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Moderate Resistance Training Volume Produces More Favorable Strength Gains Than High or Low Volumes During a Short-Term Training Cycle

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Abstract. González-Badillo, J.J., E.M. Gorostiaga, R. Arellano, and M. Izquierdo. Moderate resistance training volume produces more favorable strength gains than high or low volumes during a short-term training cycle. *J. Strength Cond. Res. 19(3):689–697. 2005.*—The purpose of this study was to examine the effects of 3 resistance training volumes on maximal strength in the snatch (Sn), clean & jerk (C&J), and squat (Sq) exercises during a 10-week training period. Fifty-one experienced (>3 years), trained junior lifters were randomly assigned to one of 3 groups: a low-volume group (LVG, $n = 16$), a moderate-volume group (MVG, $n = 17$), and a high-volume group (HVG, $n = 18$). All subjects trained 4–5 days a week with a periodized routine using the same exercises and relative intensities but a different total number of sets and repetitions at each relative load: LVG (1,923 repetitions), MVG (2,481 repetitions), and HVG (3,030 repetitions). The training was periodized from moderate intensity (60–80% of 1 repetition maximum [1RM]) and high number of repetitions per set (2–6) to high intensity (90–100% of 1RM) and low number of repetitions per set (1–3). During the training period, the MVG showed a significant increase for the Sn, C&J, and Sq exercises (6.1, 3.7, and 4.2%, respectively, $p < 0.01$), whereas in the LVG and HVG, the increase took place only with the C&J exercise (3.7 and 3%, respectively, $p < 0.05$) and the Sq exercise (4.6%, $p < 0.05$, and 4.8%, $p < 0.01$, respectively). The increase in the Sn exercise for the MVG was significantly higher than in the LVG ($p = 0.015$). Calculation of effect sizes showed higher strength gains in the MVG than in the HVG or LVG. There were no significant differences between the LVG and HVG training volume-induced strength gains. The present results indicate that junior experienced lifters can optimize performance by exercising with only 85% or less of the maximal volume that they can tolerate. These observations may have important practical relevance for the optimal design of strength training programs for resistance-trained athletes, since we have shown that performing at a moderate volume is more effective and efficient than performing at a higher volume.

Key Words. training intensity, Olympic lifts, weightlifting, dose-response volume

Introduction

Coaches and researchers with an interest in strength training attempt to identify the proper handling of program variables, including the intensity, frequency, and volume of exercise to achieve high levels of muscular fitness (1). It is believed that, for increased improvement in strength, it is necessary to systematically increase the stress-related overload placed on the body during strength training (1). There are several ways in which overload may be introduced during resistance training. One of these is increasing training volume (1), because it has been proposed that the effect of the work performed by an organism partially depends on the total number of repetitions (21). Unfortunately, the optimal volume stimulus for the development of strength and the effectiveness of stimuli within the training process have not been satisfactorily solved (18).

Several studies have investigated the effects of altering training volume on muscular strength gains during strength training (6, 10, 13, 17), whereas maximal relative strength (% 1 repetition maximum [1RM]) remained constant. These studies have reported that an increased training volume does not produce any performance change in Olympic lifts (snatch [SN] or clean & jerk [C&J]) during short-or long-term training periods (5, 6, 10). It appears that once a given "optimal" volume is reached, a further increase in training volume does not yield more gains and can even lead to reduced performance. In some instances, it is also interesting to note that after a period with an extraordinarily high volume of training, maximal strength performance may experience a "rebound effect," and a performance beyond that measured before the volume increase may be achieved (5, 6). All of these previous studies with experienced strength-trained individuals and lifters have used a time-series study design, with each subject serving as his own control, because it is currently very difficult to recruit strength-trained individuals or lifters who are willing to perform such extreme training programs. In the present study, we hypothesized that, by using a higher number of lifters and a multigroup experimental design study and controlling other variables such as training intensity and frequency, we could advance knowledge in the area of the effects that different heavy training volumes have on strength training performance. It is critical for athletes interested in maximal performance as well as individuals engaged in the practice of coaching to understand how training volume manipulation strategies can be used to enhance optimal training adaptability and avoid overtraining.

Although long-term progression-oriented studies in previously resistance-trained individuals seems to support the contention that a higher training volume is needed for increased strength improvement, the effect of al-

TABLE 1. Initial characteristics of the experimental groups (mean ± *SD*).*

Group	Age (y)	Height (cm)	Body mass (kg)	Snatch (kg)	Clean & jerk (kg)	Squat (kg)	Training years
LVG (n = 16)	16.4 ± 1.3	167.3 ± 3.9	72.7 ± 5.4	82.4 ± 11.7	101 ± 14.5	133.1 ± 20	3.5 ± 0.7
MVG (n = 17)	16.5 ± 1.4	166.7 ± 4.1	70.5 ± 5.7	82.3 ± 10.6	106.1 ± 12.1	144.4 ± 19	3.9 ± 0.6
HVG (n = 18)	16.8 ± 1.7	165.4 ± 5.6	69.4 ± 5.3	86.3 ± 13.1	108.7 ± 16.1	142.7 ± 28	3.7 ± 0.7

* LVG = low volume group; MVG = medium volume group; HVG = high volume group.

tering training volume when other training variables are controlled is not known. In addition, it is conceivable that if strength training volume is substantially increased following the principle that "the more, the better," there may be a minimum volume for resistance training at which adaptations are optimized, at least in the short term, and beyond which the performance of additional resistance training provides no further benefit (17).

In view of these considerations, the purpose of this study was to examine the effect of 3 resistance training volumes on performance in experienced junior lifters. Considering the high magnitude of volumes studied, we hypothesized that when the subjects are highly trained and other training variables are controlled, a volume threshold should exist over which performance may be compromised. Understanding the effects of using different periodized resistance training volumes with lifters may provide insights for enhancing performance and preventing injury.

METHODS

Experimental Approach to the Problem

To address the question of how 3 different magnitudes of training volume affect strength gains, we compared the effects of 3 different commonly used high-volume (3,030 repetitions), moderate-volume (2,481 repetitions), and low-volume (1,923 repetitions) resistance training programs on maximum performance in the SN, C&J, and squat (SQ) exercises in trained junior male lifters. To eliminate any possible effects of intervening variables, several strength variables such as maximal relative strength (% 1RM), average intensity, frequency of training, type of exercise, distribution of the total repetition between exercises, and distribution of repetition among zones of relative intensity were controlled by equating their values among treatment groups. This was critical to the study design, because it has been proposed that differences in overall training intensity influence performance adaptations (2, 4).

Subjects

Fifty-one junior male lifters volunteered as subjects to participate in this study with the informed consent of their parents and coaches. The subjects were recruited from a group of young competitive lifters with at least 3 years of training experience. All were ranked among the top 4% at the junior level in their national weight and age category. Three of the subjects also participated in the European and World junior championships. Their best lifting performance in the competition (consisting of the SN and C&J exercises) was 183.4, 188.1, and 195 kg, in the light-intensity group, medium-intensity group, and high-intensity group, respectively, with corresponding "Sinclair coefficients" (calculated from the individual lifting performance and body mass) (Sinclair 1985) of 234.6, 245, and 255.1, respectively (Table 1). The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee of the department responsible.

All subjects had reached their best personal performance within 6 months before the beginning of the study. Participants were ranked according to their total score in the 3 strength training exercises (SN, C&J, and SQ) and were randomly placed into one of the 3 groups: a low-volume group (LVG, n = 16), a moderate-volume group (MVG, n = 17), and a high-volume group (HVG, n = 18). To avoid unknown subsequent physiologic adaptations, only subjects who had never used anabolic steroids, β-agonists, or other drugs or nutritional supplements (e.g., creatine) that are expected to affect physical performance or hormonal balance were eligible for participation.

Testing

After a 10-week period of training, the subjects were tested using the Olympic lift tests of the SN and C&J exercises. Prior to testing, the subjects warmed up using 2 warm-up sets of 3–5 repetitions at 40–50% of their estimated 1RM. The number of attempts required to determine the 1RM load with increases of 20–2.5 kg up to the maximum was performed. After 3 misses at the same weight, the test was terminated, and the best good lift was recorded. The SQ test was carried out after the Olympic lift tests using the same protocol, although only 2 missed attempts were permitted. The baseline performances that were used in this study were the best personal performances in official competition in the SN and C&J exercises and the best personal test performed in the SQ exercise prior to beginning the research. All subjects had reached their best personal performances within 6 months before starting the experiment. The test-retest intraclass correlation coefficients of the testing procedure variables used in this study were greater than 0.95, with coefficients of variation (CV) of 3%.

Training Protocol

Before beginning the experimental period, all subjects had 2 weeks of active rest in which no strength training was carried out, although the subjects participated in recreational physical activities (e.g., cycling, swimming). This was followed by 2 weeks of progressive strength training. These 4 weeks were designed to balance previous conditions for all subjects before starting the experimental period. Following this 4-week period, the subjects trained for strength during a mesocycle of 10 weeks (4–5 days per week) Each training session was supervised by a certified trainer with several years of professional experience in weightlifting. If a lifter performed less than 95% of the proposed repetitions, he was eliminated from the study. When the relative programmed intensity was

TABLE 2. Training programs for each group.*†

Exercise	Rep.	Set	AI (%)	% of the total rep	Rep. and % of the total repetitions per exercise in the different zones of relative intensity						
					60–70	71–80	81–90	91–95	96–100	101–105	106–110
					LVG						
Snatch	551	306	75.4	28.5	204 (37.7)	242 (44.7)	72 (13.3)	16 (2.9)	7 (1.3)		
Clean & jerk	471	289	75.2	24.4	180 (38.2)	205 (43.5)	72 (15.3)	11 (2.3)	3 (0.6)		
Pulls	208	93	97.6	10.8			48 (23.1)	26 (12.5)	74 (35.6)	56 (26.9)	4 (1.9)
Squat	703	306	78.9	36.4	218 (31)	143 (20.3)	322 (45.8)	11 (1.6)	9 (1.3)		
Total	1,923	994	79.01		602 (31.1)	590 (30.5)	514 (26.6)	64 (3.3)	93 (4.8)	56 (2.9)	4 (0.2)
					MVG						
Snatch	707	344	75.2	28.5	259 (36.6)	330 (46.7)	87 (12.3)	21 (3)	10 (1.4)		
Clean & jerk	605	338	75	24.4	212 (35)	289 (47.8)	89 (14.7)	12 (2)	3 (1.4)		
Pulls	269	111	98.5	10.8		3 (1.1)	51 (18.9)	35 (13)	94 (34.9)	80 (29.7)	6 (2.2)
Squat	900	341	78.9	36.3	288 (32)	175 (19.4)	414 (46)	14 (1.5)	9 (1)		
Total	2,481	1,134	79.01		759 (30.6)	797 (32.1)	641 (25.8)	82 (3.3)	116 (4.7)	80 (3.2)	6 (0.2)
					HVG						
Snatch	862	384	75.2	28.4	314 (36.4)	404 (46.9)	107 (12.4)	25 (2.9)	12 (1.4)		
Clean & jerk	748	394	75.1	24.7	247 (33)	373 (49.9)	110 (14.7)	15 (2)	3 (0.4)		
Pulls	326	128	98.6	10.7		3 (0.9)	64 (19.6)	38 (11.6)	112 (34.3)	101 (31)	8 (2.4)
Squat	1,094	380	78.6	36.1	361 (33)	206 (18.8)	499 (45.6)	16 (1.5)	12 (1.1)		
Total	3,030	1,286	78.9		922 (30.4)	986 (32.5)	780 (25.7)	94 (3.1)	139 (4.5)	101 (3.3)	8 (0.3)

* Rep. = repetition; set = sets; AI = average intensity; LVG = low volume group; MVG = medium volume group; HVG = high volume group.

† Snatch = exercises of snatch and power snatch; clean & jerk = exercises of C&J; jerk = push jerk and power clean; pulls = exercises of snatch pulls and clean pulls; squat = exercises of back and front squat.

between 95 and 100% of 1RM, the lifters attempted to lift the maximal or near-maximal weight they could.

The resistance exercise performed and the order of it were identical for the 3 groups. The main exercises of the lifting session were SN, power snatch, C&J, jerk, push jerk, power clean, snatch pulls, clean pulls, back squat, and front squat, plus a few strengthening exercises for selected muscle groups.

Each day, all subjects performed at the same maximal relative intensity using their previous intensities up to the maximal relative intensity of the day for each group as a guide, and they also performed the same frequency of training, the same type of exercise, the same relative number of repetitions among exercises, and the same relative number of repetitions among zones of relative intensity. This was done to control all possible variables of training volume. Therefore, the only difference among the training groups was the total number of sets and repetitions at each relative load: high (HVG, 3,030 repetitions), moderate (MVG, 2,841 repetitions), and low (LVG, 1,923 repetitions). In relative terms, that means that the LVG and MVG performed 63 and 82%, respectively, of the training volume performed by the HVG. The training was periodized from moderate intensity (60–80% 1RM) and high number of repetitions per set (2–6) to high intensity (90–100%) and low number of repetitions per set (1–3). For optimal recovery, each set was separated by a 3–5 minute rest period. Tables 2–5 show in detail the exercises, total number of repetitions, number of sets, average relative intensity, and repetitions at the different zones of relative intensity, expressed as a percentage of the 1RM. During the last 2 weeks, the volume was reduced to 60 and 40% of the maximum week volume, respectively, in an effort to produce a rebound effect for all groups. The distribution of weekly training volume and average intensity during the 10-week training period is shown in Figure 1. The numbers of repetitions observed in Tables 2–5 and Figure 1 were calculated using the relative intensities of 60–100% of the 1RM for the Olympic lifts and SQ and 80–110% for the pulls. For the SN exercise and snatch pulls, all percentages of training were calculated from 1RM of the SN; for the C&J exercises and clean pulls, they were calculated from 1RM of C&J; and for the SQ exercise, they were calculated from the trainees' own 1RM. The strengthening exercises for selected muscle groups are not included.

The criteria used to decide the training volume in the HVG was the maximum training volume performed in previous years by the lifters. This volume was considered the maximum tolerated volume for this population of lifters and represented 115% of the maximal habitual training volume that had been previously used by these lifters. It is crucial to take into account that this volume could not be so difficult that the subjects were not able to perform it. In addition, this volume ought to be realistic, so that the lifters and the coaches would not refuse the training program. For the same reasons, the low training volume could not be excessively weak, but it also should be realistic. Thus, a realistic strength training program of low volume was compared to 2 realistic programs of moderate and high volume over time, while other training variables were maintained.

Statistical Analyses

Descriptive statistics (mean ± *SD*) for the different variables were calculated. Intergroup differences among the means of performances were treated with 1-way analysis of variance (ANOVA) and with analysis of covariance (ANCOVA) using pretraining performance as a covariate. A *t*-test for paired groups was used to compare group differences within the means of performances. A chi-square test (χ^2) was used to compare the frequency counts of sub-

TABLE 3. Lower volume group training protocol.*†

	Week 1 rep set RI (%)	Week 2 rep set RI (%)	Week 3 rep set RI (%)	Week 4 rep set RI (%)	Week 5 rep set RI (%)	Week 6 rep set RI (%)	Week 7 rep set RI (%)	Week 8 rep set RI (%)	Week 9 rep set RI (%)	Week 10 rep set RI (%)
Snatch	4×2×80	2×1×85	2×1×90	2×2×85	2×2×85	1×1×95	2×1×85	2×2×85	2×1×85	1×1×95
	5×2×80	3×1×85	4×1×90	2×1×95	2×1×100	1×1×85	2×1×90	1×1×100	1×1×100	1×1×85
		4×1×85		2×1×95	2×1×100			1×1×100	1×1×95	
Power snatch	3×2×80	3×2×80	2×2×80	2×2×80	2×2×80	1×2×80	2×2×80	2×2×80	2×2×80	2×2×80
	3×3×80	3×2×80		2×2×80	2×2×80	2×1×80	2×2×80	2×2×80	2×2×80	2×1×80
Clean & jerk	3×2×80	2×1×85	2×1×90	3×1×90	1×1×95	1×1×90	3×1×90	1×1×90	1×1×85	1×1×90
		3×1×85		3×1×95	3×1×95	2×1×80		1×1×100	1×1×100	2×1×80
						1×1×75		1×1×100	1×1×90	1×1×75
Jerk	3×2×80	2×1×85	2×1×90	2×2×85	2×2×85		3×1×85			
Push jerk	3×2×80		2×2×80			1×2×80	3×2×80		2×2×75	2×2×80
Power clean	3×2×80	3×2×80	2×2×80	2×1×85	2×1×85	1×2×80	3×2×80	2×1×85	2×2×75	2×2×80
Snatch pull	2×2×100	2×2×105	3×2×105	2×2×105	2×2×105	2×2×100	2×2×105	2×2×105	2×2×105	
		2×3×105		3×2×105	3×2×105			2×2×110	2×2×105	
Clean pull	2×2×100	2×2×100	3×2×100	2×2×100	2×2×100		2×2×100	1×2×105	2×2×100	
Back squat	4×3×85	2×2×90 +2×3×85	2×2×90	2×2×90	2×2×90	2×2×90	3×2×90 +2×4×85	2×2×90	1×3×80	2×2×90
	3×3×85	3×2×90 +1×3×85	2×2×80	1×1×95 +2×3×85	1×1×95 +2×3×85	1×2×90 +1×3×85	2×2×80	1×1×100 +2×3×85	2×2×90	1×2×90 +1×3×85
	5×3×85	1×2×80	3×2×90	2×2×80	2×2×80	2×2×80	4×2×85	2×2×80	2×2×80	1×2×80
		2×2×90	4×2×90 +2×5×85	2×3×85	2×3×85		1×1×100 +2×5×85	4×2×85	2×1×100	
		3×2×90 +2×5×85		3×1×95 +2×5×85	2×1×100 +2×5×85			2×1×100 +2×4×85		
Front squat	2×2×85	2×2×85	2×1×85	3×1×90	3×1×90	1×2×85	3×1×90	1×1×100	1×1×90	2×2×85

* Rep = repetition; RI (%) = maximal relative intensity expressed in percentage of 1 repetition maximum (1RM).
† The different lines in each exercise indicate the times that these exercises are performed each week.

TABLE 4. Moderate volume group training protocol.*†

	Week 1 rep set RI (%)	Week 2 rep set RI (%)	Week 3 rep set RI (%)	Week 4 rep set RI (%)	Week 5 rep set RI (%)	Week 6 rep set RI (%)	Week 7 rep set RI (%)	Week 8 rep set RI (%)	Week 9 rep set RI (%)	Week 10 rep set RI (%)
Snatch	5×2×80	3×1×85	3×1×90	2×2×85	2×2×85	2×1×95	3×1×85	2×2×85	2×1×85	1×1×95
	4×3×80	4×1×85	4×1×90	4×1×95	2×1×100	1×1×85	3×1×90	2×1×100	2×1×100	1×1×85
		5×1×85		4×1×95	2×1×100			2×1×100	1×1×95	
Power snatch	4×2×80	4×2×80	2×2×80	2×2×80	2×2×80	2×2×80	3×2×80	2×2×80	2×2×80	2×2×80
	4×3×80	4×2×80		2×2×80	2×2×80	2×1×80	3×2×80	2×2×80	2×2×80	2×1×80
Clean & jerk	4×2×80	3×1×85	3×1×90	4×1×90	2×1×95	2×1×90	4×1×90	1×1×90	2×1×85	1×1×90
		5×1×85		3×1×95	3×1×95	2×1×80		1×1×100	1×1×100	2×1×80
						1×1×75		2×1×100	1×1×90	1×1×75
Jerk	4×2×80	3×1×85	3×1×90	2×2×85	2×2×85		4×1×85			
Push jerk	4×2×80		2×2×80			2×2×80	4×2×80		2×2×75	2×2×80
Power clean	4×2×80	3×3×80	2×2×80	3×1×85	3×1×85	2×2×80	4×2×80	3×1×85	2×2×75	2×2×80
Snatch pull	3×2×100	3×2×105	3×2×105	3×2×105	3×2×105	2×2×100	3×2×105	3×2×105	3×2×105	
		3×3×105		3×3×105	3×3×105			3×2×110	2×2×105	
Clean pull	2×2×100	4×2×100	3×2×100	3×2×100	3×2×100		3×2×100	2×2×105	3×2×100	
Back squat	5×3×85	3×2×90	3×2×90	3×2×90	3×2×90	2×2×90	3×2×90	3×2×90	2×3×80	2×2×90
		+3×3×85					+2×5×85			
	4×3×85	3×2×90	2×2×80	2×1×95	1×1×100	1×2×90	2×2×80	1×1×100	3×2×90	1×2×90
		+2×3×85		+2×4×85	+2×4×85	+2×3×85		+2×4×85		+1×3×85
	6×3×85	2×2×80	3×2×90	2×2×80	2×2×80	2×2×80	3×3×85	2×2×80	3×2×80	1×2×80
		2×2×90	4×2×90	3×3×85	3×3×85		2×1×100	3×3×85	2×1×100	
			+2×6×85				+2×6×85			
		3×2×90		3×1×95	2×1×100			2×1×100		
		+2×6×85		+2×6×85	+2×6×85			+2×6×85		
Front squat	3×2×85	3×2×85	3×1×85	4×1×90	4×1×90	2×2×85	4×1×90	1×1×100	2×1×90	2×2×85

* Rep = repetition; RI (%) = maximal relative intensity expressed in percentage of 1 repetition maximum (1RM).
† The different lines in each exercise indicate the times that these exercises are performed each week.

TABLE 5. High volume group training protocol.*†

	Week 1 rep set RI (%)	Week 2 rep set RI (%)	Week 3 rep set RI (%)	Week 4 rep set RI (%)	Week 5 rep set RI (%)	Week 6 rep set RI (%)	Week 7 rep set RI (%)	Week 8 rep set RI (%)	Week 9 rep set RI (%)	Week 10 rep set RI (%)
Snatch	6×2×80	4×1×85	4×1×90	2×2×85	2×2×85	2×1×95	4×1×85	3×2×85	3×1×85	1×1×95
	5×3×80	5×1×85	5×1×90	5×1×95	3×1×100	2×1×85	4×1×90	2×1×100	2×1×100	1×1×85
		6×1×85		5×1×95	3×1×100			2×1×100	1×1×95	
Power snatch	5×2×80	5×2×80	2×2×80	2×2×80	2×2×80	2×2×80	4×2×80	3×2×80	2×2×80	2×2×80
	5×3×80	2×5×80		2×2×80	2×2×80	2×1×80	3×2×80	3×2×80	2×2×80	2×1×80
Clean & jerk	5×2×80	4×1×85	3×1×90	5×1×90	3×1×95	2×1×90	5×1×90	1×1×90	3×1×85	1×1×90
		6×1×85		4×1×95	4×1×95	2×1×80		1×1×100	1×1×100	2×1×80
						2×1×75		1×1×100	1×1×90	2×1×75
Jerk	5×2×80	4×1×85	4×1×90	2×2×85	2×2×85		5×1×85			
Push jerk	5×2×80		2×2×80			3×2×80	5×2×80		3×2×75	3×2×80
Power clean	5×2×80	4×3×80	2×2×80	4×1×85	4×1×85	3×2×80	5×2×80	4×1×85	3×2×75	3×2×80
Snatch pull	4×2×100	4×2×105	4×2×105	4×2×105	4×2×105	2×2×100	4×2×105	4×2×105	3×2×105	
		4×3×105		4×3×105	4×3×105			4×2×110	2×2×105	
Clean pull	3×2×100	5×2×100	4×2×100	4×2×100	4×2×100		3×2×100	2×2×105	4×2×100	
Back squat	4×4×85	3×2×90 +4×3×85	4×2×90	4×2×90	4×2×90	3×2×90	4×2×90 +2×6×85	3×2×90	2×3×80	3×2×90
	5×3×85	4×2×90 +2×3×85	2×2×80	3×1×95 +2×5×85	2×1×100 +2×5×85	2×2×90 +2×3×85	3×2×80	1×1×100 +2×5×85	3×2×90	1×2×90 +1×4×85
	7×3×85	2×2×80	4×2×90	3×2×80	3×2×80	3×2×80	3×3×85	3×2×80	4×2×80	1×2×80
		2×2×90	5×2×90 +3×5×85	4×3×85	4×3×85		2×1×100 +2×7×85	3×3×85	2×1×100	
		4×2×90 +2×7×85		4×1×95 +4×4×85	2×1×100 +4×4×85			2×1×100 +2×7×85		
Front squat	3×2×85	4×2×85	4×1×85	6×1×90	6×1×90	3×2×85	4×1×90	1×1×100	2×1×90	3×2×85

* Rep = repetition; RI (%) = maximal relative intensity expressed in percentage of 1 repetition maximum (1RM).
† The different lines in each exercise indicate the times that these exercises are performed each week.

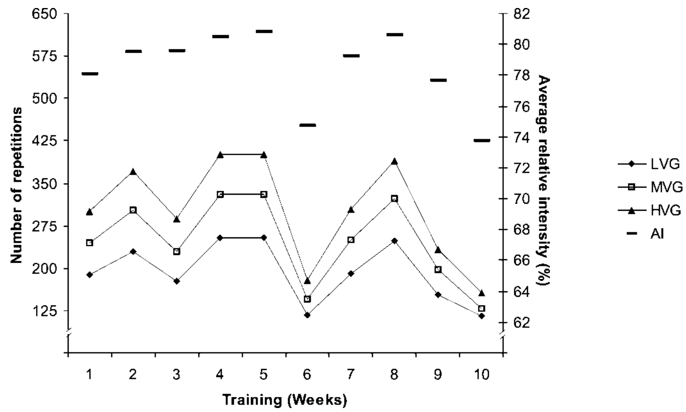

FIGURE 1. Number of repetitions per week and average intensity (AI) during the 10-week training period in the low-volume (LVG), moderate-volume (MVG), and high-volume (HVG) training groups.

jects whose results were improved, equaled, or reduced in the 3 exercises. The effect size between pre- and post-training for each group was calculated using Hedges' g (14), represented by the following formula: $g = M_{post} - M_{pre}/SD_{pooled}$, where M_{post} is the mean posttraining measure, M_{pre} is the mean pretraining measure for each group, and SD_{pooled} is the pooled *SD* of the pre- and post-measurements. The α level was set at $p \leq 0.05$.

RESULTS

No significant differences were observed between the groups in training experience, pretraining strength, and morphologic values. During the 10-week training period, the MVG showed a significant increase in the SN, C&J, and SQ exercises (6.1, 3.7, and 4.2%, respectively, $p < 0.01$), whereas in the LVG and HVG, the increases took place in the C&J exercise (3.7 and 3%, respectively, $p < 0.05$) and the SQ exercise (4.6 and 4.8%, respectively, $p < 0.05$) but not in the SN exercise (Figure 2). The effect size between pre- and post-training of the MVG was superior to the other groups in all exercises, and the mean effect size for Olympic lifts was 2.6 times greater for the MVG (0.42) than for the other 2 groups (0.16; Figure 3). The number of subjects who reduced their performance in the LVG and HVG (16.7 and 20.4%) was greater than the 7.8% (ns) observed in the MVG group (Figure 2). When the data were analyzed by ANCOVA using the better previous performance training as a covariate, the increases in the SN during the 10-week training period were significantly higher ($p = 0.015$) in the MVG than in the LVG and almost significantly higher than in the HVG ($p = 0.09$), whereas significant differences were not observed in the C&J and SQ for any of the groups tested.

DISCUSSION

The main finding of this study was that short-term resistance training using moderate volume tended to produce greater enhancements in strength performance compared with low and high training volumes of similar relative intensity in experienced, trained, young lifters. Therefore, the present data suggest that increasing the training volume in previously strength-trained athletes does not always provide a better stimulus for improving adaptations during short-term training when compared with low or moderate training volumes.

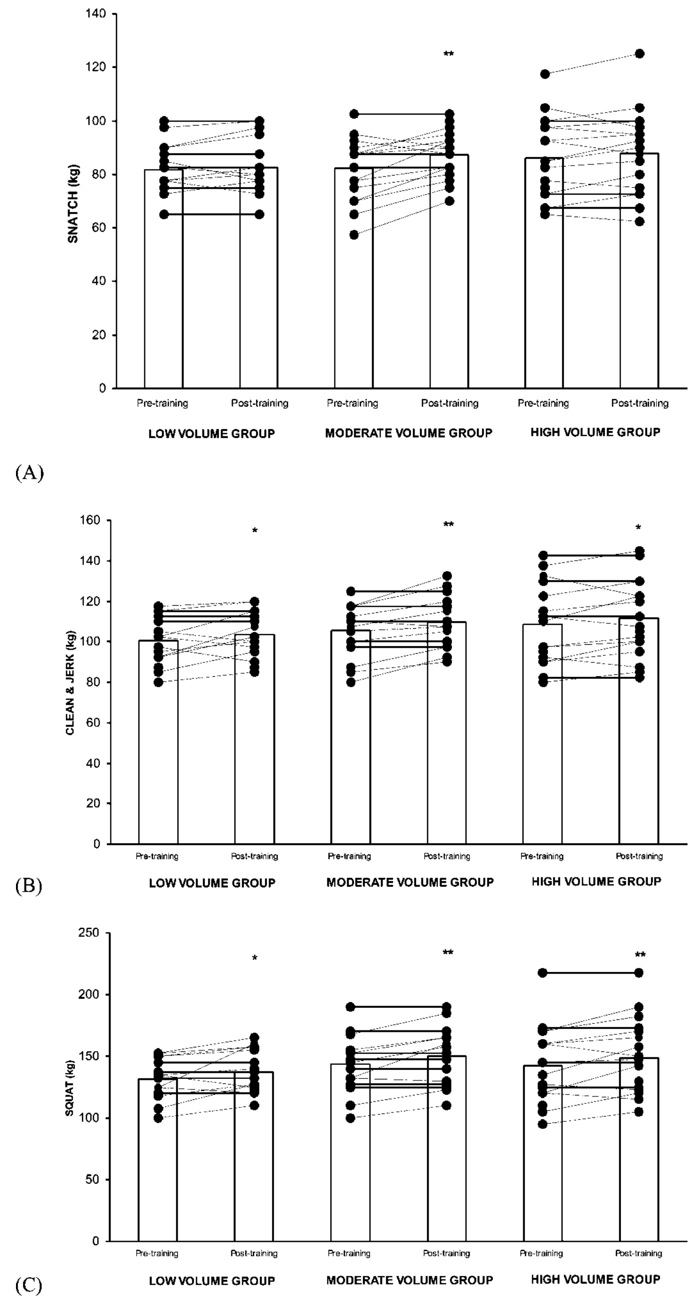

FIGURE 2. One repetition maximum (1RM) expressed in kilograms during snatch (A), clean & jerk (B), and squat (C) for the low-, moderate-, and high-volume training groups at pre-training and the subsequent 10 weeks of training for each subject. * Significantly different ($p < 0.05$) from the corresponding pretraining value. ** Significantly different ($p < 0.01$) from the corresponding pretraining value. Values are mean ± *SD.* See text for significant changes between the groups. The bars indicate the mean values.

It is well known that progressive overload is necessary for increasing muscular strength, and a stimulus exceeding that of a previous stimulus must be applied during a resistance training program for adaptations to occur (3, 19, 24). However, it also may be conceivable that when a given threshold level of strength training volume has been reached, the appropriate physiologic adaptations may be optimized, and a continued increase in the volume of resistance training provides no further benefits (5, 23)

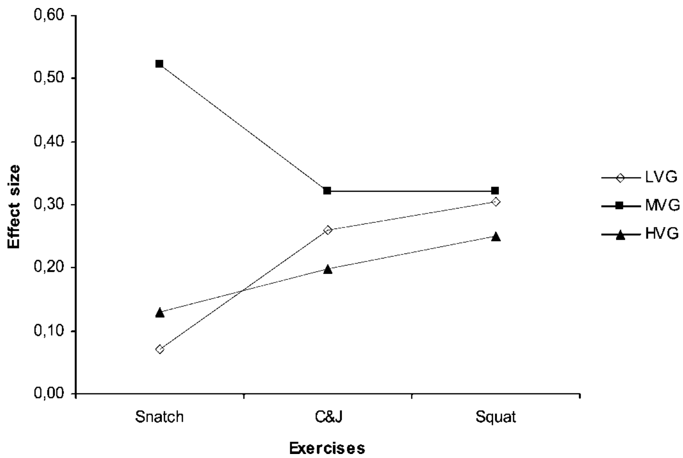

FIGURE 3. Effect size for the snatch, clean & jerk, and squat performances. LVG = low volume group; MVG = medium volume group; HVG = high volume group.

in experienced resistance-trained subjects. Conceptually, this would suggest that an optimal training volume would include only the amount of training volume that elicits maximal performance enhancements and that performance could be compromised if this volume threshold were surpassed. The results of the present study tend to support this, because the MVG showed greater increases in performance than the LVG and HVG. Another important point to consider is that the improvement of strength in the LVG was similar to that observed in the HVG, even though the training volume in the LVG was 63% of that performed in the LVG. This indicates that, in this young strength training population, physiologic mechanisms do not adapt to volume stimuli in a linear dose-response fashion. Less improvement was observed for the LVG and HVG with respect to the MVG. Furthermore, these results do not support the concept that the more, the better, because experienced young lifters can optimize performance training to only 85% or less of the maximal volume that they can tolerate.

Few studies have attempted to isolate the effects of increasing training volume while controlling other variables in long-term, experienced, resistance-trained men (1–6 years of experience) (6, 10, 13, 17). It is difficult to compare the results of these studies because they differ markedly in a number of factors, including the mode of controlling frequency, the duration, and the intensity of training; the scheduling of training sessions; the selection of dependent variables; and the magnitude of statistical power (1). These studies, using a time-series study design with each subject serving as his own control, have shown that increased training volume does not produce any performance change in Olympic lifts (SN or C&J) during short- or long-term training periods (5, 6, 8). In some instances, a rebound effect may occur, resulting in a enhanced performance when the volume of resistance training returns to a moderate volume of training (5, 6).

To our knowledge, 2 studies with a multigroup design have examined the effects of altering the volume of resistance, while controlling other variables, in long-term, experienced (1–6 years of experience) lifters who inherently have a limited potential for strength development (2–13%) through the application of high-intensity and high-frequency training (13, 17). Ostrowski et al. (17) reported similar increases when averaging the results of a 1RM SQ exercise (5–12%) for training with 3, 6, or 12 sets per exercise during a 10-week training period in highly trained men (training frequency, 4 sessions per week) with 1–4 years of resistance training experience. Hass et al. (13) found similar average increases in maximal leg extension strength (12–13%) for training with either 1 or 3 sets per exercise during a 13-week training period in recreational lifters (training frequency, 3 days per week), with an average of 6.2 years of resistance training experience. Both studies suggest that for highly experienced strength-trained subjects, there is a minimum training volume threshold over which further increases in volume are no longer advantageous. Other studies that have used a time-series study design with each subject serving as his own control (6, 12) have also failed to report any performance changes after training volume increases. The results of the present study suggest that when subjects are highly trained (4–5 days per week, high training volume, and intensity) and experienced (>3 years), their strength is probably approaching their genetic limits. The present study also suggests that when there is stringent control of training variables, increasing training volume does increase performance but only up to a point, at which time further increases do not yield more gains and can even lead to reduced performance. In the present study, it should also be noted that, during the last 2 weeks, the volume was reduced to 60 and 40% of the maximum weekly volume so that all groups could experience a rebound effect and avoid the risk that training volumes were overreaching and so that the possibility that the higher-volume subjects would see a performance enhancement would be facilitated when normal training resumed during the next cycle (6, 7).

The potential mechanisms that may be responsible for the different training adaptations observed when training volume is altered are unknown. Increased training volumes have been shown to affect neural (10, 11), hypertrophic (20), and metabolic (22) responses and subsequent adaptations to resistance training. A dramatic increase in training volume can overstrain the nervous and endocrine systems, leading to an elevated catabolic state or a lowered anabolic state and, thus, to limited strength development (8, 10, 11, 15, 16). For this hypothesis, an excessive endocrine response induced by the highest training volume in our study could compromise the optimal increase in performance.

These findings should be interpreted within the context of the study and the population examined (young lifters). To determine whether altering several training variables (i.e., increasing the number of training sessions per week or distributing the strength training volume across several daily sessions [9] or using longer-term resistance training programs) elicits similar adaptations in the present population warrants further investigation. In addition, it is possible that genetically gifted elite lifters can tolerate greater training volumes and attain additional increases in performance (7). More studies are required to optimize maximal strength development in both experienced and elite lifters.

In summary, although the optimal amount of stress continues to remain speculative, the results of the present study suggest that during the experimental strength training period, junior experienced lifters respond with a greater improvement in performance with moderate training volume than with low or high training volumes. These results do not support the notion of the more, the better, because experienced young lifters can optimize performance training by only 85% or less of the maximal volume that they can tolerate.

PRACTICAL APPLICATIONS

On the basis of our data, it appears that an extreme volume, although tolerated by the subject, does not produce the best training effect. These observations may have important practical relevance for the optimal design of strength training programs for resistance-trained athletes, given that performing a moderate volume is more effective and efficient than performing a higher resistance training volume. For various types of athletes performing at a determined training intensity, a minimum training volume may produce an optimal adaptation during a normal period of training. If these athletes decrease or increase the volume of their resistance training, a reduction in the positive effect may occur. It is possible that this optimal percentage of maximal volume can be applied to athletes with varying degrees of experience, although the maximum tolerated load at a given time may be different in and between individuals throughout their sporting life. Further investigations should be conducted that hold the volume of training constant but vary the average intensities in an attempt to identify the optimal combination of volume and intensity.

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