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A Comparison of Linear and Daily Undulating Periodized Programs With Equated Volume and Intensity for Local Muscular Endurance

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ABSTRACT

The purpose of this study was to compare linear periodization (LP), daily undulating periodization (DUP), and reverse linear periodization (RLP) for gains in local muscular endurance and strength. Sixty subjects (30 men, 30 women) were randomly assigned to LP, DUP, or RLP groups. Maximal repetitions at 50% of the subject's body weight were recorded for leg extensions as a pretest, midtest, and posttest. Training involved 3 sets (leg extensions) 2 days per week. The LP group performed sets of 25 repetition maximum (RM), 20RM, and 15RM changing every 5 weeks. The RLP group progressed in reverse order (15RM, 20RM, 25RM), changing every 5 weeks. The DUP group adjusted training variables between each workout (25RM, 20RM, 15RM repeated for the 15 weeks). Volume and intensity were equated for each training program. No significant differences were measured in endurance gains between groups (RLP = 73%, LP = 56%, DUP = 55%; $p = 0.58$). But effect sizes (ES) demonstrated that the RLP treatment (ES = 0.27) was more effective than the LP treatment (control) and the DUP treatment (ES = −0.02) at increasing muscular endurance. Therefore, it was concluded that making gradual increases in volume and gradual decreases in intensity was the most effective program for increasing muscular endurance.

Key Words: weight training, variation, plateau, resistance training, periodization

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Introduction

Periodization is a planned variation of acute and chronic program variables that is more effective in eliciting strength and body mass improvements than nonperiodized weight-training programs (5, 15, 24–26, 31), and as effective as progressive resistance training (11). The concept of planning training programs has been used in different ways for many years. The label ''periodization'' was applied by Eastern European weightlifters referring to their method of changing workouts over time to allow for better recovery and therefore greater gains in strength (17, 30). Elite athletes, body builders, and even recreational trainers are now using periodized programs in an attempt to maximize performance.

The goals of a periodized program include, but are not limited to, an attempt to maximize the principle of overload and to ensure the correct stress/recovery relationship. The principle of overload can be described as the process by which the neuromuscular system experiences loads to which it is not accustomed (13). When this system faces increased demands, it adapts with increases in muscular function. Once the system has adapted to that demand or load, increases are no longer needed and will eventually plateau. Periodization is meant to maximize the adaptation process by continually changing the load placed on this system. These changes include periods of active rest (participation in physical activity excluding weight training), which aid the neuromuscular system in recovering from prior training (24).

Periodization can be accomplished by manipulating the number of sets, reps or exercises performed; the amount or type of resistance used; the amount of rest between sets or exercises; the type of contractions performed; or the training frequency (9). Because of the many program variables that can be manipulated, numerous possible periodization programs exist. Assuming that an optimal periodized program exists, research is needed to identify such a program.

Many forms of program alterations exist, and thus there are many methods of periodization. Linear periodization (LP) gradually increases training intensity and decreases volume, with these changes being made approximately every 4 weeks. Reverse linear periodization (RLP) follows a schedule of changes in training volume and intensity in reverse order as compared with LP. Rather than gradually decreasing volume and increasing intensity, RLP gradually increases volume and decreases intensity. Undulating periodization (UP), as described by Poliquin (19), differs from LP by making changes in intensity and volume in a more frequent fashion. Rather than making changes every 4 weeks, the undulating model makes these same changes on a bi-weekly basis. UP involves increases as well as decreases in both volume and intensity throughout the training cycles. This concept led Rhea et al. (20) to make alterations in training volume and intensity on a daily basis, i.e., daily undulating periodization (DUP).

LP and DUP were originally designed to improve strength. It is unclear, however, if these programs are the most effective alteration in training variables for improving in muscular endurance. Few studies have directly compared the effects of LP and UP or DUP for strength and no study has made comparisons of gains in muscular endurance. Baker et al. (5) found no difference in strength increases between LP and UP programs. This study altered volume and intensity every 2 weeks in the undulating group and every 3–4 weeks in the linear group. These schedules for altering training variables may not have differed enough to elicit significant differences in strength improvements.

Rhea et al. (20) compared LP and DUP programs for strength. The DUP group followed a weight-training program that altered program variables on a daily basis, whereas the LP group followed the traditional form of periodization, gradually decreasing volume and increasing intensity, making changes every 4 weeks. Significantly greater increases in strength were observed favoring DUP.

To date, no study has compared LP, DUP, and RLP for muscular endurance. Increases in muscular endurance increases running economy and endurance performance (14). More endurance athletes are now participating in weight-training programs in the hope of gaining an edge and increasing athletic performance. Those individuals desiring maximal adaptations in muscular endurance would benefit from research that compares different types of training programs.

Methods

Experimental Approach to the Problem

The primary purpose of this study was to compare gains in muscular endurance for LP, DUP, and RLP programs. A secondary purpose was to examine whether the direction of changes in volume or intensity (i.e., LP or RLP) affects the degree of improvement in muscular endurance. In the present study, volume and intensity were equated for all groups throughout the training program to attribute any outcomes to the differences in periodization. An attempt was made to control physical activity outside of the training program.

Table 1. Subject characteristics: group means ± *SD*.*

Group	LP	DUP	RLP
N	20 (10m, 10w)	20 (10m, 10w)	20 (10m, 10w)
Age (y)	21 ± 2.4	21 ± 1.9	22 ± 1.6
Weight (kg)	64 ± 13.4	66.8 ± 23.2	68.6 ± 20.1

* m = men; w = women; LP = linear periodization; DUP = daily undulating periodization; RLP = reverse linear periodization.

Subjects

Sixty-eight subjects (men and women) were recruited from college weight-training courses (Table 1). Subjects reported previous participation in a weight-training program (at least 12 months immediately before beginning participation in the study). Subjects also did not report any characteristics that would impede their participation in a weight-training program.

Subjects who were willing to participate in the study agreed to sign an informed consent, limit their lower-body weight-training activities to those prescribed by the training program, and attend a minimum of 28 of the 30 training sessions over the course of the 15 week training program. Subjects were informed that 3 missed training sessions or failure to limit lower-body weight-training to those exercises prescribed resulted in disqualification from the study.

Screening of Subjects. All subjects were screened for prior participation in weight-training activities to ensure that they had similar experience levels. A minimum of 1 year and a maximum of 5 years training experience immediately before beginning the study was selected as the criterion for participation. Training experience, as well as habitual physical activity, was determined by the use of a questionnaire and interview. Activity levels were needed to ensure that all subjects participated in similar types and amounts of physical activity outside the weight-training program. After the screening process, 33 men and 31 women were deemed eligible for the study, and all of them gave their informed consent. Four subjects withdrew from the weight-training courses for unrelated reasons before being assigned to a treatment group. This resulted in a total of 60 subjects (30 men, 30 women) who completed the study.

Procedures

Assignment to Treatment Groups. Subjects were randomly assigned to 1 of 3 treatment groups: RLP, LP, and DUP. Each group consisted of 20 subjects (10 men, 10 women). Statistical analyses revealed that no significant differences existed at baseline in strength or muscular endurance between groups ($p > 0.05$) ensuring that all groups began the training program at a similar level of muscular fitness.

Testing Sessions. Local muscular endurance was measured on a Cybex 4611 leg-extension machine (Cybex International, Medway, MA). Subjects received 1 instructional session before the first testing session. During this session, subjects were instructed regarding proper warm-up and lifting technique and were able to practice on the machine. All testing and training was conducted on the same equipment, with standardized procedures for all subjects, and was monitored by the same trained investigator.

Muscular endurance testing consisted of repetitions to exhaustion on the leg-extension machine. After a short period of light cycling and stretching, each subject performed as many repetitions as possible without stopping or pausing between repetitions and maintaining a fixed cadence, with the resistance placed at 50% of the subject's body weight (4). The total number of repetitions was recorded for each subject. To ensure the reliability of the baseline measure, this process was repeated on a separate day, and the highest number of repetitions was used as the baseline measure. Statistical analyses revealed that both trials were highly correlated ($R = 0.99$), and no significant difference existed between trials ($p > 0.05$). This process was repeated in the seventh week and after the 15th week of training. The resistance for the subsequent tests was set at the same weight used in the pretest.

Subjects also completed a one repetition maximum (1RM) for the leg extension on a separate day according to NSCA guidelines for strength testing (4). All 1RM testing was conducted on the same equipment with identical subject/equipment positioning. Subjects were required to warm-up and perform light stretching before performing approximately 10 repetitions with a relatively light resistance. The resistance was then increased to an amount estimated to be less than the subject's 1RM. The resistance was progressively increased in incremental loads after each successful attempt until failure. All 1RM values were determined in 3–5 attempts. This process was repeated after the 15th week of training.

Repeated circumference measures were taken using a Gulick tape measure. Standardized procedures for circumference measures were taken at midthigh (2, 16).

Equated Volume and Intensity. Training intensity (repetition maximum, RM) was equated for all training groups. Training sets and repetitions were equated for all groups for the 15-week training program. Daily volume (total repetitions per set × total sets × mass lifted per set) was recorded throughout the training program and analyzed for differences between groups to ensure that the only difference between the 3 programs was the order in which training volume and intensity were adjusted.

Table 2. Training programs cycle repeated throughout the 15 wk.*

LP group	
Week 1–5	3 × 25 RM
Week 6–10	3 × 20 RM
Week 11–15	3 × 15 RM
RLP group	
Week 1–5	3 × 15 RM
Week 6–10	3 × 20 RM
Week 11–15	3 × 25 RM
DUP group	
Workout 1	3 × 25 RM
Workout 2	3 × 20 RM
Workout 3	3 × 15 RM
Workout 4	3 × 25 RM
Workout 5	3 × 20 RM
Workout 6	3 × 15 RM

* LP = linear periodization; DUP = daily undulating periodization; RLP = reverse linear periodization; RM = repetition maximum.

Training Programs. Each group followed a distinct leg extension program (Table 2), training 2 days per week (15 weeks), for muscular endurance according to the RM continuum set forth by Fleck and Kraemer (10).

All groups followed the same protocol for performing the exercise. After a warm-up consisting of light cycling and stretching, subjects set the weight at an amount of weight pursuant to the RM for the day. Repetitions were performed at a constant pace of 1 repetition every 3 seconds. One to 2 minutes rest was given between each set. The LP group performed 3 sets of 25RM during weeks 1–5, 3 sets of 20RM during weeks 6–10, and 3 sets of 15RM during weeks 11–15. The RLP group performed 3 × 15RM during weeks 1–5, 3 × 20RM during weeks 6–10, and 3 × 25RM during weeks 11–15. The DUP group changed training volume and intensity every exercise day: 3 × 25RM, 3 × 20RM, and 3 × 15RM (repeated continuously for 15 weeks).

Subjects were advised to follow a similar program for leg curls throughout the training program to ensure that both the quadriceps and hamstring muscle groups improve simultaneously. Subjects were asked to continue their normal physical activity patterns throughout the training program but were prohibited from performing any other weight-training exercises for quadriceps strength or endurance.

Table 3. Results: group means ± *SD*.†

Group	LP	DUP	RLP
Total volume (kg)	85,496.5 ± 23,477.7	80,121.2 ± 28,824.6	82,152.3 ± 28,571.1
Endurance (reps)			
T1	23.4 ± 7.2‡	22.8 ± 6.3‡	21.3 ± 7.5‡
T2	31.4 ± 10.1‡	29.0 ± 9.2‡	28.9 ± 7.4‡
T3	36.0 ± 13.7‡*	35.0 ± 15.9‡*	33.1 ± 8.0‡*
% Change T1–T2	36.75 ± 38.6‡	29.7 ± 34.4‡	45.2 ± 40.7‡
% Change T2–T3	13.85 ± 12.3‡	18.7 ± 22.5‡	16.6 ± 23‡
% Change T1–T3	55.9 ± 48.9‡*	54.5 ± 56.1‡*	72.8 ± 77.9‡*
Effect size	Control	−0.02	0.27
1RM (kg)			
PRE	78.8 ± 16.5‡	74.5 ± 19‡	73.2 ± 24.3‡
POST	85.1 ± 15.5‡*	80.7 ± 21.2‡*	76.6 ± 23.9‡*
% Change	9.1 ± 11.4‡	9.8 ± 21.3‡	5.6 ± 11.4‡
Effect size	Control	0.04	−0.31
Leg circumference (cm)			
PRE	52.4 ± 4.4‡	53.7 ± 8.1‡	53.1 ± 6.6‡
POST	51.0 ± 4.4‡*	52.2 ± 8.3‡*	52.0 ± 6.4‡*
Change	−1.4‡	−1.5‡	−1.1‡

†LP = linear periodization; DUP = daily undulating periodization; RLP = reverse linear periodization.
‡ Different superscript signifies significant differences between groups.
* Signifies statistical differences ($p \leq 0.05$) pre/post.

Statistical Analyses

Pearsons *R* was used to determine the correlation between trials of pretest measures. Analysis of variance, with repeated measures, was used to examine possible differences among groups and where necessary, Tukey's post hoc tests were used. Significance level was set at $p \leq 0.05$.

Results

Table 3 summarizes the results of statistical analyses.

Total Volume

An analysis of total volume performed by each group throughout the 15-week program revealed no significant differences between groups.

Muscular Endurance

All groups significantly increased muscular endurance and 1RM strength pre- to posttest. Muscular endurance increases (T1 to T3) for LP, DUP, and RLP were 55.9, 54.5, and 72.8%, respectively. Although the RLP group increased the most, no statistical differences were found between groups. All groups demonstrated significantly greater gains in muscular endurance between T1 and T2 than between T2 and T3.

Strength

Strength measures (1RM) revealed that the DUP group increased 9.8%, LP group increased 9.1%, and RLP group increased 5.6%. Although DUP and LP groups increased strength almost twice that of RLP group, this did not result in a statistically significant difference.

Thigh Circumference

All groups significantly decreased leg circumference measures from pre- to posttest, however, no differences between groups was measured.

Comparison of Effect Sizes

With the LP group serving as the control, effect sizes (ES) for DUP and RLP for endurance were calculated, using means and pooled standard deviations, to be −0.02 and 0.27, respectively. Only the ES for RLP was found to be significantly different. For strength, ES for DUP and RLP were calculated to be 0.04 and −0.31, respectively, and again the ES for RLP was significantly different.

Discussion

The purpose of this study was to compare muscular endurance gains after 15 weeks of 3 different periodized programs. The results demonstrate that all 3 groups significantly increased local muscular endurance performance after the programs. An analysis of ES (the magnitude of the effect of the treatment) demonstrated that the RLP treatment (ES = 0.27) was more effective at eliciting endurance improvements than the LP treatment and the DUP treatment (ES = −0.02). This demonstrates that RLP increased muscular endurance by almost one-third of a standard deviation above LP and DUP.

This is the first study to compare LP and RLP programs for muscular endurance. It is apparent that gradual increases in volume (in a reverse linear fashion) are more effective at eliciting endurance gains than increases in intensity. This could be a result of the RLP group's training with greater volume (25RM) than the LP group (15RM) immediately before posttesting. The daily changes in volume and intensity in the DUP group failed to have as beneficial an effect for endurance as shown in our previous research on strength (20).

One potential weakness of this study is the use of a percentage of subjects' body weight as resistance for endurance testing. This places those subjects with the most mass at a disadvantage. But statistical analyses of baseline body weight demonstrated that no significant differences existed between any of the groups ($p > 0.05$). Also, 5 subjects were considered to be outliers when examined for bodyweight. Removal of these subjects from the statistical analyses did not affect the results. Therefore, they were included in the analysis.

Another possible weakness is the large variance observed within the training groups. This variance was present at baseline and may be because of the inclusion of both men and women in the training groups. It might also suggest that although subjects reported being recreationally trained, some may have been more highly trained than others. Several outliers were identified regarding improvements in muscular endurance. But removal of these subjects insignificantly affected the results of the study and thus they were included in the statistical analyses.

Although not the main focus of this study, the significant decrease in leg circumference measure is of particular interest. Muscle biopsy and body composition measures were beyond the scope of this study therefore it is unclear whether changes in muscle physiology or body fat elicited this decrease. But muscular endurance weight-training programs decreases the cross-sectional area of Type II fibers (8, 21, 23, 28, 29). This adaptation may explain the resultant decrease in leg circumference measures in the current study. A decrease in the thickness of the fat layer around the thigh could also have resulted in such a decrease. Further research is needed to identify the cause of such a change.

An increase in body mass may decrease relative maximal oxygen uptake, which is very dependent on body mass ($ml \cdot kg^{-1} \cdot min^{-1}$). But the programs employed in this study demonstrated an increase in muscle function with a reduction in body mass (in thigh measurements). Theoretically, this combination would be optimal for endurance performance. The increased muscle function increases performance efficiency (14), and the reduction in body mass may increase relative maximal oxygen uptake.

A somewhat unexpected outcome elicited by participation in the muscular endurance training program described here was the significant increases in strength measured for all training groups. Although each program effectively increased strength, a comparison of ES revealed a trend opposite that of the endurance effects. Regarding strength, the DUP treatment (ES = 0.04) and LP treatment were more effective at eliciting strength than the RLP treatment (ES = −0.31). This would lend support to the DUP and LP programs, which were originally developed as strength programs, for eliciting strength gains.

The strength increases observed in this study demonstrate that although maximal strength increases occur when training with low volume and high intensity (≈2–8RM) (1, 3, 6, 10, 18, 27), training at a higher volume with less resistance can result in significant strength gains. Some individuals may experience anxiety when faced with training with heavy weights. This situation can be remedied by prescribing a training program as described in this study (12–25RM) to elicit increases in muscular function.

The difference in the pattern of results in strength and endurance by groups is indicative of the specificity of training theory. Training specificity refers to the distinct adaptations to the physiological systems that arise from a training program (12, 22). DeLorme (7) was among the first to identify the concept of specificity and asserted that adaptations in strength occurred to a greater extent at high intensity/low volume training, whereas improvements in endurance occurred with high volume/low intensity training.

Adaptations to training are limited to the physiological system overloaded by the training program (12, 22). In this study, both muscular endurance and strength significantly increased but to different degrees according to the type of program followed. All 3 training programs adequately overloaded those aspects of the neuromuscular system related to both strength and endurance apparent in the significant increases after training. But the RLP program has overloaded endurance functions to a greater extent than the other 2 programs (as demonstrated by percent increases and ES). The DUP and LP programs were apparently more effective at overloading strength functions as seen by the greater increases in strength. Further research is needed to verify this occurrence.

Gradual increases in volume and decreases in intensity may result in greater gains in muscular endurance than the classic strength programs that gradually increase intensity and decrease volume regardless of the frequency of these alterations. This may be a result of high volume training immediately before testing for muscular endurance. It is also apparent that training for muscular endurance can result in significant gains in strength while reducing circumference measures. But if maximal improvements in muscular endurance are sought, RLP should be prescribed.

Practical Applications

Experienced weight trainers desiring improvements in muscular endurance can reach this goal most effectively by participating in RLP training. Athletes such as runners, swimmers, triathletes, and endurance bicyclists who employ weight-training programs to increase levels of muscular endurance may experience greater gains if they participate in RLP training as compared with DUP or LP. Further research employing highly endurance-trained populations is needed to verify the findings of the current study in such populations.

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