1 set × 8–12 reps	
					bench press	0.55
					row	0.83
					bicep curl	0.70
					leg extension	0.80
					leg curl	0.79
					3 sets × 8–12 reps	
					bench press	0.92
					row	1.20
					bicep curl	0.99
					leg extension	0.94
					leg curl	1.13
De Hoyos et al. (1997) (abstract) (15)	1RM	Yes	3	10	1 set × 10–15 reps	
					bench press	0.20
					leg press	0.5
					3 sets × 10–15 reps	
					bench press	0.31
					leg press	0.71
Gotshalk et al. (1997) (21)	1RM	Yes	NI	NI	1 set × 10 reps	ID
					3 sets × 10 reps	
Hass et al. (1998) (abstract) (22)	1RM	Yes	3	13	1 set × 8–12 reps	
					leg extension	0.43
					leg curl	0.36

TABLE 1. Continued

Study	Strength measures	Until failure	Frequency (d/wk)	Program duration (wk)	Modality	Effect size
					bench press	0.21
					shoulder press	0.19
					bicep curl	0.17
					3 sets × 8–12 reps	
					leg extension	0.42
					leg curl	0.45
					bench press	0.24
					shoulder press	0.28
					bicep curl	0.24
Hass et al. (2000) (23)†	1RM and isometric extension and flexion	To volitional fatigue	3	13	*Weight machine*	
					1 set × 8–12 reps (kg/LBM)	
					leg extension	0.75
					leg curl	0.33
					bench press	0.33
					shoulder press	0.25
					bicep curl	0.33
					3 sets × 8–12 reps (kg/LBM)	
					leg extension	0.75
					leg curl	1.00
					bench press	0.31
					shoulder press	0.50
					bicep curl	0.33
Hurley et al. (1995) (25)†	3RM	Near-maximum effort for each repetition	3	16	*Pneumatic machine*	
					1 set × 15 reps	
					bench press	1.66
					lateral pulldown	1.73
					shoulder press	2.60
					upper back	2.88
					2 sets × 15 reps	
					leg press	2.14
					leg extension	2.09
Jacobson (1986) (26)	1RM and isometric	Yes	3	10	*Nautilus machine*	ID
					leg extension	
					1 set × 6 reps MR	
					1 set × 6 reps MR isometric	
					3 sets × 6 reps	
					3 sets × 6 reps isometric	
Koffler et al. (1992) (28)	3RM and isokinetic torque	Near-maximum effort for each repetition	3	13	*Pneumatic machine*	ID
					1 set × 15 reps	
					UB (mean ± *SEM*)	
					2 sets × 15 reps	
					LB (mean ± *SEM*)	
Kraemer (1997) experiment 2 (29)†	1RM	Yes	3	12	*Nautilus machine*	
					1 set × 8–12 reps	
					bench press	0.07
					leg press	0.13
					3 sets × 8–12 reps	
					bench press	0.19
					leg press	0.76
Kraemer (1997) experiment 3 (29)†	1RM	Yes	3	14	*Universal and marcy weight machines*	
					1 set × 8–10 reps	
					bench press	
					hang clean from knees	0.08
					Free weights and universal machine	0.06
					2–5 sets × 1–10 reps	
					bench press	0.31
					hang clean from knees	0.39
Kraemer (1997) experiment 4 (29)†	1RM	Yes	3	24	*Weight machine and free weights*	0.24
					1 set × 8–12 reps	

TABLE 1. Continued

Study	Strength measures	Until failure	Frequency (d/wk)	Program duration (wk)	Modality	Effect size
					leg press	0.59
			4		2–5 sets × 3–15 reps	
					leg press	
Kraemer et al. (2000) (30)†	1RM	Yes	2–3	36	1 set × 8–10 reps	
					bench press	0.42
					shoulder press	0.33
					leg press	0.08
					2–4 sets × 4–15 reps	
					bench press	1.5
					shoulder press	1.1
					leg press	1.2
Kramer et al. (1997) (31)†	1RM squat		3	14	*Free weights*	
		Yes			1 set × 8–12 reps	0.62
		No			3 sets × 10 reps	0.69
		No			1–3 sets × 2–10 reps	0.59
Marx et al. (2001) (34)†	1RM	Yes	3	24	1 set × 8–12 reps	
			4			
					bench press	1.69
					leg press	1.37
					2–4 sets × 3–15 reps	
					bench press	6.38
					leg press	4.69
McGee et al. (1992) (35)	Reps × mass	1 × 12 to failure, other groups not to failure	3	7	squat	ID
					1 set × 12 reps	
					3 sets × 3–10 reps	
					3 sets × 10 reps	
Messier and Dill (1985) (36)†	Cybex II isokinetic dynamometer	To fatigue	3	10	*Nautilus machine*	
					1 set × 15–20 reps LB	
					knee extensors	−0.31
					knee flexion	1.07
					1 set × 8–12 reps UB	
					elbow extensors	2.78
					elbow flexors	0.42
					Free weights	
					3 sets × 6 reps	
					knee extensors	1.94
					knee flexion	0.92
					elbow extensors	1.94
					elbow flexors	0.86
Miller et al. (1994) (37)†	3RM	Near-maximum effort for each repetition	3	16	*Pneumatic machine*	
					1 set × 15 reps UB	10.81
					2 sets × 15 reps LB	5.22
Mulligan et al. (1996) (39)	NI	Yes	NI	NI	*Universal machine*	ID
					1 set × 10 reps	
					3 sets × 10 reps	
Nicklas et al. (1995) (40)	3RM	Near-maximum effort for each repetition	3	16	*Pneumatic machine*	ID
					1 set × 15 reps	
					bench press	
					shoulder press	
					lateral pulldown	
					upper back row	
					2 sets × 15 reps	
					leg press	
					leg extension	
Ostrowski et al. (1997) (41)†	1RM	Yes	4	10	*Free weights*	
					1 set × 9–12 reps	
					squat	0.35
					bench press	0.32
					2 sets × 9–12 reps	
					squat	0.35
					bench press	0.48

TABLE 1. Continued

Study	Strength measures	Until failure	Frequency (d/wk)	Program duration (wk)	Modality	Effect size
					4 sets × 9–12 reps	
					squat	0.68
					bench press	0.17
Pollock et al. (1998) (abstract) (42)	NI	To fatigue	3	25	1 set × 8–12 reps	ID
					3 sets × 8–12 reps	
Reid et al. (1987) (43)†	Isometric strength	Yes	3	8	*Weight machine*	
					1 set × 15 reps	
					elbow flexion	1.01
					elbow extension	2.51
					knee flexion	0.27
					knee extension	1.89
					shoulder flexion	1.36
					shoulder extension	0.47
					1 sets × 3–10 reps	
					elbow flexion	0.86
					elbow extension	0.71
					knee flexion	0.76
					knee extension	0.89
					shoulder flexion	1.02
					shoulder extension	0.59
					3 sets × 6 reps	
					elbow flexion	0.59
					elbow extension	0.87
					knee flexion	1.31
					knee extension	0.64
					shoulder flexion	0.99
					shoulder extension	0.93
					2 sets × 15 reps	
					elbow flexion	0.57
					elbow extension	0.75
					knee flexion	0.88
					knee extension	0.82
					shoulder flexion	1.06
					shoulder extension	1.45
Ryan et al. (1995) (45)†	Peak isometric torque	Near-maximum effort for each repetition	3	16	*Pneumatic machine*	
					1 set × 15 reps RT	
					bicep curl	2.26
					tricep extension	0.73
					1 set × 15 reps RTWL	
					bicep curl	0.20
					tricep extension	3.68
					2 sets × 15 reps RT	
					leg extension (30°/s)	0.59
					leg extension (180°/s)	0.95
					2 sets × 15 reps RTWL	
					leg extension (30°/s)	1.48
					leg extension (180°/s)	1.44
Ryan et al. (1994) (46)†	3RM	Near-maximum effort for each repetition	3	16	*Pneumatic machine*	
					1 × 15 reps	
					bench press	1.55
					lateral pulldown	1.63
					shoulder press	2.40
					upper back	2.88
					2 × 15 reps	
					leg press	1.85
					leg extension	2.09
Sanborn et al. (2000) (48)†	1RM	Yes	3	8	1 set × 8–12 reps	
					squat	2.70
					3–5 sets × 2–10 reps	
					squat	4.00

Table 1. Continued

Study	Strength measures	Until failure	Frequency (d/wk)	Program duration (wk)	Modality	Effect size
Schlumberger et al. (2001) (49)†	1RM	Yes	2	6	1 set × 6–9 reps	
					leg extension	0.4
					bench press	0.3
					3 sets × 6–9 reps	
					leg extension	1.00
					bench press	0.7
Silvester et al. (1982) (51)	Cable tension	NI	3	8	@ 90°	ID
					1 set × 10–12 reps	
					bicep curl	
					3 sets × 6 reps	
					bicep curl	
					1 set to failure (NM)	
					bicep curl	
					3 sets × 6 reps (NM)	
					bicep curl	
Starkey et al. (1996) (52)†	Isometric strength measures at various angles	To volitional fatigue	3	14	*Isometric strength*	
					1 set × 8–12 reps	
					knee extension	1.65
					knee flexion	3.00
					3 sets × 8–12 reps	
					knee extension	1.98
					knee flexion	2.30
Starkey et al. (1994) (abstract) (53)	Isometric torque at various angles	To fatigue	3	14	*Isometric torque*	ID
					1 set × 8–12 reps	
					knee extension	
					knee flexion	
					3 sets × 8–12 reps	
					knee extension	
					knee flexion	
Stowers et al. (1983) (57)	1RM	To exhaustion	3	7	1–5 sets × 3–10 reps	ID
					1 set × 10 reps	
					3 sets × 10 reps	
Terbizan and Bartles (1985) (abstract) (58)	1RM	NI	3	8	*Universal machine*	ID
					1 set × 6–9 reps	
					1 set × 10–15 reps	
					3 sets × 6–9 reps	
					3 sets × 10–15 reps	
Teruth et al. (1994) (59)†	3RM	Near-maximum effort for each repetition	3	16	*Pneumatic machine*	
					1 set × 15 reps UB	2.05
					2 sets × 15 reps LB	1.85
Vincent et al. (1998) (abstract) (60)	1RM isometric peak torque training weights	NI	NI	25	1 set	ID
					knee extension	
					3 sets	
					knee extension	
Wescott (1986) (61)	NI	NI	3	4	*Weight machine*	ID
					1 set × 10 reps	
					2 sets × 10 reps	
Wescott et al. (1989) (62)	Number of repetitions	Yes	3	10	*Gravitron machine*	ID
					1 set × 5, 10, 15 reps	
					3 sets × 5, 10, 15 reps	
Wolfe et al. (2001) (abstract) (63)	1RM	NI	3	10	1 set × 6 reps	ID
					3 sets × 6 reps	

* ID = insufficient data; LB = lower body; LBM = lean body mass; MR = manual resistance; NI = not indicated; NM = Nautilus machine; rep = repetition; RM = repetition maximum; RT = resistance training; RTWL = resistance training with weight loss; UB = upper body.

† Included in analysis.

TABLE 2. Effective values (mean ± *SD*) for the coded characteristics of the studies.*

Main effects	N	Mean	*SEM*	*p* Value†
Sex differences				NS
Male 1 set	37	1.11	0.08	
Male multiple set	36	0.98	0.90	
Female 1 set	8	1.11	0.28	
Female multiple set	7	1.30	0.30	
Age differences				$p < 0.001$
15–25 years 1 set	14	0.61	0.36	bch
15–25 years multiple set	15	1.08	0.35	e
37–41 years 1 set	6	0.56	0.55	ag
37–41 years multiple set	6	1.03	0.55	df
47–65 years 1 set	14	2.57	0.36	abcde
47–65 years multiple set	10	1.93	0.43	fgh
Training status				$p < 0.001$
Trained 1 set	16	0.29	0.31	abe
Trained multiple set	16	0.70	0.30	acd
Untrained 1 set	39	1.69	0.19	bc
Untrained multiple set	33	1.73	0.21	de
Program length				NS
6–16 weeks 1 set	49	1.26	0.15	a
6–16 weeks multiple set	45	1.21	0.16	b
17–40 weeks 1 set	7	0.78	0.41	c
17–40 weeks multiple set	7	2.66	0.41	abc
Training method				NS
Trained to failure 1 set	16	0.82	0.26	
Trained to failure multiple set	16	1.36	0.25	
Untrained not to failure 1 set	39	1.76	0.25	
Untrained not to failure multiple set	33	1.44	0.27	
Training status by set end point				$p < 0.01$
Trained to failure	23	0.51	0.25	a
Trained not to failure	10	0.48	0.39	b
Untrained to failure	31	1.49	0.21	
Untrained not to failure	43	1.86	0.18	ab
Journal impact factors				NS
0–2	51	1.15	0.09	
≥2.1	53	0.93	0.1	
Research design				$p < 0.001$
RCT	22	0.41	0.80	a
Control	36	1.89	0.17	ab
NC	66	0.79	0.06	b

* N = number of studies; NC = no control; NS = no significant difference; RCT = randomized controlled trial.

† Effect sizes with similar letters are significantly different from one another ($p < 0.05$).

found for set number and program length. Specifically, multiple-set programs produced superior increases in strength in resistance training programs that lasted 17–40 weeks when compared with those that used a single set only ($p < 0.002$). An analysis related to "set end point" was also conducted. Set end point referred to whether researchers encouraged their subjects to perform resistance exercises until muscular failure was achieved vs. allowing the subject to determine his/her own end point. An analysis of simple main effects revealed no significant difference for set end point and the number of set performed ($p < 0.052$). When the data were partitioned by training status, the highest mean ES was generated by untrained individuals who did not train to failure.

It stands to reason that the most rigorously designed and reviewed studies tend to be those that are submitted to research journals with the highest IFs. A journal's IF represents the number of times the average recent article in the journal has been cited in other recent articles. The IF represents the average influence of a journal's articles; therefore, it provides a measure of the influence of the journal and a good index of overall quality of its articles. Since these studies are usually RCTs, we hypothesized that these studies would yield lower overall treatment effects. To that end, we were interested to learn if the IF of the journals included in our analyses affected the magnitude of the muscular strength ESs. We partitioned IFs into 2 groups (0–2 vs. ≥2.1). The results of an independent *t*-test revealed that the mean ES for the 0–2 IF group was higher (1.3 ± 0.56); however, it was not significantly different from studies with higher IFs (0.94 ± 0.67).

Finally, a subgroup analysis of the primary outcomes partitioned by research design (RCTs, CTs, and NC) was performed to determine the impact of design on components of the exercise prescription. For this analysis, the 2 × 2, 1 between-factor, 1 within-factor ANOVA was performed. The between factor was research design with 3 levels (RCTs, CTs, and NC), and the within factor was the number of sets used for resistance training (single and multiple). The differences in the mean values among the different levels of research design were significant ($p < 0.001$). The highest mean ES was found for the CTs; however, there was no statistically significant interaction between research design and the number of sets performed. Subgroup analyses are summarized in Table 4.

DISCUSSION

The purpose of this quantitative review was to identify the factors most responsible for the success of resistance training programs using single vs. multiple sets. Previously published reviews by Carpinelli and Otto (10), Berger (9), and Feigenbaum and Pollock (17) indicated that most investigators found comparable strength improvements when untrained subjects used either single sets or high-volume resistance exercise. Conversely, Kraemer and colleagues (29–31) published several studies that demonstrated the superiority of multiple sets of resistance training exercise when compared with single-set regimens. This difference was largely attributed to the training status of the subjects; namely, the participants tended to be collegiate football players, tennis players, or recreational lifters with prior resistance training experience. However, since the reviews mentioned above were qualitative, the authors could not quantify the multitude of factors known to accompany strength improvements after resistance training in relation to training volume.

Although the women in this analysis generated slightly higher ES values for strength, sex differences were not significant, regardless of the number of sets performed. This finding should be interpreted cautiously, since few data are available that control for the effect of sex, and most of the studies included in this review used male subjects. The analysis for age of the subjects revealed significantly higher ESs for muscular strength for older individuals (47–71 years) when compared with their younger

TABLE 3. Coded characteristics of the studies: subject characteristics.*

Study	N	Age (y), mean ± *SD* or range	Subject characteristics
Abe et al. (2000) (1)	50 (17 M, 20 F, 13 C)	25–50	Untrained, healthy
Berger (1962) (6)	177 M	College age	Healthy
Borst et al. (2001) (7)	31	37 ± 7	Healthy, untrained
Coleman (1977) (12)	60 M	20.8 ± 1.4	Healthy
Craig and Kang (1994) (13)	4 M	24.3 ± 0.4	Healthy, trained
De Hoyos et al. (1998) (abstract) (14)	30	40.6 ± 6	Healthy
De Hoyos et al. (1997) (abstract) (15)	20	15.8 ± 9	Adolescent tennis players, healthy
Gotshalk et al. (1997) (21)	8 M	25.4 ± 4.14	Healthy, trained
Hass et al. (1998) (abstract) (22)	40	39.3 ± 6	Healthy, untrained
Hass et al. (2000) (23)	42	39.7 ± 6.2	Healthy, trained
Hurley et al. (1995) (25)	35 M	60 ± 5	Healthy, untrained
Jacobson (1986) (26)	45 M	College age	Healthy, trained
Koffler et al. (1992) (28)	7 M	60 ± 2	Healthy, untrained
Kraemer (1997) (29) (experiment 2)	40 M	20 ± 2.3	Healthy, trained
Kraemer (1997) (29) (experiment 3)	34 M	20 ± 4.3	Healthy, trained
Kraemer (1997) (29) (experiment 4)	44 M	19.9 ± 4.3	Healthy, trained
Kraemer et al. (2000) (30)	24 F	17–21	Healthy women, trained
Kramer et al. (1997) (31)	43 M	20.3–1.9	Healthy, trained
Marx et al. (2001) (34)	34 F	16–27	Healthy, untrained
McGee et al. (1992) (35)	27 M	17–26	Healthy
Messier and Dill (1985) (36)	36 M	College age	Healthy
Miller et al. (1994) (37)	11 M	50–63	Healthy, untrained
Mulligan et al. (1996) (39)	10 F	24.1 ± 4.3	Healthy, trained
Nicklas et al. (1995) (40)	13 M, 9 C	60 ± 4	Healthy, untrained
Ostrowski et al. (1997) (41)	27 M	18–29	Healthy, trained
Pollock et al. (1998) (abstract) (42)	30	40.6 ± 6	Healthy
Reid et al. (1987) (43)	45 M	18–35	Healthy
Ryan et al. (1995) (45)	15 F	50–69	Postmenopausal obese women, untrained
Ryan et al. (1994) (46)	37 (21 M, 16 C)	51–71	Healthy, untrained
Sanborn et al. (2000) (48)	17 F	18–20	Healthy, untrained
Schlumberger et al. (2001) (49)	27 F	20–40	Healthy, trained
Silvester et al. (1982) (51)	48 M	College age	Healthy
Starkey et al. (1996) (52)	48 (21 M, 27 F)	18–50	Healthy, untrained
Starkey et al. (1994) (abstract) (53)	28 (10 C)	ANS	Healthy
Stowers et al. (1983) (57)	84 M	College age	Healthy, untrained
Terbizan and Bartles (1985) (abstract) (58)	101 F	18–35	Healthy, untrained
Teruth et al. (1994) (59)	13 M, 9 C	60 ± 4	Healthy, untrained
Vincent et al. (1998) (abstract) (60)	42	33–46	Healthy
Wescott (1986) (61)	44	ANS	Healthy, untrained
Wescott et al. (1989) (62)	77 (54 M, 23 F)	ANS	NI
Wolfe et al. (2001) (abstract) (63)	16 (3 M, 13 F)	18–25	Healthy, untrained

* ANS = age not specified; C = control; F = female; M = male; N = number of subjects; NI = not indicated.

counterparts (15–25 and 37–41 years) ($p < 0.001$). The difference in the mean values among the different levels of sets performed was not statistically significant after allowing for the effects of age differences. Older subjects who performed multiple sets obtained comparable strength gains to those who performed 1 set only ($\bar{\chi}$ES = 1.9 vs. $\bar{\chi}$ES = 2.5). We attribute the significant strength difference in the older age group to low baseline strength values. This explanation is also plausible for the analysis of untrained vs. trained individual vs. the number of sets performed. The untrained individuals generated the greatest strength improvements; again, this was most likely a result of low initial indices of strength. Furthermore, in untrained individuals, strength increases are the results of a combination of neural adaptations and muscular hypertrophy (47).

We anticipated that trained subjects would enjoy the greatest strength improvements when they performed multiple sets, since these factors are widely promulgated as an explanation for differences in strength outcomes in the scientific literature. The data supported the idea that during an initial short training period, single-set programs result in similar gains to multiple-set programs. Intuitively, this finding is logical, since every study included in our analysis that used trained subjects (with the exception of one [22]) reported multiple-set superiority. Interestingly, the 1962 Berger (6, 9) study (that was recently cited as the basis for the support of multiple- over single-set programs) did not meet our criteria for inclusion in the analysis. The Berger study was uncontrolled; therefore, the number of subjects from each training group who completed the study was necessary to compute the ESs, since the pooled variance formula is weighted for sample size. These data were not present in the article.

With regard to untrained subjects, the finding that

TABLE 4. Coded characteristics of the studies: research design, significance of the studies, and journal impact factors.*

Study	Study design	Significance between single and multiple sets	Journal quality impact factor
Abe et al. (2000) (1)	RCT	NI	0.983
Berger (1962) (6)	NI	SD	1.125
Borst et al. (2001) (7)	CT	SD	2.110
Coleman (1977) (12)	NI	NS	0.592
Craig and Kang (1994) (13)	NI	NI	0.009
De Hoyos et al. (1998) (14) (abstract)	NI	NS	2.110
De Hoyos et al. (1997) (15) (abstract)	NI	NS	2.110
Gotshalk et al. (1997) (21)	RAN	NI	1.333
Hass et al. (1998) (22)	RAN	NS	2.110
Hass et al. (2000) (23)	RCT	NS	2.110
Hurley et al. (1995) (25)	CT	NI	1.025
Jacobson (1986) (26)	RCT	NS	NI
Koffler et al. (1992) (28)	NI	NI	2.110
Kraemer (1997) (29) (experiment 2)	RAN	SD	0.009
Kraemer (1997) (29) (experiment 3)	RAN	SD	0.009
Kraemer (1997) (29) (experiment 4)	RAN	SD	0.009
Kraemer et al. (2000) (30)	RCT	SD	2.110
Kramer et al. (1997) (31)	NI	SD	0.009
Marx et al. (2001) (34)	RCT	SD	2.110
McGee et al. (1992) (35)	NI	SD	NI
Messier and Dill (1985) (36)	CT	NS	1.125
Miller et al. (1994) (37)	NI	NI	2.275
Mulligan et al. (1996) (39)	RAN	NI	0.009
Nicklas et al. (1995) (40)	CT	NI	1.025
Ostrowski et al. (1997) (41)	RCT	NS	NI
Pollock et al. (1994) (abstract) (42)	NI	NI	2.110
Reid et al. (1987) (43)	RAN	NI	0.943
Ryan et al. (1995) (45)	NI	NI	2.275
Ryan et al. (1994) (46)	CT	NI	2.275
Sanborn et al. (2000) (48)	RAN	SD	0.009
Schlumberger et al. (2001) (49)	RCT	SD	0.009
Silvester et al. (1982) (51)	RAN	NS	NI
Starkey et al. (1996) (52)	RCT	NS	2.110
Starkey et al. (1994) (53) (abstract)	CT	NS	2.110
Stowers et al. (1983) (57)	RAN	SD	NI
Terbizan and Bartles (1985) (58) (abstract)	RCT	NS	2.110
Teruth et al. (1994) (59)	CT	NI	2.275
Vincent et al. (1998) (60) (abstract)	RAN	NI	2.110
Wescott (1986) (61)	NI	NS	NI
Wescott et al. (1989) (62)	NI	NS	NI
Wolfe et al. (2001) (63) (abstract)	RCT	NS	2.110

* C = control; NI = not indicated; NS = no significant difference; RAN = randomized; RCT = randomized control trial; SD = significant difference.

multiple sets did not impart any significant advantage is interpreted as positive, primarily for reasons of subject safety and time prioritization. These data offer support for untrained individuals who wish to incorporate low-volume, short resistance training during the initial period of training.

Subgroup analyses showed that higher strength outcomes were obtained when subjects trained for 17–40 weeks vs. 6–16 weeks and that the greatest strength increases were observed when long programs were combined with a multiple-set approach. This increase in strength could be attributed to the opportunity for increased neural adaptations related to progressive increases in training intensity during a longer period. Kraemer et al (30) suggested that short-term increases in strength might be attained with either single- or multiple-set programs during the early neural stages of training. However, they also indicated that periodized, long, multiple-set programs resulted in superior performances in sport-specific athletes, such as tennis players. In the present study, the results of the multiple comparison procedures support the contention that extended strength programs produce the greatest strength increases when multiple sets are performed.

We also found that differences in training status were not statistically significant after allowing for the effects of differences in set end point (training to failure vs. volitional fatigue), but a positive mean trend was observed for untrained individuals who did not train to failure ($\bar{\chi}$ES = 1.8). Specifically, untrained individuals who stopped performing repetitions on their own volition generated the highest strength increases when compared with those who were untrained but completed repetitions until muscular failure and with those who were trained and also stopped repetitions on their own volition. It seems reasonable to speculate that encouragement until muscular failure would be inappropriate for novice or previously sedentary individuals because of the propensity for increased muscular soreness, which could, in turn, affect exercise adherence. Furthermore, the completion of repetitions to volitional fatigue would permit individuals to recover faster before the next exercise or set, thereby allowing for a better performance. There was no difference between trained individuals who exercised until failure ($\overline{\chi}$ES = 51) and those who exercised until volitional fatigue ($\overline{\chi}$ES = 0.49). The potential fine line that exists between volitional fatigue and muscular failure in individuals who are already trained may explain this finding. Trained individuals may already be so highly motivated that they have the ability to exercise until volitional fatigue and muscular failure at the same time.

Our final analyses were of journal quality as measured by the IF and research design. We were interested to know if journals with high IFs had differences in strength outcomes when compared with low-IF journals. We speculated that journals with high IFs were probably well controlled and reviewed rigorously and might, therefore, have the lowest overall treatment effects. However, we found that the mean ES changes in strength outcomes were not significantly different as a function of journal IF. We also considered the role of research design on reported strength outcomes. We hypothesized that ESs would differ significantly between studies without control groups when compared with CTs and RCTs. Unexpectedly, the highest ESs were found for the CTs and RCTs, respectively. We expected the studies without controls to generate the highest treatment effects, since they did not control for variation or potential sources of bias. In light of the small number of RCTs in this analysis, additional research using this research design with trained subjects is warranted.

PRACTICAL APPLICATIONS

The results of this quantitative review should offer additional perspective on the debate regarding the role of single- vs. multiple-set training programs with trained and untrained individuals, respectively. These data support the use of multiple-set programs for trained individuals and single-set programs for untrained individuals during the initial short training period. This finding presents a significant advantage in terms of time economy and reduced participation attrition rates (44) for untrained subjects. A reasonable research line of inquiry for future study is a mechanistic explanation of the functional changes in skeletal muscle during various resistance training programs.

REFERENCES

1. ABE, T., D.V. DE HOYOS, M.L. POLLOCK, AND L. GARZARELLA. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. *Eur. J. Appl. Physiol.* 81:174–180. 2000.
2. AMERICAN COLLEGE OF SPORTS MEDICINE. Position stand: The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness in healthy adults. *Med. Sci. Sports Exerc.* 30:975–991. 1998.
3. AMERICAN COLLEGE OF SPORTS MEDICINE. *Guidelines for Graded Exercise Testing and Exercise Prescription* (6th ed.). Philadelphia: Williams and Wilkins, 2000.
4. AMERICAN COLLEGE OF SPORTS MEDICINE. Position stand: Progression models in resistance training for healthy adults. *Med. Sci. Sports Exerc.* 34:364–380. 2002.
5. ATHA, J. Strengthening muscle. *Exerc. Sport Sci. Rev.* 9:1–73. 1981.
6. BERGER, R.A. Effect of varied weight training programs on strength. *Res. Q.* 33:168–181. 1962.
7. BORST, S., D.V. DE HOYOS, L. GARZARELLA, K. VINCENT, B.H. POLLOCK, D. LOWENTHAL, AND M.L POLLOCK. Effects of resistance training on insulin-like growth factor-1 and IGF binding proteins. *Med. Sci. Sports Exerc.* 33:648–653. 2001.
8. BRZYCKI, M. Overload: Multiple sets vs. "single set to failure". *Scholastic Coach* 60:84–85. 1990.
9. CARPINELLI, R.N. Berger in retrospect: Effect of varied weight training programs on strength. *Br. J. Sports Med.* 36:319–324. 2002.
10. CARPINELLI, R.N., AND R.M. OTTO. Strength training: Single versus multiple sets. *Sports Med.* 26:73–84. 1998.
11. COHEN, J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, NJ: Erlbaum, 1988. pp. 22–45.
12. COLEMAN, A.E. Nautilus vs universal gym strength training in adult males. *Am. Corr. Ther. J.* 31:103–107. 1977.
13. CRAIG, B.W., AND H.Y. KANG. Growth hormone release following single versus multiple sets of back squats: Total work versus power. *J. Strength Cond. Res.* 8:270–275. 1994.
14. DE HOYOS, D.V., T. ABE, L. GARZARELLA, C. HASS, M. NORDMAN, AND M. POLLOCK. Effects of 6 months of high- or low-volume resistance training on muscular strength and endurance [abstract]. *Med. Sci. Sports Exerc.* 30:S165. 1998.
15. DE HOYOS, D.V., D. HERRING, L. GARZARELLA, G. WERBER, W.F. BRECHUE, AND M.L. POLLOCK. Effect of strength training volume on the development of strength and power in adolescent tennis players [abstract]. *Med. Sci. Sports Exerc.* 29:S164. 1997.
16. EFRON, B., AND R. TIBSHIRANI. *An Introduction to the Bootstrap.* London: Chapman and Hall, 1993. pp. 2–56.
17. FEIGENBAUM, M.S., AND M.L. POLLOCK. Strength training: Rationale for current guidelines for adult fitness programs. *Phys. Sportsmed.* 25:44–64. 1997.
18. FLECK, S.J., AND W.J. KRAEMER. *Designing Resistance Programs* (2nd ed.). Champaign, IL: Human Kinetics, 1997. pp. 3–11, 83–115.
19. GLASS, G.V. Integrating findings: The meta-analysis of research. *Rev. Res Educ.* 5:351–379. 1977.
20. GOLDBERG, A.P. Aerobic and resistive exercise modify risk factors for coronary heart disease. *Med. Sci. Sports Exerc.* 21:669–674. 1989.
21. GOTSHALK, L.A., C.C. LOEBEL, B.C. NINDL, M. PUTUKIAN, W.J. SEBASTIANELLI, R.U. NEWTON, K. HAKKINEN, AND W.J. KRAEMER. Hormonal responses of multi set versus single-set heavy resistance exercise protocols. *Can. J. Appl. Physiol.* 22:244–255. 1997.
22. HASS, C.J., D.V. DE HOYOS, L. GARZARELLA, AND M.L. POLLOCK. Effects of training volume on strength and endurance in experienced resistance trained adults [abstract]. *Med. Sci. Sports Exerc.* 30:S115. 1998.
23. HASS, C.J., L. GARZARELLA, D. DE HOYOS, AND M.L. POLLOCK. Single versus multiple sets in long term recreational weightlifters. *Med. Sci. Sports Exerc.* 32:235–242. 2000.
24. HEDGES, L.V., AND I. OLKIN. *Statistical Methods for Meta-analysis.* San Diego: Academic Press, 1985. pp. 3, 18.
25. HURLEY, B.F, R.A. REDMOND, R.E. PRATLEY, M.S. TREUTH, M.A. ROGERS, AND A.P. GOLDBERG. Effects of strength training on muscle hypertrophy and muscle cell distribution in older men. *Int. J. Sports Med.* 16:378–384. 1995.
26. JACOBSON, B.H. A comparison of two progressive weight training techniques on knee extensor strength. *Athletic Training* 21: 315–318,390. 1986.
27. JESSE, C., J. MCGEE, J. GIBSON, AND M.H. STONE. A comparison of nautilus and free weight training. *J. Appl. Sports Sci. Res.* 2:59. 1988.
28. KOFFLER, K.H., A. MENKES, R.A. REDMOND, W.E. WHITEHEAD, R.E. PRATLEY, AND B.F. HURLEY. Strength training accelerates gastrointestinal transit in middle-aged and older men. *Med. Sci. Sports Exerc.* 24:415–419. 1992.
29. KRAEMER, W.J. A series of studies: The physiological basis for strength training in American football: Fact over philosophy. *J. Strength Cond. Res.* 11:131–142. 1997.
30. KRAEMER, W.J., N. RATAMESS, A.C. FRY, T. TRIPLETT-MC-

Bride, P. Koziris, J.A. Bauer, J.M. Lynch, and S.J. Fleck. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *Med. Sci. Sports Exerc.* 28:626–633. 2000.
31. Kramer, J.B., M.H. Stone, H.S. O'Bryant, M.S. Conley, R.L. Johnson, D.C. Nieman, D.R. Honeycutt, and T.P. Bake. Effects of single vs. multiple sets of weight training: Impact of volume, intensity, and variation. *J. Strength Cond. Res.* 11: 143–47. 1997.
32. Leighton, J.R., D. Holmes, J. Benson, B. Wooten, and R. Schmerer. A study on the effectiveness of ten different methods of progressive resistance exercise on the development of strength, flexibility, girth and bodyweight. *J. Assoc. Phys. Mental Rehabil.* 21:78–81. 1967.
33. Lemura, L.M., and M.T. Maziekas. Factors that alter body fat, body mass, and fat-free mass in pediatric obesity. *Med. Sci. Sports Exerc.* 34:487–496. 2002.
34. Marx, J.O., N.A. Ratamess, B.C. Nindl, L.A. Gotshalk, J.E. Volek, K. Dohi, J.A. Bush, A.L. Gomez, S.A. Mazzetti, S.J. Fleck, K. Hakkinen, R.U. Newton, and W.J. Kraemer. Low-volume circuit versus high-volume periodized resistance training in women. *Med. Sci. Sports Exerc.* 33:635–643. 2001.
35. McGee, D., T.C. Jessie, M.H. Stone, and D. Blessing. Leg and hip endurance adaptations to three weight training programs. *J. Appl. Sport Sci. Res.* 6:92–95. 1992.
36. Messier, S.P., and M.E. Dill. Alterations in strength and maximal oxygen uptake consequent to nautilus circuit weight training. *Res. Q. Exerc. Sport.* 56:345–351. 1985.
37. Miller, J.P., R.E. Pratley, A.P. Goldberg, P.G. Gordon, M.R. Rubin, M.S. Treuth, A.S. Ryan, and B.F. Hurley. Strength training increases insulin action in healthy 50- to 65-yr-old men. *J. Appl. Physiol.* 77:1122–1127. 1994.
38. Miller, W.J., W.M. Sherman, and J.L. Ivy. Effect of strength training on glucose tolerance and post-glucose insulin response. *Med. Sci. Sports Exerc.* 16:539–543. 1984.
39. Mulligan, S.E., S.J. Fleck, S.E. Gordon, L.P. Koziris, N.T. Triplett-McBride, and W.J. Kraemer. Influence of resistance exercise volume on serum growth hormone and cortisol concentrations in women. *J. Strength Cond. Res.* 10:256–262. 1996.
40. Nicklas, B.J., A.J. Ryan, M. Treuth, S.M. Harman, M.R. Blackman, B.F. Hurley, and M.A. Rogers. Testosterone, growth hormone and IGF-1 responses to acute and chronic resistive exercise in men aged 55–70 years. *Int. J. Sports Med.* 16:445–450. 1995.
41. Ostrowski, K.J., G.J. Wilson, R. Weatherby, P.W. Murphy, and A.D. Lyttle. The effect of weight training volume on hormonal output and muscular size and function. *J. Strength Cond. Res.* 11:148–154. 1997.
42. Pollock, M.L., T. Abe, D.V. De Hoyos, L. Garzarella, C.J. Hass, and G. Werber. Muscular hypertrophy response to 6 months of high- or low-volume resistance training [abstract]. *Med. Sci. Sports Exerc.* 30:S116. 1998.
43. Reid, C.M., R.A. Yeater, and H. Ullrich. Weight training and strength cardiorespiratory functioning and body composition of men. *Br. J. Sports Med.* 21:40–44. 1987.
44. Rejeski, W.J., and E.A. Kenney. *Fitness Motivation: Preventing Participant Drop-out.* Champaign, IL: Human Kinetics, 1988.
45. Ryan, A.S., E. Pratley, D. Elahi, and A.P. Goldberg. Resistance training increases fat-free mass and maintains RMR despite weight loss in postmenopausal women. *J. Appl. Physiol.* 79:818–823. 1995.
46. Ryan, A.S., M.S. Trueth, M.A. Rubin, J.P. Miller, B.J. Nicklas, D.M. Landis, R.E. Pratley, C.R. Libanati, C.M. Gundberg, and B.F. Hurley. Effects of strength training on bone mineral density: Hormonal and bone turnover relationships. *J. Appl. Physiol.* 77:1678–1684. 1994.
47. Sale, D.G. Neural adaptations to resistance training. *Med. Sci. Sports Exerc.* 20:S135–S145. 1988.
48. Sanborn, K., R. Boros, J. Hruby, B. Schilling, H.S. O'Bryant, R.L. Johnson, T. Hoke, M.E. Stone, and M.H. Stone. Short-term performance effects of weight training with multiple sets not to failure vs. a single set to failure in women. *J. Strength Cond. Res.* 14:328–331. 2000.
49. Schlumberger, A., J. Stec, and D. Schmidtbleicher. Single vs. multiple set strength training in women. *J. Strength Cond. Res.* 15:284–289. 2001.
50. *Sigma Stat 2.0* [software]. SPSS Inc, 2002.
51. Silvester, L.J., C. Stiggins, C. McGown, and G.B. Bryce. The effect of variable resistance and free-weight training programs on strength and vertical jump. *Natl. Strength Cond. Assoc. J.* 3:30–33. 1982.
52. Starkey, D.B, M.L. Pollock, Y. Ishida, M.A. Welsch, W.F. Brechue, J.E. Graves, and M.S. Feigenbaum. Effects of resistance training volume on strength and muscle thickness. *Med. Sci. Sports Exerc.* 28:1311–1320. 1996.
53. Starkey, D.B., M.A. Welsch, M.L. Pollock, J.E. Graves, W.F. Bechue, and Y. Ishida. Equivalent improvements in strength following high intensity, low and high volume training. *Med. Sci. Sports Exerc.* 6:S116. 1994.
54. Stone, M.H. Implications for connective tissue and bone alterations resulting from resistance exercise training. *Med. Sci. Sports Exerc.* 20:S162–S168. 1988.
55. Stone, M.H., S.J. Fleck, W.J. Kraemer, and N.T. Triplett. Health and performance related changes adaptations to resistance training. *Sports Med.* 11:210–231. 1991.
56. Stone, M.H., S.S. Plisk, M.E. Stone, B.K. Schilling, H.S. O'Bryant, and K.C. Pierce. Athletic performance development: Volume load − 1 set vs. multiple sets, training velocity and training variation. *Strength Cond.* 20:22–31. 1998.
57. Stowers, T. J. McMillan, D. Scala, V. Davis, D. Wilson, and M. Stone. The short-term effects of three different strength power training methods. *Natl. Strength Cond. Assoc. J.* 5:24–247. 1983.
58. Terbizan, D.J., and R.L. Bartles. The effect of set-repetition combination on strength gain in females age 18–35 [abstract]. *Med. Sci. Sports Exerc.* 17:S267. 1985.
59. Trueth, M.S., A.S. Ryan, R.E. Pratley, M.A. Rubin, J.P. Miller, B.J. Nicklas, J. Sorkin, S.M. Harman, A.P. Goldberg, and B.F. Hurley. Effects of strength training on total and regional body composition in older men. *J. Appl. Physiol.* 77:614–620. 1994.
60. Vincent, K., D. De Hoyos, L. Garzarella, C. Hass, M. Nordman, and M. Pollock. Relationship between indices of knee extension strength before and after training [abstract]. *Med. Sci. Sports Exerc.* 30:S163. 1998.
61. Westcott, W.L. 4 key factors in building a strength program. *Scholastic Coach* 55:104–105,123. 1986.
62. Westcott, W.L., K. Greenberger, and D. Milius. Strength training research: Sets and repetitions. *Scholastic Coach* 58: 98–100. 1989.
63. Wolfe, B.L., T.A. Valerio, K. Strohecker, and L. Szmedra. Effect of single versus multiple-set resistance training on muscular strength. [abstract] *Med. Sci. Sports Exerc.* 33:S76. 2001.

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