

The Effects of Training Volume on the Performance of Young Elite Weightlifters

by

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The purpose of this study was to determine the effects of increasing training volume on improvements in performance, physical fitness test records, and body composition variables in young elite weight lifters.

Sixteen young elite weightlifters who volunteered to participate in the study undertook the training program included specific weightlifting training with an 80%-90% of individual records. Volume of training increased according to the Fry et al. protocol. Training for subjects consisted primarily of large muscle mass exercises made up of front and back squats, overhead lifts, dead lifts, the snatch, clean and jerk, and their variations. Vertical jump height and rearward weight throws were determined using a force platform with specifically designed software and distance covered by the subjects to the nearest 1cm, respectively.

No significant changes in snatch and clean & jerk records were observed from pre- to mid- and from mid- to post-testing phases (snatch: 75.18±34.58 vs. 71.61±22.07 vs. 74.46±33.74 kg, $P \geq 0.05$; clean & jerk: 91.96±47.84 vs. 88.21±42.85 vs. 92.82±43.56 kg, $P \geq 0.05$). There were no significant changes in the front squat records from pre-to mid and from mid-to post testing (111.57±48.57 vs. 109.07±49.80 vs. 108.79±49.46 kg; $P \geq 0.05$). Results showed decreases (no significant) from pre-to mid testing but remarkable increase from mid- to post testing for back squat (130.36±56.79 vs. 125.89±57.48 vs. 163.07±101.90 kg; $P \geq 0.05$).

The data showed that performing additional session per day of high intensity weightlifting training does not lead to significantly greater improvements in performance of young elite weightlifters. Therefore, coaches could use one instead of two sessions of high intensity lifting training per day.

Key words: weightlifting, training load, snatch, clean & jerk, physical fitness test

Introduction

As a prime component of training, volume is the quantitative prerequisite for high physical, technical, and tactical achievements. Volume of training refers to the sum of work performed during a training phase. For elite athletes, there are no shortcuts for the high quantity of work they must perform (Bompa, 1999). Only a high number of repetitions can ensure the quantitative accumulation of skills necessary for qualitative improvements in performance. It has been shown a high correlation between

the volume of hours of training per year and desired performance. However, too great an increase in the work volume can be harmful (Bompa, 1999). Fry et al. (1991) and Stone et al. (1982) have suggested that overtraining signs and symptoms may represent a continuum that is related to changes in training volume. Harre (1982) suggested that excessive increase in the volume of training leads to fatigue, low training efficiency, uneconomical muscle work, and increased risk of injury.

Since many elite athletes use increased daily training frequencies to increase training load, Hartman et al. (2007) compared the physiological re-

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sponses to twice- and once-daily training sessions with similar training volumes in nationally competitive male weightlifters who were matched on body mass and training experience, then randomly assigned to train either once or twice daily for 3 wk. Variables such as isometric knee-extension strength (ISO), muscle cross-sectional area, vertical-jump peak power, resting hormone concentrations, neuromuscular activation (EMG), and weightlifting performance were measured before and after the experimental training period. Their results did not reveal any significant main effects or interaction effects for any of the dependent variables. Their results also showed no significant differences when variables were expressed as percentage change, but the twice-daily training group had a greater percentage change in ISO (+5.1% vs +3.2%), EMG (+20.3% vs. +9.1%), testosterone (+10.5% vs +6.4%), and testosterone/cortisol ratio (-10.5% vs. +1.3%) than did the once-daily training group. According to the Hartman et al. study there were no additional benefits from increased daily training frequency in national-level young male weightlifters, but the increase in ISO and EMG activity for the twice-daily group might provide some rationale for dividing training load in an attempt to reduce the risk of overtraining (Hartman, 2007).

Neuromuscular adaptations were investigated in ten female athletes during a "normal" intensive strength training period for 3-weeks (I) as well as during a separate second 3-week training period (II), when the same total training volume was distributed into two daily sessions. They showed no systematic changes in the maximal voluntary neural activation (averaged integrated EMG) of the leg extensor muscles, in the cross-sectional area (CSA) of the quadriceps femoris muscle or in maximal voluntary isometric strength of the leg extensor muscles over training period I with one daily session. However, a significant increase was observed in maximal strength from 2493 +/- 553 to 2620 +/- 598 N ($p \leq 0.05$) during period II accompanied also by a significant ($p \leq 0.05$) enlargement in the cross-sectional area of the muscle and by slight increases in the maximum IEMGs of the trained muscles. The individual changes in the maximum IEMGs of the trained muscles during period II correlated significantly ($p \leq 0.01$) with the individual changes in maximal strength. Their results suggested that the distribution of the volume of intensive strength training into smaller units, such as two daily sessions, may create more

optimal conditions not only for muscular hypertrophy but by producing effective training stimuli especially for the nervous system. These kinds of training conditions may lead to further strength development in athletes being greater than obtained during "normal" strength training of the same duration (Häkkinen and Kallinen 1994).

In order to figure out the relationships between training volume, physical performance capacity, and serum hormone concentrations during prolonged training a follow-up study was performed by Häkkinen et al. (1987) on 11 male elite weightlifters. Several variables including training volume, weightlifting performance, and serum hormone concentrations were measured during seven test occasions. In addition, the same measurements were repeated three times during a 6-week period preceding the primary competition. The primary results were observed during the 6-week period from which the first 2 weeks of stressful training was associated with significant decreases ($P \leq 0.001$) in serum testosterone concentration, in testosterone/cortisol and in testosterone/SHBG ratios, and with a significant ($P \leq 0.001$) increase in serum LH concentration. The individual changes during the stressful training in serum testosterone/SHBG ratio were related ($R = 0.63$; $P \leq 0.05$) to the individual changes in the weight lifting result in the clean and jerk lift. During the following "normal" 2-week and reduced 2-week training periods, the concentration of serum testosterone remained unaltered, but serum cortisol and serum LH decreased significantly ($P \leq 0.01$). During these periods, the serum testosterone/SHBG ratio increased significantly ($P \leq 0.01$). The individual changes during this preparatory 4-week training before the primary competition in serum testosterone/SHBG ratio and the individual changes in the weightlifting result in the clean and jerk lift correlated significantly with each other ($R = 0.68$; $P \leq 0.05$) (Häkkinen, et al. 1987).

González-Badillo et al. studied the effects of 3 resistance training volumes on maximal strength in the snatch, clean & jerk, and squat exercises during a 10-week training period. Their results indicated 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 they have shown that performing at a moderate volume is more effective and efficient than performing at a higher volume

(Gonzalez-Badill et al., 2005). The physiological adaptations resulting from a well-designed resistance training program include increased strength, muscle hypertrophy, lean body mass, bone mass, connective tissue thickness, and improved physical function (Kraemer et al., 1990; Kuipers et al., 1988; Lambert et al., 1990).

There are few published studies examining the effects of training volume on muscular hypertrophy and strength in previously resistance trained adults. Apparently, the optimal volume of weightlifting training for elite weightlifters is undetermined. Further, the efficacy of one-session per day compared to two-sessions per day programs has not been evaluated in professional lifters. Therefore, the purpose of this study was to determine whether increasing training volume (from one to two sessions per day) would elicit greater improvements in performance (snatch & clean& jerk) as well as physical fitness tests (vertical jump and, weight throwing over the head) records in elite weightlifters.

Methods

Experimental design and subjects

To determine the effects of increased training volume on changes in the performance, physical fitness, and body composition variables in young elite weight lifters the study was conducted for a 27 days during a pre-competition macrocycle (included of four microcycles). Increased volume of training according to the Fry et al. (1991) protocol allowed the comparison of pre to mid and mid to post test results. As the training protocol included 4 days of normal, 6 days of increased volume, and once again 14 days of normal training program respectively, we could be sure that the changes were due to increased training volume.

Sixteen young elite weightlifters volunteered to participate in the study. The research protocol has been approved by the Research Ethical Committee in the University of Mohaghegh Ardabili. The information sheet and consent form have been reviewed and signed by the subjects. Subjects were apparently healthy volunteers with no history of cardiovascular disease, orthopedic problems, or other medical conditions that would contraindicate exercise (N=16; mean (SD) age 21.28 (3.23) years, height 166.71 (8.65) cm, weight 68.27 (20.51) kg). All the subjects were National to Asian championships level weight lifters with an average of three years lifting experience in

the weightlifting championships. Our subjects were those who qualified for the annual national camp. They had a training session per day for 3 years. Subjects had to complete 100% of the training sessions to be included in the study. Characteristics of those who completed the study are listed in Table 1.

Procedure

Based on the Swain et al. equation ($\%MHR = 0.64 \times \%VO_2 \text{ Max} + 37$), the subjects completed a 15 minute warm up at 55–65% of VO_{2max} (equal to 72–79% of MHR) before physical test protocols were performed. Each training session was conducted and monitored by the investigators. Subjects were encouraged to exert maximal effort on all tests. Subjects were instructed to maintain their normal diet and not to participate in any exercise program. Pre, mid and post testing times were the same on the day of the main trials, the subjects transported to the laboratory as well as sport complex at approximately the same time of day (9–12 A.M.±1h).

Training Program

According to the literature and the performance level as well as the age group of the subjects, the training protocol was used. Following the initial evaluations, subjects were instructed to maintain the same level of physical activity throughout the study. The training program included specific weightlifting training with an 80%-90% of individual records. Volume of training increased according to the Fry et al. (1991) protocol (Figure 1).

Day	Protocol description
1	Subject meeting - explanation of study, obtain informed consents, Training.
2-4	Normal training
5	Pre-test
6-11	Increased volume of training (approximately doubled over typical training).
12	Mid-test
13-26	Normal training
27	Post-test

Figure 1

Training and testing protocol

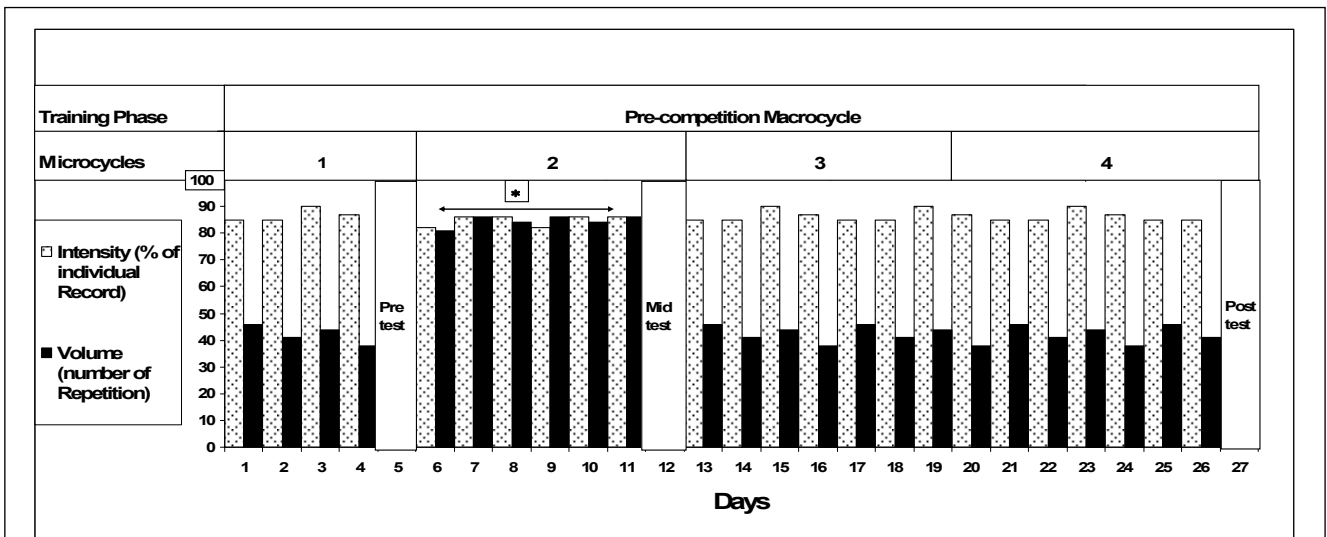


Figure 2

Training load (volume and intensity) dynamics

*. Mean of AM and PM training intensity.

Dynamics of training load (volume and intensity) figured out in the base of daily, microcycle, and mesocycle calculations as follow (Figure 2).

Training for subjects consisted primarily of large muscle mass exercises made up of front and back squats, overhead lifts, dead lifts, the snatch, clean and jerk, and their variations. During normal training consisting of one workout per day, the volume of training as measured by the volume load (repetitions × mass lifted) ranged from 2800 to 5500 kg per training day (days 2-4 and days 13-26) with a relative intensity (% 1 RM) of approximately 86.75% for the target sets (Table 2).

During the increased volume phase, two workouts per day were used and the volume of training ranged from 6000 to 12000 kg per training day (days 6-11) with a relative intensity of approximately 86.67% for the target sets (Table 3).

Vertical jump

Vertical jump height was determined using a force platform with specifically designed software (Bioware, Kistler, Switzerland). Ground reaction as well as moments of force was collected by a Bertec force plate (Model 4060A). A video-based (60 Hz),

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Table 1

Descriptive characteristics of the subjects						
Variables	Age (year)	Height (cm)	Weight (kg)	Body fat (%)	Lean body mass (kg)	WHR* (%)
Mean± SD	21.28 ±3.23	166.71±8.65	68.27±20.51	21.63±13.17	51.50±12.97	0.87±0.0058

Data are means± standard deviations. *. Wrist to Hip Ratio

Table 2

Four days normal training program*				
Days	Mon	Tue	Wed	Thu
No. of Rep.	46	41	44	38
Intensity (%)	85	85	90	87

*. The last fourteen days training program was the same as the first four days.

Table 3

Six days volume increased training program						
Days	Sat	Sun	Mon	Tue	Wed	Thu
Total No. of Rep.	81	86	84	86	84	86
Mean of Intensity (%)	82	86	86	82	86	86

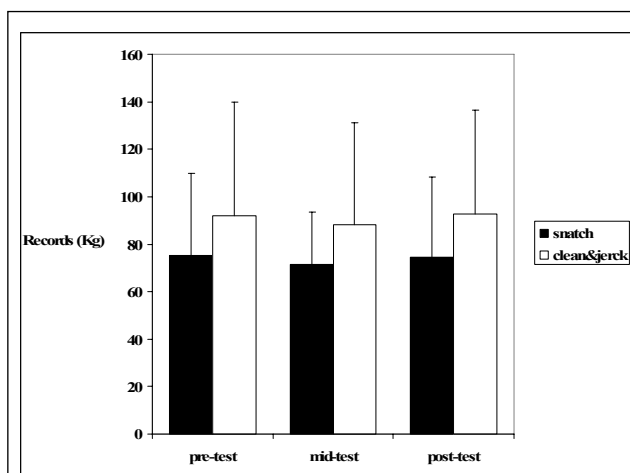


Figure 3

Comparison of Pre, Mid, and post-testing records for snatch and clean & jerk

three-dimensional motion analysis system (Motion Analysis Corp.) was used to collect and process the cinematic data. Cinematic data were refreshed by a low-pass, fourth-order Butterworth filter with an effective cutoff frequency of 8Hz. Jumping height was determined as the centre of mass displacement calculated from force development and measured body mass. Each lifter had three trials interspersed with a one minute rest interval between each jump. During the test, subjects were used hands in the jumping motion. The best jump from each subject was used in data analysis.

Rearward weight throw

After the 15 minute warm up, test was done by standing with the legs apart (25-35 cm) and semi flexed, with the 5 kg free weight in the hands in front at the level of the knees: it is thrown backward with the extended arms, through the fast extension of the legs and the maximum extension of the trunk. Each subject completed three trials and the best throwing distance to the nearest 1cm considered as a subject record. Three minutes rest intervals exist among the trails for regeneration. Before compilation of each trails, they used the magnesium powder for better throwing.

Body composition variables

To estimate the percentage of body fat the three points' skinfold measurement (chest, abdomen, and thigh) were taken on the right side. Measurements were taken when the skin is dry, and not overheated. To eliminate inter-observer variability only one

highly trained investigator performed these procedures. The Lafayette standard caliper was used to measures the skin-fold thickness in millimeters. Body density was then determined using the equation of Jackson and Pollock (Jackson and Pollock, 1978) Relative body fat was calculated using the Siri equation (Siri, 1961). Anthropometric measurements included height to the nearest 0.1 cm (Harpenden Stadiometer, model 602; Holtain Ltd., Holtain, U.K.) and weight to the nearest 0.1 kg (Detecto Scale, model number 8430; Webb City, MO). All anthropometric measurements were taken in accordance to the methods of Pollock and Wilmore (1990). Waist-to-hip ratio (WHR) is the ratio of the circumference of the waist to the hip. Waist at the level of iliac crest, and hip circumferences were measured to the nearest centimeter using tape rule while the subject is standing erect (Nieman, 1999).

Statistical analysis

Descriptive statistics (Mean \pm SD) for age, height, and weight were calculated for the subjects. Pre, mid, and post-training variables were compared using repeated measures ANOVA. Significant results were followed by *Bonfroni post hoc* comparisons to identify where differences occurred. Statistical significance was accepted at $P \leq 0.05$.

Results

Snatch and clean & jerk

Comparison of pre, mid, and post-testing records for snatch and clean & jerk using repeated measures ANOVA showed in figure 3. No significant changes in snatch and clean & jerk was observed from pre- to mid- and from mid- to post-testing phases (snatch: 75.18 \pm 34.58 vs. 71.61 \pm 22.07 vs. 74.46 \pm 33.74 Kg, $P > 0.05$; clean & jerk: 91.96 \pm 47.84 vs. 88.21 \pm 42.85 vs. 92.82 \pm 43.56 Kg; $P > 0.05$; Figure 3). Snatch records decreased by 5.33% from pre-to mid testing and increased by 4.23% from mid- to post-testing. Furthermore, clean & jerk records decreased by 4.35% from pre-to mid testing and increased by 5.68% from mid- to post-testing.

Additionally, there were no significant changes in snatch and clean & jerk records from pre- to mid- and mid- to post-testing phases in the strongest and weakest lifters (strongest snatch: 118.5 \pm 10.55 vs. 111 \pm 11.40 vs. 116.6 \pm 11.67 kg, $P > 0.05$; strongest clean & jerk: 151.5 \pm 19.01 vs. 141 \pm 17.10 vs. 146.5 \pm 18.51 kg,

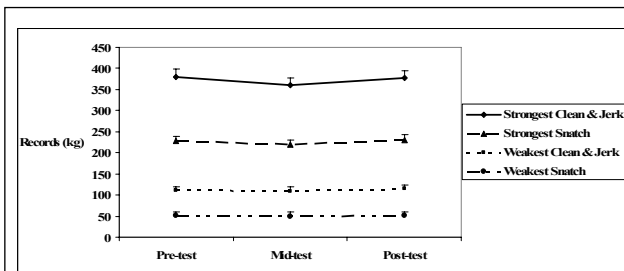


Figure 4
Comparison of snatch and clean & jerk records changes in the strongest and weakest lifters during the study

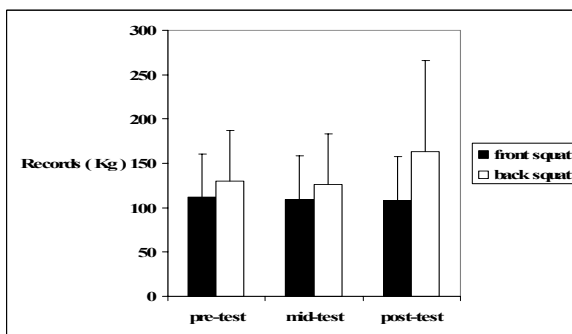


Figure 5
Comparison of front and back squat records during the study

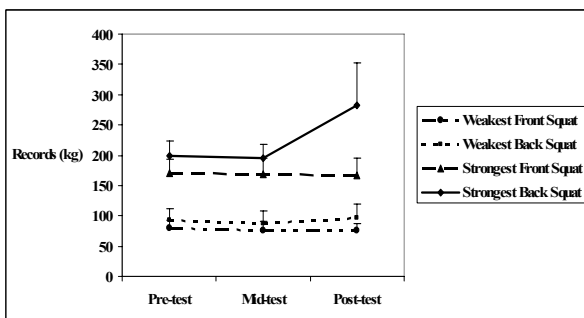


Figure 6
Comparison of front and back squat record changes in the strongest and weakest lifters during the study

P>0.05; weakest snatch: 51.11±7.92 vs. 49.72±9.87 vs. 51.11±8.01 kg, P>0.05; weakest clean & jerk: 58.89±9.61 vs. 58.89±11.39 vs. 63±10.54 kg, P>0.05, Figure 4).

Front and back squat

There were no significant changes in the front squat records from pre-to mid and from mid-to post testing (111.57±48.57 vs. 109.07±49.80 vs. 108.79±49.46 Kg; P>0.05). Results showed a de-

creases but no significant for back squat from pre-to mid testing; However, there was a remarkable but no significant increase in the back squat records from mid- to post testing ((130.36±56.79 vs. 125.89±57.48 vs. 163.07±101.90 Kg; P>0.05; Figure 5).

Front squat records decreased by 2.24% from pre- to mid testing and as well as 1.17% from mid- to post-testing. On the other hand, back squat records decreased by 3.43% from pre-to mid testing and increased by 30.03% from mid- to post-testing. Furthermore, when we compared the strongest with the weakest lifters, we showed only significant increases in back squat records from pre and mid to post-testing phases in the strongest lifters (strongest front squat: 170.4±22.98 vs. 168.40±27.75 vs. 166.80±29.48 kg, P>0.05; strongest back squat: 199±24.08 vs. 195±23.45 vs. 282.4±71.14 kg, P≤0.05; weakest front squat: 78.89±14.31 vs. 76.11±14.95 vs. 75±12.44 kg, P>0.05; weakest back squat: 92.22±19.22 vs. 87.5±21.25 vs. 96.78±22.35 kg, P>0.05; Figure 6).

Vertical jump and rearward weight throw

Physical fitness as measured by the vertical jump and rearward weight throw tests improved steadily over the study period. It is notable that the increases in physical fitness variables throughout the study were not significant (P>0.05, table 4).

Table 4

Vertical jump and rearward weight throw during Pre, Mid, and post-testing

Variables	pre-test	mid-test	post-test
Vertical jump (cm)	96.43 ±17.92	100.76 ±17.68	101.86 ±18.53
Rearward weight throw (m)	9.25 ±3.19	9.44 ±3.28	9.84 ±3.47

Data are means±standard deviations

Table 5

Body composition variables changes during Pre, Mid, and post-testing

Variables	pre-test	mid-test	post-test
Fat (%)	21.63 ±13.17	20.69 ±11.49	18.85 ±12.10
Lean body mass (Kg)	51.50 ±12.97	52.54 ±12.47	53.80 ±12.14
Body mass index (Kg/m ²)	24.12 ±6.46	24.24 ±6.35	24.31 ±6.24
Wrist to hip ratio (%)	0.87 ±0.0058	0.86 ±0.0054	0.87 ±0.0054

Data are means± standard deviations

Body composition variables

No significant differences were observed from pre- to mid- and mid- to post-testing phases in any of the body composition variables. However, it should be pointed out that % fat and lean body mass of subjects decreased and increased steadily over the study period, respectively (Table 5).

Discussion

The purpose of this study was to determine whether increasing training volume from one session to two sessions per day would elicit greater improvements in performance, physical fitness, and body composition in elite young weightlifters (average 3 to 6 yr weightlifting experience). Our data indicate that increased volume of weightlifting Fry et al. protocol do not significantly improved the performance variables of elite young weightlifters. However, there were improvements regarding body composition, physical fitness, snatch, clean & jerk, and back squat from pre-to post-test phases, even though these changes were not significant. These improvements occurred mainly from mid-to post-test days. As expected the performance of subjects remained unchanged or decreased from pre-to mid-test due to the increased demands of increased volume of training as well as lack of enough rest intervals for physiological adaptations.

Except for the strongest lifter back squat records, the weakest and strongest lifters had similar pattern for performance response to the increased training volume (Fig 4 and 6). Considering involvement of larger muscles and load impart on lumbar and hamstring muscles might be responsible when we compare back squat with front squat records even though the difference is not significant. The performance changes during test protocol in the young elite weightlifters did not affect by performance level, because increased training volume individualized according to the athlete's record. Base on this argument it is plausible that athlete body composition variables play a major role; therefore, it would be worthy to look at the lean body mass (LBM) as well as %fat beside performance records to organize the training volume and intensity.

Longitudinal (Pierce et al., 1987; Stone et al., 1982; Stone et al., 1983; Stone et al., 1983) and cross-sectional (Lambert et al., 1990; Stone et al., 1987) studies have noted beneficial adaptations in various physiological parameters as a result of weight train-

ing suggesting an improved tolerance to exercise. High-volume training using large muscle mass exercise appears to stimulate these beneficial adaptations to a greater extent than low-volume training or using small muscle mass training (Stone et al., 1991).

As Hopkins et al. was assessed the research aimed at measuring performance enhancements that affect success of individual elite athletes in competitive events, statistical significance may not be the criterion measure. They suggested that enhancements in test and event may differ when factors that affect performance differ between test and event (Hopkins et al., 1999).

While Häkkinen and Kallinen (1994) investigated neuromuscular adaptations in female athletes during a "normal" intensive strength training period for 3-weeks as well as during a separate second 3-week training period, when the same total training volume was distributed into two daily sessions, we studied the effects of increasing training volume on improvements in performance, physical fitness, and body composition variables in young male elite weightlifters. Our study was conducted for a 27 days during a pre-competition macrocycle consisted of four microcycles.

Despite of our results, Häkkinen and Kallinen results with female athletes suggested that the distribution of the volume of intensive strength training into smaller units, such as two daily sessions, may create more optimal conditions not only for muscular hypertrophy but also by producing effective training stimuli especially for the nervous system. The subject's gender, age group as well as training program characteristics and fitness level of subjects may be attributed to the different results. It is important to note that increasing the workload (training volume) will result in greater fatigue accumulation which will then require a period of unloading, which is dictated by the volume of the overload encountered, prior to the expression of performance gains. In fact, fatigue may have masked the performance gains as the fatigue-fitness paradigm.

Kraemer et al. (1990) showed that training with multiple sets not performed to failure was superior to a single set to failure for increasing the 1-RM squat. Subjects in the study of Kramer et al. were considered moderately trained and they were able to squat at least equal to their body mass and were not participating in any other exercise activity. Activities that involve greater skill and coordination (i.e. squat) may require a greater frequency of the stimulus and

promote greater strength gains. As we showed in the back squat results of strongest lifters, the large increase in strength could therefore be attributed to increase in neural adaptation and may be related to training intensity (% of 1 RM).

Kraemer suggested that though intensity plays a major role, the volume of training may also have interacted to produce the larger increases in strength. Thus, it appears that the inclusion of higher intensity training (80–90% of 1-RM loads for few repetitions) and the variation of intensity and volume will result in greater strength gains more than training with moderate weights for 8–12 repetitions to exhaustion (Fry et al., 1991; Kuipers and Keizer, 1988).

A learning effects as the sole cause of increased performance is unlikely because the subjects were very familiar with the tests, and in fact regularly performed the snatch, and clean & jerk or variations of these exercises in training. However, it is possible that much of our results are due to improvements (not significantly) regarding body composition, physical fitness, and performance variables would be plausible to be related to neural activations of motor units. It should be pointed out that from the pre- to mid test period, where the volume of weightlifting training increased, occurrence of non-functional overreaching as well as time limitation from the concentrated load until the performance tests to realize gains may be explain the lack of statistical improvements. However, Hopkins has argued with elite athletes, statistical significance may not be the best appraisal for their performance (Hopkins et al., 1999).

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Physical fitness as measured by the vertical jump and rearward weight throw tests, improved steadily but no significance seen over the 27 days weightlifting protocols. Previous experimentation did not produce performance improvements after a week of high-volume training in the elite junior weightlifters (Warren et al., 2000). The Berger study (Berger et al. 1962) reveals that after the 12 wk of training the difference in strength increase among the one-, two-, and three-set groups were less than 4 pounds. No studies have shown a significant difference in strength development when comparing one versus two sets of exercise. These studies clearly indicate that single-set training promotes significant improvements in strength of both the upper and lower extremities and postural muscles and that these improvements are comparable with those attained from a higher volume of training. The majority of these studies was 8–12 wk in duration using previously sedentary adults and used single isolation exercises. Whether more compound multi joint movements respond similarly to low volume and high volume training warrants further investigation

In summary, the data show that performing additional session per day of high intensity weightlifting training does not lead to significantly greater improvements in performance and body composition variables than training using a single session per day in young elite weightlifters. However, the strongest and weakest lifter as a result of the 27 days experimental training program showed a similar response. Therefore, coaches could use one instead of two sessions of high intensity lifting training per day.

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