

Periodization: The Effect on Strength of Manipulating Volume and Intensity

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ABSTRACT

This study examined the effects of manipulating volume and intensity on strength and power in experienced male athletes. Subjects ($N = 22$) were tested for maximum strength in the squat and bench press lifts, vertical jump (VJ), lean body mass (LBM), and neural activation levels (IEMG). They trained 3 days a week for 12 weeks according to a linear periodization model ($n = 8$), an undulating periodization model ($n = 5$), or a nonperiodized control model ($n = 9$). Training volume and relative intensity were equated for all groups. Maximal squat, bench press, and LBM all improved significantly in each group, and changes in maximal strength correlated significantly with changes in LBM. IEMG levels were generally unchanged and did not correlate with changes in strength. The VJ increased significantly through training, but there were no differences between groups. Changes in VJ were not significantly correlated with changes in squat, LBM, or IEMG levels. The results indicate that in short-term training using previously trained subjects, no differences in maximal strength are seen when training volume and relative intensity are equated.

Key Words: hypertrophy, squat, bench press, vertical jump

Introduction

High levels of strength are necessary for optimal performance in many sports. Strength levels can discriminate between athletes of differing performance levels not only in competitive weightlifting and powerlifting but also in a number of sports such as American football (7), volleyball (8), rowing (41), and kayaking (9).

Increases in strength may be attributed to a combination of neural and hypertrophic adaptations. The neural adaptations are thought to be the dominant initial mechanism for strength increases, but after several months of training the hypertrophic adaptations become more dominant (13, 15, 29). Neural adaptations

include increased motor unit activation, as evidenced by increased integrated electromyographic (IEMG) activity (15), skill learning and coordination (37), and motor unit synchronization (28). Hypertrophic responses mainly include an increase in the size of individual muscle fibers (6, 11, 13, 18) due to an increased myofibrillar volume (23).

The relative contribution of hypertrophic and neural mechanisms to changes in strength varies due to the athlete's training background and program design (12). High intensity training is seen to result principally in neural adaptations whereas high volume training is reported to enhance the hypertrophic responses (40). There is considerable debate as to the most effective way to structure strength training in terms of manipulations of volume (total repetitions) and intensity (repetition maximum load or percent of maximum load) to maximize the neural and morphological adaptations from such training.

At present there appear to be three distinct schools of thought as to what type of strength training is best for developing maximal strength and related muscular functions:

1. The nonperiodized, traditional method advocated by Berger (4) and O'Shea (32) is a nonvaried prescription of training volume and intensity. This structure is typically characterized by three sets of a 6-RM load that Atha (3), in an extensive review, concluded represents the optimal load for strength training. This nonvaried prescription of volume and intensity may theoretically increase strength via both neural and hypertrophic mechanisms, as it would appear to be a compromise between the hypertrophy methods (high volume) and neural methods (high intensity) of strength training.

2. The linear periodized method is based on the training programs of elite strength athletes (e.g., 48) and the concept of training periodization (24, 42, 48). This structure is characterized by a large initial training volume at a moderate intensity (5×10 RM), with progressive increases in intensity and sharp decreases in volume while working toward a peaking of intensity ($3 \times 1-3$ RM) over a typical 10- to 12-week training cycle. Although there may be variations in intensity and volume within the week, the magnitude

of variation is less than in the undulating method. It has been theorized that the early high volume period emphasizes the hypertrophic adaptations, as evidenced by significant increases in lean body mass (LBM) (42), and the later high intensity periods stress the neural responses, thus providing a more efficient training structure for strength gain than the nonperiodized method (43).

3. The undulating periodized method advocated by Poliquin (34) is characterized by a more undulatory manipulation of volume and intensity across a training cycle. Poliquin rationalized that short periods of high volume training emphasizing the hypertrophic responses, alternated with short periods of high intensity training emphasizing the neural responses (40), would offer a better alternative to the linear intensification model (42). It is believed that prolonged linear intensification leads to "neural fatigue" (22) which could compromise strength gain. Thus, by combining high intensity training with intermittent periods of high volume/lower intensity training, optimal strength gains may result.

The linear periodization structure has been reported to result in greater increases in strength, power, and high intensity endurance as compared to the more traditional nonperiodized approaches (e.g., 3×6 RM, 3×10 – 12 RM, 1×10 – 12 RM, 5×10 RM, 6×8 RM) (26, 31, 41, 42, 44, 50). This led O'Bryant et al. (31) to state that the higher intensity of the linear periodized model was the major factor influencing the significantly greater gains found by those using this model.

However, in the research of O'Bryant et al. (31) and Stone et al. (42), the training volume of the periodized and traditional groups was not equated. In fact the traditional groups performed approximately only 56% of the periodized group's training volume. A higher training volume would be advantageous for novices, as used in these studies, as each repetition can be seen as a "trial" for motor skill acquisition and, accordingly, more trials would allow greater learning and coordination, factors that greatly influence strength in novices (37).

Volume is also an important variable in the principle of overload, and consequently greater volume results in greater overload of the musculature. Therefore, since volume was not equated when comparing the traditional nonperiodized strength training methods to the linear periodized method, it is not clear whether the differences reported by Stone et al. (42) and O'Bryant et al. (31) were due to increased volume, intensity, or the structure of the periodized model used.

Willoughby (50) partially equated training volume (in terms of workload, not number of repetitions) and reported superior results for the linear periodized method compared to nonperiodized high volume training, a finding partially supported by the work of Stowers et al. (44). However, neither study controlled for intensity; the periodized groups trained at a higher

level of intensity. Thus previous periodization studies have attempted to control for the effects of intensity or volume, but not both.

Furthermore, the evidence reported has not shown the linear model to be always more effective in developing upper body strength (44), which is an observation also reported by Stone et al. (43). Thus, from previous research it is not clear whether greater volume, intensity, or the structure of training produces the more favorable results that linear periodized training has produced compared to nonperiodized training.

Data on the effectiveness of the undulating method of manipulating volume and intensity during periodized strength training are sparse. Ivanov et al. (20) reported more favorable results in an experimental group using this method compared to the nonperiodized hypertrophy (3×10 RM) and neural methods (5×3 RM) alone.

The purpose of this study was to compare the effectiveness of these three strength training structures on maximal strength and vertical jump in previously trained males. Training volume and relative intensity were equated so that differences between the groups after the study could be attributed to the different manipulations of volume and intensity inherent in the training structures, rather than to larger dosages of volume or intensity. Measures indicating hypertrophy (increases in LBM) and neural activation levels (IEMG) were taken to determine their relative contribution to changes in strength and to monitor their responses in relation to the manipulation of volume and intensity.

Methods

Subjects

Thirty-three male weight trainers with at least 6 months weight training experience, but who were not competitive strength athletes, volunteered for this study. To be included in the study, each subject had to have a 1-RM bench press and a 1-RM squat greater than body mass. After signing informed consent, subjects were assigned equally to one of three groups, based on the results of initial testing, so that each group was matched for muscular function: nonperiodized control, linear periodized, and undulating periodized. Unfortunately, due to an influenza epidemic, only 22 subjects completed the study. Their characteristics are listed in Table 1.

Procedures

All tests were carried out before and after the 12-week training study. In addition, IEMG and anthropometric measures were carried out during the 4th and 8th training weeks. In all tests only the best trial at any given testing period was recorded.

Strength Testing. Maximal lower body strength was assessed via the 1-RM squat using the methods described by Stone et al. (42). Maximal upper body

Table 1
Description of Subjects

Group	Age (yrs)		Height (cm)		Weight (kg)		LBM (kg)		Fat (%)	
	M	SD	M	SD	M	SD	M	SD	M	SD
Control (n = 9)	19.0	1.1	182	8	77.6	6.0	71.2	5.5	8.2	2.4
Linear (n = 8)	20.2	1.2	180	4	75.5	8.9	68.0	7.1	9.7	3.6
Undulat. (n = 5)	21.4	5.0	176	4	69.4	10	63.2	8.1	8.6	2.9

strength was assessed via the 1-RM bench press using the methods described by Wilson et al. (51).

Vertical Jumping. Vertical jump (VJ) height was determined by the jump and reach procedure (39) using a countermovement jump with arm swing. After a number of warm-up jumps, the best effort from two maximal trials was recorded as the VJ height. The rest period between the two maximum efforts was at the subject's discretion and usually ranged from 1 to 2 min.

IEMG Measurement. Electromyographic (EMG) activity was measured in the vastus medialis (VM) and pectoralis major (Pec) during a maximal voluntary contraction (MVC) isometric test using Quantec surface electrodes. The MVC tests included a unilateral knee extension test (15) and a unilateral bench press test, modified from Schmidtbleicher and Buerhle (40). Subjects were shaven, cleansed with alcohol, and abraded to ensure that interelectrode resistance was below 5,000 ohms. The electrodes were positioned over the belly of the muscle as to be oriented parallel to the active fibers under investigation. Electrode positions were recorded using anatomical landmarks as reference points, similar to the method of Narici et al. (30).

During the MVC, the EMG signals were recorded for 3 sec, sampled at a rate of 1 kHz, and stored on a disc using an IBM-AT compatible computer with Wasp system software (Quantec Systems, University of Queensland). The EMG signals were full-wave rectified, integrated (IEMG) in 50-ms intervals, and analyzed for the first 500 ms after the activity began, using the procedures of Hakkinen et al. (13).

Anthropometric Measurement. Body mass was determined in a postabsorptive state to the nearest 0.02 kg on an electronic scale. Body fat was measured with Harpenden skinfold calipers using the eight sites and methods described by Telford et al. (45). An additional measure was taken at the chest, as advocated by Jackson and Pollock (21). Percentage body fat was calculated using the density equation of Jackson and Pollock (21) and the equation of Brozek et al. (5). Lean body mass (LBM) was determined by subtracting fat mass

(% fat \times body mass) from body mass. Increases in LBM were used to indicate hypertrophic responses.

Statistical Analysis. Differences in strength and vertical jump data between groups were compared using a 3×2 (Group \times Test) ANCOVA. Anthropometric and muscular activity variables were compared using a 3×4 (Group \times Test) ANCOVA. The covariate in each analysis was the pretraining value of the dependant variable. If a significant ANCOVA was observed, Bonferoni post hoc comparisons were used to identify which groups differed. If the ANCOVA was not significant, group data were collapsed and paired *t* tests were done to examine whether the variables differed as a function of testing occasion. In addition, Pearson's product moment correlation test was performed to examine the relationships between variables. Statistical significance was accepted at a 0.05 alpha level.

Training. Training was performed 3 days a week for 12 weeks according to a linear periodization method (42), an undulating periodization method (34), and a nonperiodized control method of constant volume and relative intensity (5×6 RM). Training loads for the maximal strength exercises were preceded by a light warm-up set of 10 reps and then progressively larger loads for one to three sets of minimal volume (2 to 3 reps) to ensure that subjects were adequately prepared for high intensity loads. The subjects progressively increased all training loads throughout the study.

Training volume in terms of total repetitions performed (27, 35, 43), and relative intensity in terms of RM load (34), were equated for all groups so that any differences found after training could be attributed to the manipulation of volume and intensity rather than to larger dosages of volume or intensity. In this regard, the control group was used as a control for manipulations of volume and intensity rather than an as inactive control group. In addition, various assistance exercises were performed to make the training more comprehensive and realistic to the training regimens of strength athletes. As with the core exercises, the total volume and relative intensity (8-RM loads) of these exercises were equated across the 12-week training period according to the periodization structure of that group. Thus there were no differences between groups in the total volume or relative intensity either for core or assistance exercises. Details of the training programs, volume of training, and method for determining relative intensity are found in Table 2.

Results

The dynamic 1-RM strength data are outlined in Table 3. Prior to training, all groups recorded statistically similar 1-RM strength values. The training resulted in all groups improving maximal 1-RM squat strength by equal amounts of 26.1, 27.7, and 28.4% for the control, linear, and undulating groups, respectively. Improvements in bench press strength were also significant pre to post for all groups, with no differences be-

Table 2
Training Performed

Control		Weeks 1-12				
		5×6 ^a	3×8 ^b			
Linear	Weeks 1-4	Weeks 5-8	Weeks 9-11	Week 12		
	5×10 3×10	5×5 3×8	3×3, 1×10 3×6	3×3 3×6		
Undulat.	Wks 1-2	Wks 3-4	Wks 5-6	Wks 7-8	Wks 9-10	Wks 11-12
	5×10 3×10	5×6 3×8	5×8 3×10	5×4 3×6	5×6 3×8	4×3 3×6
Day 1		Day 2		Day 3		
Squat		Clean pull		Squat		
Bench press		Power shrug		Bench press		
Upper body push ^c		Upper body push		Upper body push		
Upper body pull ^d		Upper body pull		Upper body pull		
Triceps ^e		Triceps, biceps		Biceps ^f		
Total reps (training volume)						
	Squats & bench	Clean pull	Assistance	Arms		
Control	720	360	864	576		
Linear	732	366	864	576		
Undulat.	728	364	864	576		
Mean training load (intensity) ^g						
	Squats, bench, pulls			Other exercises		
Control	6 RM			8 RM		
Linear	6.65 RM			8 RM		
Undulat.	6.27 RM			8 RM		

Note. ^aCore max. strength exer. (squat, bench press, clean pull); ^bassistance exer. (all others); ^cincline press, incline dumbbell press, shoulder press, or dips; ^dchins, rows, or pulldowns; ^etricep exten, pushdown, or dips; ^fbarbell curl, dumbbell curl, or preacher curl; ^grelative load (total reps, sets), this equating of training intensity being as close as possible while maintaining integrity of training structures.

Table 3
Maximal Strength for Pre- and Posttraining Testing Occasions

Groups	Pretraining		Posttraining	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
1-RM squat (kg)				
Control (<i>n</i> = 9)	115.00	21.21	143.61	20.65
Linear (<i>n</i> = 8)	113.75	28.25	142.50	28.90
Undulat. (<i>n</i> = 5)	107.00	30.33	134.00	22.54
1-RM bench press (kg)				
Control (<i>n</i> = 9)	84.16	11.99	94.44	11.91
Linear (<i>n</i> = 8)	82.50	12.53	91.87	12.44
Undulat. (<i>n</i> = 5)	78.00	11.09	90.50	11.09

tween groups. The improvements were 12.5, 11.6, and 16.4% for the control, linear, and undulating groups, respectively (Table 3).

Results for the vertical jump are outlined in Table 4. After training, the improvements in VJ for each

Table 4
Vertical Jump for Pre- and Posttraining Testing Occasions

Groups	Vertical jump height (cm)			
	Pretraining		Posttraining	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Control (<i>n</i> = 9)	47.66	6.28	52.11	4.68
Linear (<i>n</i> = 8)	52.87	7.95	54.87	8.50
Undulat. (<i>n</i> = 5)	48.20	5.69	53.10	2.30

Table 5
LBM for Pre-, Mid-1, Mid-2, and Posttraining Testing Occasions

Groups	Lean body mass (kg)							
	Pretraining		Mid-1		Mid-2		Posttraining	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Control								
(<i>n</i> = 9)	71.26	5.58	72.32	6.46	72.58	6.13	73.57	5.79
Linear								
(<i>n</i> = 8)	68.09	7.19	69.22	7.33	70.01	7.36	70.00	7.63
Undulat.								
(<i>n</i> = 5)	63.27	8.12	64.07	8.11	64.63	7.78	65.39	7.68

group were statistically similar. In collapsing the group data, a significant increase of 8.3% was observed in vertical jump from pre- to posttraining. Results for the LBM data are shown in Table 5. After training, all groups exhibited significant and similar improvements in LBM across the 12-week period.

Body fat levels remained unaltered throughout the investigation. Since there were no changes in body fat levels, the body mass changes reflected the changes in LBM exactly.

IEMG data for the VM are outlined in Table 6. Prior to training there were no differences between groups in IEMG values. The ANCOVA revealed a significant group effect so that the control group values were significantly greater than the linear group values. No other combination of groups was significant. IEMG levels of the pectoralis major remained unaltered in all groups across the training period (Table 6).

Discussion

Strength

The degree of improvement in 1-RM squat and bench press is in agreement with the results of other researchers (10, 13, 14, 50) who used similar subjects and training periods. Since the improvement was the same for all groups, it would suggest that when the same volume and relative intensity are performed during a

Table 6
Muscular Activity of VM and Pec for Pre-, Mid-1, Mid-2,
and Posttraining Testing Occasions

Groups	Pretraining		Mid-1		Mid-2		Post-training	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>VM IEMG (mV · s⁻¹)</i>								
Control								
(<i>n</i> = 9)	.281	.118	.301	.060	.280	.098	.355	.110
Linear								
(<i>n</i> = 8)	.296	.132	.298	.078	.256	.103	.245	.119
Undul.								
(<i>n</i> = 5)	.254	.078	.227	.087	.304	.125	.280	.086
<i>Pec IEMG (mV · s⁻¹)</i>								
Control								
(<i>n</i> = 9)	.210	.169	.184	.105	.168	.077	.169	.060
Linear								
(<i>n</i> = 8)	.171	.069	.151	.044	.177	.045	.136	.062
Undul.								
(<i>n</i> = 5)	.174	.088	.171	.097	.165	.098	.147	.075

short training cycle, subjects of this level achieve similar results regardless of training structure adopted. Consequently, the success of the linear model over the more traditional strength training methods in earlier studies may have been due to the higher training volume (31, 42, 44) or higher intensity (50) rather than to training structure, as was previously suggested (42, 43, 50).

In contrast to the results observed in this study, Willoughby (50) recently reported that linear periodized training was superior to nonperiodized training. However, the groups in Willoughby's study were not controlled for training intensity, with the linear group performing at a higher intensity. Further differences are that Willoughby used subjects who had not previously trained for at least 6 months, and used a training program that involved only monthly variations in load. Additionally, Willoughby reported only changes in strength per unit body mass, which did not allow for a comparison of hypertrophy-induced strength adaptations between training groups.

The present research confirms the findings of Stowers et al. (44), who also reported no differences in bench press strength between the linear method and a more traditional strength training method of nonvaried volume and intensity (3×10 – 12 RM). The results of the present research also suggest that the relative improvements in upper body strength (11.6 to 16.4%) are not as high as improvements in lower body strength (26.1 to 28.4%), a finding that has previously been reported (44, 50).

A significant relationship was observed between changes in LBM and changes in strength. For the squat, the correlation between the two variables was 0.59,

while for the bench press the relationship was stronger, $r = 0.68$. This suggests that almost 50% of the improvements in bench press strength may be accounted for by increases in LBM. A multiple correlation between changes in squat and bench press strength and changes in LBM revealed an even stronger relationship ($r = 0.81$, $r^2 = 0.65$), suggesting that changes in LBM are the principal factor for increasing maximal strength in athletes of this level. Based on this finding, it would seem prudent to establish the enhancement of LBM as a primary goal when training to increase maximal strength.

Vertical Jump

The improvement in VJ was similar for each group, and comparable in magnitude to that reported by other researchers using heavy strength training (1). No relationship was observed between changes in LBM and VJ ($r = 0.26$), despite a strong relationship between the changes in LBM and strength. Similarly, no relationship was observed between the changes in 1-RM squat and VJ ($r = 0.11$). Clearly the mechanisms that underlie changes in strength and power differ, and it has yet to be determined whether these mechanisms are based in the muscle or the nervous system. This suggests that improvements in maximal strength do not necessarily equate to improvements in power activities, such as jumping. The reasons for this are not clear and definitely warrant further investigation.

Anthropometric Changes

Figure 1 depicts the time course of the changes in LBM, as the manipulation of volume and intensity were varied. Although there were no between-group differences, the observable trend from these data is the unchanged level in LBM consequent to a reduction in training volume in the linear periodized group. This is clearly seen in the final 4 weeks of the linear group. Considering the relationship between LBM and strength, this appears to be an undesirable phenomenon.

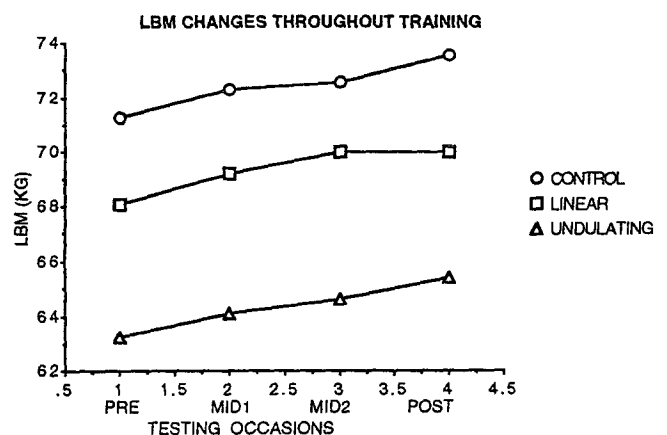


Figure 1. Lean body mass (LBM) changes throughout training.

Stone et al. (43) also reported this occurrence, and consequently O'Bryant et al. (31) modified the linear method to include a set of 10 reps during the high intensity/low volume training period in order to maintain an adequate training volume for stimulating hypertrophic adaptations. This procedure was incorporated in the present study but did not result in continued increases in LBM through the high intensity period (Weeks 8 to 12).

This limitation of the linear model should be taken into account when designing strength training programs for experienced athletes in long-term training, as strength gains are heavily dependent on increases in LBM. Hence prolonged periods of low volume/high intensity training can halt hypertrophic adaptations and compromise continued strength gains.

Body fat levels remained unaltered throughout the investigation. This may be due in part to the subjects' low levels of body fat at baseline in comparison to norms for same-age males (21).

Muscular Activity Levels

As a result of the training, only the IEMG of VM for the control group increased significantly (34.2%). This was unexpected, as previous research has indicated that IEMG levels are linked closely to the load intensity (13), and consequently it was thought that the periodized training groups, using higher intensities in the latter periods, would also exhibit increased IEMG levels. The fact that these remained unaltered may be due to "neural fatigue" (22) from prolonged exposure to high intensity loads (13).

The improvement in neural activation of the VM muscle in the control group may be due to the fact they did not use maximal loads (greater than 5 RM) in training, and consequently may not have suffered the neural fatigue suggested by Komi (22). The 6-RM loads used by the control training group would equate with approximately 80% of the 1-RM load (25) that Hakkinen et al. (13, 17, 19) believed was needed to ensure the maintenance of optimal neural activation levels in experienced trainers.

Hakkinen and Komi (15) reported anomalies in the IEMG responses to strength training and isometric MVC testing. Specifically, IEMG levels measured during a bilateral isometric test increased, but not the IEMG levels measured during a unilateral test. Furthermore, the IEMG levels of the VM in particular remained unaltered in both tests following 16 weeks of strength training. These data suggest that even the type of isometric test used would have some bearing on results. Thorstensson et al. (47), and more recently Sale et al. (38), have also reported unaltered motor unit activation levels during an isometric MVC following strength training.

The fact there were no increases in IEMG levels in the linear or undulating groups may also be due to differences in joint position affecting motor unit

recruitment (49). MVC was measured only at an angle of 90° at the knee, yet training was performed through the range of motion, and conceivably there might be enhanced activation only for certain motor units at certain angles or joint positions (46).

The IEMG levels of the pectoralis major remained unaltered in all groups across the training period. While there was a great deal of subject variability in these measures that would affect statistical interpretation, it must also be assumed that strength training does not cause an increase in IEMG levels, as measured during a maximal isometric MVC.

No relationship was observed between changes in IEMG levels in the VM and changes in the 1-RM squat ($r = -0.228$). Similarly, the correlation between changes in Pec IEMG and 1-RM bench press strength were nonsignificant ($r = 0.24$). Based on these results, IEMG levels measured during isometric contractions do not correlate with changes in 1-RM strength; and as discussed above, LBM changes rather than neural adaptations appear to be the dominant mechanism accounting for strength changes in experienced trainers, as proposed by Moritani and DeVries (29).

Studies by Hakkinen et al. (13, 17, 19), using intermediate and elite lifters, revealed that IEMG levels remained unchanged during maximal isometric tests but increased during heavy dynamic tests (loaded jump squats with 100 to 140 kg). It should be noted that IEMG levels remained unchanged during isometric testing but increased during dynamic free postural tests of strength and power. Therefore the nature of the test may affect the resulting IEMG levels, and the data achieved in isometric tests may have little relationship to the adaptations that have occurred during the dynamic training tasks. Consequently, the validity of isometric tests to monitor the neural responses believed to be induced through dynamic training may be questionable.

The results of this study indicate that in short-term training with experienced weight trained subjects, no differences in maximal strength are observed when training volume and relative intensity are equated. Accordingly, the previously reported benefits of training periodization (31, 42, 44, 50) may stem not from the structure of training itself but from the fact that it allowed the subjects to employ a higher training volume or relative training intensity. Consequently, the importance of structuring training according to periodization models may apply more to advanced trainers or to strength training periods of longer than 12 weeks.

In comparing the results of this research, in which the training volume was equated, with the results of previous research (2, 31, 36, 42, 44), in which volume was not equated, it appears that training volume should be an important consideration in designing strength training programs. Also, increases in maximal strength appear largely accounted for by changes in LBM ($r = 0.81$; $r^2 = 0.65$), which itself seems to be mainly influenced by training volume.

The performance of low volume training over a period of weeks may eliminate LBM gains, particularly in long-term training, and reduce the potential for continued strength gains. Consequently, it seems prudent to limit low volume training to short time periods before increasing the volume again to emphasize the hypertrophic adaptations. Thus the hypertrophy of muscle, as indicated by increases in LBM, should be a priority for the training of maximal strength, with only brief exposures to high intensity loads to ensure that the various neural adaptations are reinforced.

Changes in VJ appear unrelated to changes in LBM or strength. This anomaly between changes in strength and power warrants further investigation. Changes in neural activation (IEMG) levels were generally nonsignificant and demonstrated no relationship to changes in maximal strength. However, the use of isometric testing to examine adaptations induced by dynamic training may invalidate the neural activation data obtained. Future studies might investigate IEMG levels during the actual 1-RM strength tests to determine whether neural activation levels increase during the actual training/testing movement, as isometric testing appears to have considerable limitations.

Practical Applications

This research suggests several important implications for the development of resistance training programs:

- Over a short training cycle, nonperiodized strength training results in the same gains in strength and vertical jump as does linear and undulating periodized strength training, when training volume and relative intensity are equated.
- Large increases in strength do not necessarily equate to power increases, and more specific power training may be required to increase power. In fact it appears that the mechanisms contributing to the development of strength and power are quite different.
- Increases in LBM are the most important mechanism accounting for strength increases in weight trained individuals, and programs should be structured so that the manipulation of training variables enhances LBM.
- Training volume appears to be an important variable for developing LBM and muscular strength. Prolonged high intensity/low volume training should be avoided.

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