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Moderate Volume of High Relative Training Intensity Produces Greater Strength Gains Compared With Low and High Volumes in Competitive Weightlifters

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Abstract. González-Badillo, J.J., M. Izquierdo, and E.M. Gorostiaga. Moderate volume of high relative training intensity produces greater strength gains compared with low and high volumes in competitive weightlifters. *J. Strength Cond. Res. 20(1)73–81. 2006.*—The purpose of this study was to examine the effect of 3 volumes of heavy resistance, average relative training intensity (expressed as a percentage of 1 repetition maximum that represented the absolute kilograms lifted divided by the number of repetitions performed) programs on maximal strength (1RM) in Snatch (Sn), Clean & Jerk (C&J), and Squat (Sq). Twenty-nine experienced (>3 years), trained junior weightlifters were randomly assigned into 1 of 3 groups: low-intensity group (LIG; $n = 12$), moderate-intensity group (MIG; $n = 9$), and high-intensity group (HIG; $n = 8$). All subjects trained for 10 weeks, 4–5 days a week, in a periodized routine using the same exercises and training volume (expressed as total number of repetitions performed at intensities equal to or greater than 60% of 1RM), but different programmed total repetitions at intensities of >90–100% of 1RM for the entire 10-week period: LIG (46 repetitions), MIG (93 repetitions), and HIG (184 repetitions). During the training period, MIG and LIG showed a significant increase ($p < 0.01$–0.05) for C&J (10.5% and 3% for MIG and LIG, respectively) and Sq (9.5% and 5.3% for MIG and LIG, respectively), whereas in HIG the increase took place only in Sq (6.9%, $p < 0.05$). A calculation of effect sizes revealed greater strength gains in the MIG than in HIG or LIG. There were no significant differences between LIG and HIG training volume-induced strength gains. All the subjects in HIG were unable to fully accomplish the repetitions programmed at relative intensities greater than 90% of 1RM. The present results indicate that short-term resistance training using moderate volumes of high relative intensity tended to produce higher enhancements in weightlifting performance compared with low and high volumes of high relative training intensities of equal total volume in experienced, trained young weightlifters. Therefore, for the present population of weightlifters, it may be beneficial to use the MIG training protocol to improve the weightlifting program at least in a short-term (10 weeks) cycle of training.

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

Introduction

Coaches and researchers in weightlifting training attempt to identify the most effective relationship between several indices of training variables such as volume (e.g., total number of repetitions performed), intensity (e.g., average relative intensity expressed as a percentage of 1 repetition maximum [1RM] that represents absolute kilograms lifted divided by the number of repetitions performed), frequency, and weightlifting performance. It is believed that to further improve weightlifting performance it is necessary to systematically increase the stress-related overload placed upon the body during resistance training (2).

There are several ways in which overload may be introduced during resistance training. From the various training variables, it appears that training intensity is the most important variable to consider when designing a resistance training program to target maximum strength in competitive experienced and elite strength athletes (18, 20, 31). Several studies have shown that training with loads corresponding to 80–100% of 1RM is most effective for increasing maximal dynamic strength (2, 3) because this loading range appears to maximally recruit muscle fibers and produce further neural adaptations (15, 23). Between this intensity range of 80–100% of 1RM, experienced weight-trained athletes and weightlifters routinely incorporate inordinate amounts of their strength training time using extremely heavy loads (>90% of 1RM) (5, 13, 14, 17, 20, 26–28), because it is believed that effective increases in maximal strength can be reached by training at these relative intensities. However, the optimal intensity stimulus at these extremely heavy loads for the development of strength and weightlifting performance is not known.

To our knowledge, only 1 study has investigated the effects of increasing heavy relative resistance training intensity in strength performance in men who are experienced, competitive weightlifters. Häkkinen et al. (17) found an increase in weightlifting performance during a 4-month training period, when the number of lifts performed in the intensity range of 80–90% and 90–100% of 1RM was increased. However, it is conceivable that if weightlifting training intensity is further increased at these heavy loads, there may be a high training intensity beyond which physiological maladaptations occur and the increase in performance is attenuated or abolished (7). This ceiling effect in strength gain has been observed in some studies with experienced weight-trained men (not weightlifters) showing that increasing resistance training intensity by lifting more repetitions at loads greater than 90% of 1RM with free weights (13) or resistance machines (9, 12) during 2–3 weeks produces increases (9), decreases (9, 12, 13), or no changes (13) in strength performance.

We hypothesized that utilizing a greater number of weightlifters, a multigroup experimental design study, and controlling other variables such as training frequency

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

Group	Age (years)	Height (cm)	Body mass (kg)	Snatch (kg)	Clean & jerk (kg)	Squat (kg)	Training years
LIG* (n = 12)	17.1 ± 1.7	168.0 ± 4.1	73.7 ± 5.5	85.6 ± 9.8	104.8 ± 11.7	145.6 ± 21	4.0 ± 0.8
MIG* (n = 9)	16.9 ± 1.7	167.0 ± 4.0	74.0 ± 3.9	84.7 ± 13.7	105.8 ± 14.8	140.6 ± 21.3	3.8 ± 1.0
HIG* (n = 8)	17.5 ± 1.9	169.1 ± 3.6	72.0 ± 2.3	87.8 ± 12.8	110.9 ± 16.8	149.1 ± 26.9	4.3 ± 1.2

* LIG = low-intensity group; MIG = moderate-intensity group; HIG = high-intensity group.

and volume, we could advance the knowledge of the effects of different heavy training intensities on weightlifting performance.

In view of the above considerations, the purpose of this study was to examine the effect of 3 volumes of heavy resistance training intensity on performance in experienced junior weightlifters. Considering the high magnitude of loads lifted, we hypothesized that when the subjects are highly trained and other training variables are controlled, a training threshold should exist over which performance may be compromised. Understanding the effects of using different periodized resistance training volumes of high intensity with weightlifters 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 average training intensity affect strength gains, we compared the effects of 3 different volumes of commonly used resistance training programs (high-intensity, 182 repetitions with loads greater than 90% of 1RM; moderate intensity, 91 repetitions with loads greater than 90% of 1RM; or low intensity, 44 repetitions with loads greater than 90% of 1RM) on maximum performance in snatch (Sn), clean & jerk (C&J), and back squat (Sq) in trained, junior male weightlifters over a 10-week training cycle. This number of repetitions with more than 90% of 1RM refers to the sum of Olympic lifts (Sn and C&J) and Sq. To eliminate any possible effects of intervening variables, several strength variables such as total volume of training, the volume and intensity of the rest of the exercises different from Olympic and Sq exercises, frequency of training, and type of exercise, were controlled by equating their values among treatment groups. The control of volume was critical to the study design because differences in the overall training volume have been proposed to influence performance adaptations (27). On the basis of previous studies (González-Badillo et al., unpublished data), the performed training volume was chosen because it has been shown that over a similar experimental short-term training period, experienced junior weightlifters respond with greater improvement in strength performance with moderate training volume (2,481 total repetitions) than with low (1,923 repetitions) or extreme training volumes (3,010 repetitions; González-Badillo et al., unpublished data). Additionally, the criterion to decide the training volume and intensity was the training program that had been performed in previous years by the lifters. It is crucial to take into account that each one of these training programs had to be realistic, and therefore, could not be so hard that it would create a hostile relationship between the researchers and the coaches and athletes.

Subjects

Twenty-nine male weightlifters met the experimental screening criteria and volunteered as subjects to participate in the study with the informed consent of their parents and coaches. The subjects were recruited from a group of young, competitive weightlifters with at least 3 years of training experience (Table 1). All of them were ranked among the top 4 junior levels in their national weight and age category. Three of the subjects also participated in European and world junior championships. Their best weightlifting performance in the competition (consisting of the Sn and C&J) was 190.4, 190.5, and 198.7 kg in the low-intensity group (LIG), medium-intensity group (MIG), and high-intensity group (HIG), respectively, with a corresponding Sinclair coefficient (calculated from the individual weightlifting performance and body mass) (29) of 241.4 kg, 239.4 kg, and 253.8 kg, respectively. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the department responsible.

Before the investigation, participants were ranked according to their total score in the 3 weightlifting exercises (Sn, C&J, and Sq), and were randomly placed into one of the 3 groups: LIG, n = 12; MIG, n = 9; and HIG, n = 8. The subjects were not taking exogenous anabolic-androgenic steroids or other drugs expected to affect physical performance or hormonal balance for several months before or during this study.

Procedures

All subjects had reached their best personal performances within the last 6 months before starting the experimental period. Baseline performance was considered the subjects' best personal performances in official competition in Sn and C&J, and the best personal test performed in Sq in training before starting the 10-week experimental period. After the 10-week experimental periods, maximal performance for Sn, C&J, and Sq was tested during 1 testing session.

For testing Sn and C&J, subjects warmed up using 2 warm-up sets of 3–5 repetitions at 40–50% of their estimated 1RM followed by 5–7 separate attempts from 60–100% of 1RM until the subject was unable to properly perform a good lift. After 3 misses with the same weight, the test was terminated. The best good lift was recorded as the result of the test. The squat test protocol was the same as that of Olympic lifts, although only 2 missed attempts were permitted. To quantify the effort to benefit ratio, training efficiency was defined as the average percentage gain in Sn, C&J, and Sq performance during the 10-week training period divided by the total number of repetitions lifted at loads greater than 90% of 1RM in Sn, C&J, and Sq, respectively.

Training Protocol

After the last official competition, and before beginning the experimental period, all subjects had 2 weeks of active rest during which time 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 the same progressive training. These 4 weeks were designed to balance training programs for all subjects before starting the experimental period. Following this 4-week period, the subjects trained for weightlifting 4–5 times a week for 10 weeks (45 sessions altogether).

Resistance exercise choice and order were identical for the 3 treatment groups. The training included the normal strengthening exercises used by elite weightlifters, such as the Olympic lifts (Sn and C&J), various power lifts, various pulling exercises, various squat-lifts to strengthen the legs, various pressing exercises to strengthen the arms and shoulders, and some other strengthening exercises for selected muscle groups. The primary exercises of the weightlifting sessions were Sn, power snatch, C&J, jerk, push jerk, power clean, snatch pulls, clean pulls, Sq, front squat, plus a few strengthening exercises for selected muscle groups.

During the overall training period all subjects performed the same training volume, frequency of training, type of exercises, and distribution of repetitions among exercises. This was done to control the influence of any other different variable of training intensity. Training volume was expressed as total number of repetitions performed at loads equal to or greater than 60% of 1RM during the experimental period. Average relative intensity was expressed as the percentage of 1RM that represented the absolute kilograms lifted divided by the number of repetitions performed. The only difference between groups in the training program was in the distribution of repetitions among zones of relative intensity in Olympic exercises and Sq, and consequently, in the average relative intensity (Table 2).

Given that it has been proposed that intensities ≥80% of 1RM are the most effective for strength gain in weight-training athletes (2, 5, 14, 15, 17, 19, 26), but that excessive training with more than 90% of 1RM can impair (13) and even reduce performance (12), we equated the volume in the zone >80–90% for all groups in Sn (124 repetitions), C&J (80 repetitions), and Sq (343 repetitions), but the programmed total number of repetitions at loads of >90–100% of 1RM was higher in HIG (83, 42, and 61 repetitions for Sn, C&J, and Sq, respectively) than in MIG (42, 18, and 31 repetitions, respectively) and LIG (20, 9, and 15 repetitions, respectively). Thus, to equate the total training volume, the programmed total number of repetitions at loads of 60–80% of 1RM was higher in LIG (269, 181, and 400 repetitions, for Sn, C&J, and Sq, respectively) than in MIG (245, 173, and 389 repetitions, respectively) and HIG (207, 149, and 360 repetitions, respectively) (Tables 2 and 3). This means that the total number of repetitions programmed at loads equal to or greater than 60% of 1RM was the same between the groups, but average relative training intensity was higher in HIG than in MIG and LIG (see Table 3). Additionally, the number of repetitions actually performed for each group at all high intensities was different between all groups ($p < 0.01$ to 0.001) (see Table 3).

The training was periodized from middle intensity (60–80% 1RM) and moderate number of repetitions per set (2–6) to high intensity (90–100%) and low number of repetitions per set (1–3). During the final 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 volume and average intensity over the 10-week training period is shown in Figure 1. Table 2 presents the detailed description of the primary training exercises and the average number of lifts programmed for each group at the different zones of relative intensity during the experimental period. For the Sn exercises and snatch pulls, all percentages of training were calculated from 1RM of Sn, for C&J exercises, and clean pulls from 1RM of C&J, and from Sq 1RM.

Each training session was supervised by a certified trainer by the Spanish Weightlifting Federation with several years of professional experience in weightlifting. Each coach kept training diaries for the entire experimental period so that the training could be analyzed in detail and the training volume and intensity (load) in each training session could be determined (20). Compliance with the study was 100% of the programmed sessions. When the relative proposal intensity was within 95% to 100% of 1RM, the lifters attempted to lift the maximal or near-maximal weight they could.

Statistical Analyses

Descriptive statistics (mean ± *SD*) for the different variables were calculated. Intergroup differences among the means of performances were treated with one-way analysis of variance. A *t*-test for paired groups was used to compare group differences within the means of performances. The linear product-moment correlation coefficient was applied to determine the relation between the number of real performed repetitions and strength performance. The effect size (ES) between pretraining and post-training for each group was calculated using Hedges' *g* (22), represented by the formula:

$$g = \frac{M_{post} - M_{pre}}{SD_{pooled}},$$

where M_{post} is the mean for post-training and M_{pre} is the mean for pretraining in each group, and SD_{pooled} is the pooled standard deviation of the pretraining and post-training measurements. The α level was set at $p \leq 0.05$.

RESULTS

Comparison Between Training Programmed and Training Accomplished

Table 3 shows the number of repetitions programmed and accomplished in selected zones of intensity as well as the average training intensity for Sn, C&J, and Sq in the 3 groups. The disparity between programmed repetitions and lifts accomplished was due to the inability of the subjects to accomplish the repetitions programmed at relative intensities greater than 90% of 1RM. The previously programmed training lifts performed at relative intensities ≤90% of 1RM were accomplished by all the subjects. However, the lifts accomplished at relative intensities >90% of 1RM in Sn (79, 79, and 75%), C&J (88, 87, and 79%) and Sq (93, 92, and 92%) were 7–25% lower than the lifts previously programmed in LIG, MIG, and HIG,

TABLE 2. Training programs for each group.

Exercise	Repetitions	Sets	AI* (%)	% of total repetitions	60–70	71–80	81–90	91–95	96–100	101–105	106–110
					Repetitions and (%) of total repetitions per exercise in the different zones of relative intensity						
Low-intensity group											
Snatch†	706	358	75.5	28.5	253 (35.8)	309 (43.8)	124 (17.6)	12 (1.7)	8 (1.1)		
Clean & jerk†	605	343	75.8	24.4	211 (34.9)	277 (45.8)	108 (17.9)	7 (1.2)	2 (0.3)		
Pulls‡	269	111	98.5	10.9		3 (1.1)	51 (19)	35 (13.0)	94 (34.9)	80 (29.7)	6 (2.2)
Squat§	896	330	78.4	36.2	298 (33.3)	193 (21.5)	388 (43.3)	10 (1.1)	7 (0.8)		
Total	2,476	1,142	79.1		762 (30.8)	782 (31.6)	671 (27.1)	64 (2.6)	111 (4.5)	80 (3.2)	6 (0.2)
Moderate-intensity group											
Snatch†	703	373	76.2	28.4	247 (35.1)	291 (41.4)	123 (17.5)	25 (3.6)	17 (2.4)		
Clean & jerk†	606	349	76.1	24.4	210 (34.7)	270 (44.6)	108 (17.8)	11 (1.8)	7 (1.2)		
Pulls‡	269	111	98.5	10.9		3 (1.1)	51 (19.0)	35 (13.0)	94 (34.9)	80 (29.7)	6 (2.2)
Squat§	901	345	78.6	36.3	298 (33.1)	182 (20.2)	388 (43.1)	22 (2.4)	11 (1.2)		
Total	2,479	1,178	79.5		755 (30.5)	746 (30.1)	670 (27.0)	93 (3.8)	129 (5.2)	80 (3.2)	6 (0.2)
High-intensity group											
Snatch†	707	412	77.6	28.5	227 (32.1)	273 (38.6)	124 (17.5)	50 (7.1)	33 (4.7)		
Clean & jerk†	602	364	76.7	24.3	207 (34.4)	249 (41.4)	108 (17.9)	23 (3.8)	15 (2.5)		
Pulls‡	269	111	98.5	10.9		3 (1.1)	51 (19.0)	35 (13.0)	94 (34.9)	80 (29.7)	6 (2.2)
Squat§	900	370	79.3	36.3	281 (31.2)	170 (18.9)	386 (42.9)	45 (5.0)	18 (2.0)		
Total	2,478	1,257	80.3		715 (28.9)	695 (28.0)	669 (27.0)	153 (6.2)	160 (6.5)	80 (3.2)	6 (0.2)

* AI = average intensity.
† Snatch includes snatch and power snatch; Clean & jerk includes jerk, push jerk, and power clean.
‡ Pulls include snatch and clean pulls.
§ Squat includes back and front squat.

TABLE 3. Programmed and performed repetitions in selected zones of intensity for Olympic exercises and back squat, and average intensity. All subjects performed the programmed repetitions from 60–90%.

Exercise	Repetitions and average intensity	Lower-intensity group		Moderate-intensity group		High-intensity group	
		Programmed	Performed	Programmed	Performed	Programmed	Performed
Snatch	Total repetitions	413	413	410	410	414	414
	60–80	269	269	245	245	207	207
	85–90	124	124	123	123	124	124
	91–95	12	11.3 ± 1.4	25	22.3 ± 3.0	50	44.9 ± 4.9
	96–100	8	4.5 ± 2.9	17	10.7 ± 2.9	33	17.4 ± 6.9
	Average int.	77.7	77.5 ± 0.2	78.8	78.4 ± 0.3	81.2	80.3 ± 0.4
Clean & jerk	Total repetitions	270	270	271	271	267	267
	60–80	181	181	173	173	149	149
	85–90	80	80	80	80	80	80
	91–95	7	6.2 ± 1.2	11	10.6 ± 1.3	23	21.6 ± 1.3
	96–100	2	1.7 ± 1.0	7	5.1 ± 1.8	15	8.4 ± 3.4
	Average int.	77.8	77.7 ± 0.1	78.4	78.2 ± 0.2	79.8	79.2 ± 0.3
Back squat	Total repetitions	758	758	763	763	762	762
	60–80	400	400	389	389	360	360
	85–90	343	343	343	343	341	341
	91–95	9	8.7 ± 0.5	21	20.4 ± 1.2	44	42.6 ± 4.1
	96–100	6	5.3 ± 0.9	10	8.1 ± 1.9	17	13.8 ± 4.0
	Average int.	78.7	78.7 ± 0.03	79	78.9 ± 0.1	79.8	79.7 ± 0.1

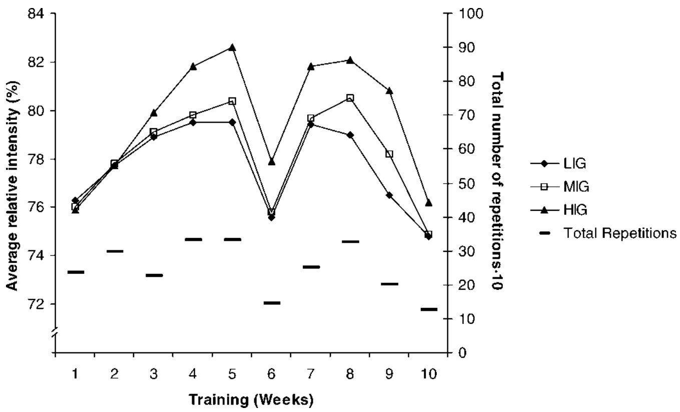

FIGURE 1. Number of total lifts and the mean of average relative intensity for Olympic exercises and back squat over the 10-week training period. LIG = low intensity group; MIG = moderate intensity group; HIG = high intensity group.

respectively. No subject in HIG could fully accomplish the total number of lifts programmed at relative intensities >90% of 1RM in Sn and C&J, whereas in Sq, only 50% of the subjects (4 subjects) could fully accomplish the number of lifts programmed. Significant differences ($p < 0.001$) were observed between groups in relative training intensity and in the average number of lifts performed at intensities >90% of 1RM in Sn, C&J, and Sq. However, there were no significant differences between groups in the number of total lifts performed throughout the duration of the study (Table 3).

Squat and Weightlifting Results

At the beginning of the training program, no significant differences were observed among the groups in pretraining age, height, body mass, years of training experience, and Sn, C&J, and Sq results. During the 10 weeks of training, statistically significant increases occurred in the C&J and the Sq in LIG (3.0%, $p < 0.05$, and 5.3%, $p < 0.01$, respectively), and in MIG (10.5 and 9.5%, $p < 0.05$, respectively), whereas in HIG the increase took place only in the Sq (6.9%, $p < 0.05$) (Figure 2). The effect size between pretraining and post-training of MIG was superior to other groups in all exercises, so that the mean total effect size for Olympic lifts and Sq was 1.96 times greater for the MIG (0.61) than for the LIG (0.31), and 2.54 times greater for the HIG (0.24). Similar effect sizes were observed in the pretraining and post-training between LIG (0.31) and HIG (0.24) groups.

Training Efficiency

During the experimental period average training efficiency in LIG (0.23%·lift^{-1}, 0.37%·lift^{-1}, and 0.39%·lift^{-1} in Sn, C&J, and Squat, respectively) and MIG (0.15%·lift^{-1}, 0.78%·lift^{-1}, and 0.36%·lift^{-1} in Sn, C&J, and Sq, respectively) was 305–804% higher ($p < 0.05$) than in HIG (0.045%·lift^{-1}, 0.01%·lift^{-1}, and 0.12%·lift^{-1} in Sn, C&J, and Sq, respectively). No differences were observed in training efficiency between the LIG and MIG groups.

Relationships Between Training Intensity and Results in Sn, C&J, and Sq

During the 10-week training period, significant linear correlations ($r = 0.52$; $p = 0.015$) were observed in LIG

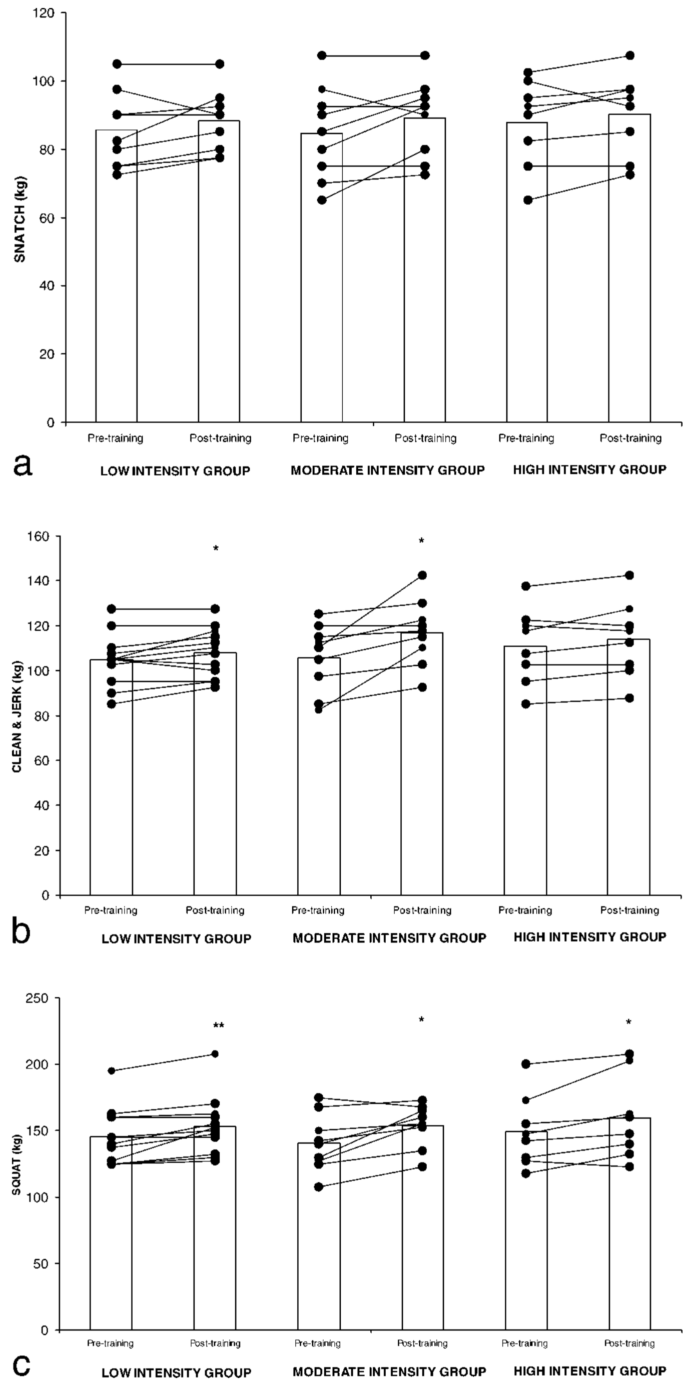

FIGURE 2. One repetition maximum expressed in kilograms during snatch (a), clean & jerk (b), and squat (c) for the low-, moderate-, and high-intensity training groups at pretraining and the subsequent 10 weeks of training for each subject. *Significantly different ($p < 0.05$) from the corresponding pretraining value. **Significantly different ($p < 0.01$) from the corresponding pretraining value. Values are means ± *SD*. The bars indicate the mean values.

and MIG as a whole between the individual total number of lifts performed at a relative intensity of 100% of 1RM in the Sn and the individual changes in the results in the Sn (Figure 3A). Significant linear correlations ($r = 0.47$; $p = 0.03$) were also observed in LIG and MIG between the individual total number of lifts performed at a rela-

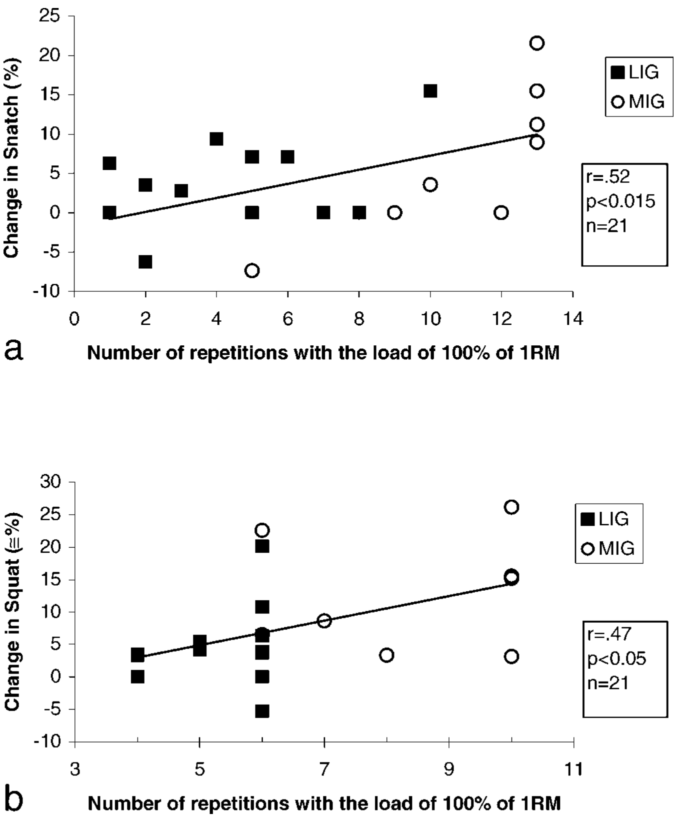

Figure 3. Relationships between the individual relative changes in snatch (a) and squat (b) and the individual total number of lifts performed at a relative intensity of 100% in the respective exercises. LIG = low intensity group; MIG = moderate intensity group; 1RM = 1 repetition maximum.

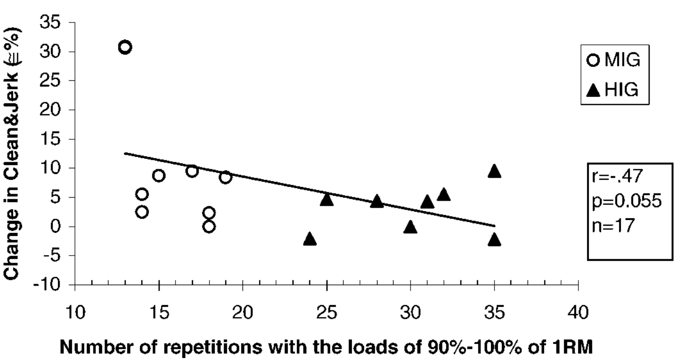

Figure 4. Relationships between the individual relative changes in clean & jerk and the individual total number of lifts performed in the relative intensity ranges of >90–100% in the clean & jerk. MIG = moderate intensity group; HIG = high intensity group; 1RM = 1 repetition maximum.

tive intensity of 100% in the Sq and the individual changes in the results in the Sq (Figure 3B). The negative linear correlations observed in MIG and HIG between the individual total number of lifts performed in the relative intensity ranges of >90–100% in the C&J and the changes in the results in the C&J approached statistical significance ($r = -0.47$; $p = 0.055$) (Figure 4).

Discussion

The primary finding of this study was that short-term resistance training using moderate volumes of high relative intensity tended to produce higher enhancements in weightlifting performance compared with low and high volumes of high relative training intensities of equal total volume in experienced, trained young weightlifters. In addition, significant correlations were observed between changes in the total number of lifts performed at high relative intensity and the changes in weightlifting results. Therefore, the present data suggest that in previously trained junior weightlifters, increasing training intensity does not always provide a better stimulus for improving adaptations during short-term training periods when compared with low or moderate training intensities.

It is well known that progressive overload is necessary to increase muscular strength and that for adaptations to occur, a stimulus exceeding a previous stimulus needs to be applied during a resistance training program (4, 27). However, it also may be conceivable that when a given threshold level of strength training intensity has been reached in experienced resistance-trained subjects, the appropriate physiological adaptations may be optimized and the performance of additional resistance training intensity provides no further benefits (8, 12, 13, 24). Conceptually, this would suggest that an optimal training volume with a determined training intensity would reflect the optimal amount of training with a determined intensity eliciting maximal performance enhancements and that performance could be also compromised if a given threshold of strength training volume with that intensity was surpassed. The results of the present study tend to support this concept because the MIG experienced a greater increase in performance than the LIG and HIG. This happened despite training in the crucial range from 81–90% of 1RM was the same for all groups. This indicates that, in this young weightlifting population, the physiologic mechanisms do not adapt to intensity stimuli in a linear dose-response fashion, with the lower results obtained for the LIG and HIG with respect to the MIG. On the basis of the present data, there appears to be an inverted, U-shaped relationship between resistance training intensity and increase in weightlifting performance when training intensity is very high and the experienced, trained subjects are approaching their genetic limits. Therefore, in the context of a short-term resistance training cycle of 10 weeks, experienced young weightlifters can optimize performance training only by 50% or less of the maximal number of lifts that they can tolerate at high intensities (>90–100% of 1RM).

Few studies have attempted to isolate the effects of increasing training intensity by lifting more repetitions at loads greater than 90% of 1RM in experienced weight-trained men (9, 12, 13). These studies have shown that increasing resistance training intensity during 2–3 weeks produces increases (9) or decreases (9, 12, 13), or it does not change (13) strength performance. The discrepancies between the results of these studies may result in part from differences with respect to the length of the experimental period, the devices used (free weight or machine), the relative training intensity, the frequency and total volume of training, the length of recovery periods within training sessions, and the pretraining physical fitness status or sport specialty of the subjects (1). Thus, it is not possible to compare training programs using resistance machines (9, 12) with training programs using free weights (13), because training with resistance machines is associated with lower energy expenditure and endocrine requirements compared with free weights (9, 13). Nevertheless, taking the results as a whole, a general trend is that when training intensity is increased at loads greater than 90% of 1RM in weight-trained subjects, there must be a maximum training intensity threshold over which further increases in intensity are no longer advantageous, and if this threshold is surpassed it could even cause a decreased effect on performance.

To our knowledge, only one study has investigated the effects of increasing relative resistance training intensity in strength performance in elite, male competitive weightlifters. Häkkinen et al. (17), in a time-series study design with each subject serving as his own control, found an increase in weightlifting performance during a 4-month training period, when the number of lifts performed in the intensity range of 80–90% and 90–100% of 1RM was increased, and the average training intensity increased from 79 to 80% of 1RM. This agrees with the results of the present multigroup experimental design study, because the group training at average relative intensity of 78–79% of 1RM (the MIG group) improved its weightlifting performance more than the group training at lower average training intensity (LIG, 77–78% of 1RM) (Table 3). In addition, the results of the present study show that when the average training intensity is further increased to 80–81% of 1RM (the HIG group) (Table 3), the improvement in weightlifting performance is lower than training at slightly lower average training intensity. This indicates that in junior competitive male weightlifters, there is an upper intensity limit above which increases in the number of lifts performed at training intensities ranges of >90–100% of the maximum can have a negative effect on strength and weightlifting results.

Some information was obtained regarding the interrelationships between variations in training intensity and weightlifting result increments. Significant linear correlations were observed in LIG and MIG overall between the individual total number of lifts performed at a relative intensity of 100% of 1RM in the Sn and the Sq, and the individual changes in the results in the Sn and the Sq, respectively. This indicates that experienced, junior male weightlifters who accomplished a greater number of lifts at extreme relative intensities of 100% of 1RM in Sn and Sq during a 10-week training period may be able to obtain greater increases in Sn and Sq performance vs. those accomplishing fewer lifts, when the total number of lifts accomplished at loads of 100% of 1RM consist of between 1 and 13 ($r = 0.52$; $p < 0.015$) and between 4 and 10 ($r = 0.47$; $p < 0.05$), for Sn and Sq, respectively (Figure 3). In addition, negative linear correlations ($p < 0.055$) were observed in MIG and HIG overall between the individual total number of lifts performed in the relative intensity ranges of >90–100% of 1RM in the C&J and the changes in the results in the C&J (Figure 4). This indicates that during a 10-week training period, junior weightlifters who performed more C&J lifts at loads greater than 90% of 1RM may be able to obtain lower strength gains in the C&J performance. These observations may have important practical relevance for the optimal design of strength training programs for experienced young weightlifters. However, these relationships between number of lifts and weightlifting performance are at least partially dependent on the specific characteristics of the short-term training program and the characteristics of the subjects tested.

The magnitude of increases in strength was the same in the present study for both LIG and HIG training groups, despite the fact that the average number of lifts accomplished in the intensity range of >90–100% in LIG (38 repetitions) was 25% of that performed in HIG (149 repetitions) (Table 3), and training efficiency was almost 6 times greater in LIG than in HIG. This suggests that training with high levels of demand and fatigue does not appear to be a critical stimulus for strength gains (6), and that high-intensity resistance exercise can be effective without accomplishing a large number of high-intensity lifts. Another important consideration is that none of the subjects in HIG could accomplish the total number of lifts previously programmed at relative intensities greater than 90% of 1RM. This observation indicates that the training program accomplished by HIG is near the limit of training tolerance and that training near the maximal individual's capacity to tolerate intense training does not lead to the highest increase in weightlifting performance.

The gains in performance in MIG were greater than in LIG, whereas training efficiency was similar in both groups. This means that the MIG training protocol is more effective than the LIG training protocol to improve weightlifting performance in a short-term (10-week) training period. In the present study, it should also be taken into consideration that during the final 2 weeks the volume was reduced to 60 and 40% of the maximum week volume, to accomplish a rebound effect for all groups, and to avoid to some extent that the training volumes were not overreaching in nature, so that the greater volume would see a performance enhancement when normal training resumed over the next cycle (9, 12). Whether this increased strength gain in MIG compared to LIG and HIG is maintained during longer weightlifting training periods or when normal training is resumed over the next cycle remains to be elucidated.

Because no biochemical, physiological, or psychological responses were measured in the present study, it is beyond the scope of the present investigation to determine the physiological mechanisms responsible for the different training adaptations taking place when training intensity is altered. Häkkinen et al. (17, 21) have found that the increases in elite weightlifting results observed after increasing average training intensity in the range of 80–100% of 1RM are primarily related to significant increases in the neural activation of the trained muscles and in a balanced or increased anabolic-androgenic activity (e.g., increase in resting serum concentrations of testosterone and some reduction in the resting concentration of cortisol), whereas the magnitude of muscle growth is slight or minimal. Therefore, the greater increases in weightlifting performance observed in MIG compared to LIG could be partly explained by increased neural activation and the anabolic hormone environment. The underlying mechanisms responsible for the attenuated performances observed when relative intensity was further increased (HIG training program) are unknown but could be related to a complex state of overreaching or overtraining (11). Some research has suggested that in short-term, high-intensity resistance exercise, overreaching or overtraining is related to peripheral alterations (12), altered functions of the sympathetic system and skeletal muscle adrenergic receptors regulating alterations in resting endocrine profiles (10, 13, 25), and deterioration in technique (30). However, whether such different responses in weightlifting performance are mediated by these mechanisms remains beyond the scope of the present data.

These findings should be interpreted within the context of the study and the population examined (experienced young weightlifters). Whether altering several training variables (e.g., increasing the number of training sessions per week or distributing the high-intensity strength training in several daily sessions (16), using longer-term resistance-training programs or resuming over the next cycle), or improving recovery methods (or both), elicit similar adaptations in the present population warrants further investigation. In addition, it is possible that weightlifters with more experience or less training may have a different response pattern to changes in training intensity (17). Besides, it is possible that genetically gifted, elite weightlifters can tolerate greater relative training intensities and obtain further increases in performance (12). More studies are required to optimize maximal strength development in both experienced and elite weightlifters.

In summary, although the question about how much high-relative-intensity weight training is too much continues to remain speculative, the present study suggests that if experienced weightlifters try to perform the maximal number of repetitions that they can tolerate they do not reach their best weightlifting performance. The present results also indicate that over the experimental strength training period accomplished in the present study, experienced junior weightlifters respond with a greater improvement in performance with moderate, high-intensity training compared with low or high training volumes of high intensities. Finally, these findings should be interpreted within the context of the study and the population of young experienced weightlifters examined.

PRACTICAL APPLICATIONS

Three critical implications for practitioners may be derived from this investigation to optimize training and avoid overreaching or overtraining. First, this study shows that in experienced junior weightlifters performance increases with increased relative training intensity, but only to a point, near an average relative intensity of 79% of 1RM. Once this optimum relative training intensity is reached a further increase in training intensity may not yield more gains in weightlifting performance and may even cause regression. Second, for the present population of weightlifters, it may be beneficial to use the MIG training protocol to improve the weightlifting program at least in the short term (10 weeks of training). Third, the HIG training protocol is near the maximal of an individual's capacity to tolerate intense training but is less effective and less efficient than a lower relative resistance training intensity in this experienced junior weightlifting population.

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