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A Comparison of Linear and Daily Undulating Periodized Programs with Equated Volume and Intensity for Strength

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ABSTRACT

The purpose of this study was to compare linear periodization (LP) and daily undulating periodization (DUP) for strength gains. Twenty men (age = 21 ± 2.3 years) were randomly assigned to LP (n = 10) or DUP (n = 10) groups. One repetition maximum (1RM) was recorded for bench press and leg press as a pre-, mid-, and posttest. Training involved 3 sets (bench press and leg press), 3 days per week. The LP group performed sets of 8 RM during weeks 1–4, 6 RM during weeks 4–8, and 4 RM during weeks 9–12. The DUP group altered training on a daily basis (Monday, 8 RM; Wednesday, 6 RM; Friday, 4 RM). Analysis of variance with repeated measures revealed statistically significant differences favoring the DUP group between T1 to T2 and T1 to T3. Making program alterations on a daily basis was more effective in eliciting strength gains than doing so every 4 weeks.

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

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Introduction

Determining the most effective and efficient method of strength development has been a primary focus of strength coaches and strength researchers for decades. Whether it is an elite athlete looking for an edge on the playing field, a police officer preparing for possible confrontations, or an elderly individual hoping to maintain an independent lifestyle, increasing strength can be an important goal. It is vital that professionals be able to prescribe the most appropriate and effective program for these individuals, ideally a program that has been tested in an objective research setting and has demonstrated its effectiveness.

Although the strength training community has yet to agree on the optimal program design for strength development, one concept that strength-training experts generally agree upon is that some form of periodization must be a major part of any program to optimize strength gains. Periodization is a planned variation of acute program variables that has been shown to be more effective in eliciting strength and body mass improvements than nonperiodized programs (2, 7, 10, 13–15, 17). The concept of periodization can be traced to Selye's general adaptation syndrome (12), which theorizes that systems will adapt to any changes they might experiences in an attempt to meet the demands of stressors. The goal of a periodized program is to optimize the principle of ''overload'', the process by which the neuromuscular system adapts to unaccustomed loads or stressors. For the neuromuscular system to adapt maximally to the training load or stress, it is important to alter training volume and intensity as demonstrated by the body of research comparing periodized programs to nonperiodized programs (cited previously). Faced with increased demands, the neuromuscular system adapts with increases in muscular strength. Once the system has adapted to that demand or load, strength increases are no longer needed and increases will eventually stop. Periodization is designed to avoid this problem by continually changing the load placed on the neuromuscular system. In addition to increasing overload, periodization may be beneficial by adding variation to workouts, thus avoiding staleness and plateaus in strength gains.

Periodization can be accomplished by manipulating the number of sets, repetitions, 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. The classic form of linear periodization (LP) divides a typ-

Table 1. Subject descriptives.*

Group†	Age (y)	Height (cm)	Weight (kg)	% Body fat	Training experience (y)
LP (n = 10)	21.2 (3.1)	178.2 (6.8)	90.4 (16.5)	16.3 (4.2)	5.4 (2.1)
DUP (n = 10)	20.2 (2.4)	181.8 (8.4)	86.3 (21.4)	17.6 (8.7)	5.0 (2.6)

* Values expressed represent group means (standard deviation).
† LP = linear periodization; DUP = daily undulating periodization.

ical strength-training program into different periods or cycles: macrocycles (9–12 months), mesocycles (3–4 months), and microcycles (1–4 weeks), gradually increasing the training intensity while decreasing the training volume within and between cycles. A less-used form of periodization called undulating periodization, first advocated by Poliquin (11), is characterized by more frequent alterations in the intensity and volume. Rather than making changes over a period of months, the undulating model makes these same changes on a weekly or even daily basis. For example, a subject may progress from high volume–low intensity to low volume–high intensity within the same week by performing sets of 12–15 repetition maxima (RM) on Monday, sets of 8–10 RM on Wednesday, and sets of 3–5 RM on Friday. The phases are much shorter in undulating periodization, providing more frequent changes in stimuli, which are speculated to be highly conducive to strength gains (11). The above program may place considerable stress on the neuromuscular system because of the rapid and continuous change in program variables. It is this stress that theoretically makes the program effective in eliciting increased amounts of strength gain or in aiding athletes to overcome staleness (a plateau) in their training.

Most previous research has only focused on differences between periodized and nonperiodized programs. Few studies have investigated undulating periodization, and only one study (2) has ever attempted to compare linear periodization with undulating periodization. Baker et al. (2) reported no significant difference in strength gains when altering the volume and intensity every 2 weeks in an undulating group and every 3–4 weeks in a linear group. No significant differences in strength gains were found between groups. It is likely that the differences between the linear and undulating training programs were not severe enough to elicit statistically significant differences.

Ivonov et al. (6) compared undulating periodization with a nonperiodized program in track athletes competing in throwing events. Undulating periodization was found to be superior in eliciting strength gains as compared with the nonperiodized program in both bench press and squat exercises.

Kraemer et al. (8) compared a multiset version of daily undulating periodization (DUP) to a nonperiodized, single-set program in female collegiate tennis players. This study, which spanned 9 months, demonstrated superiority of the DUP program in eliciting strength increases.

Researchers have recently declared the need for further research regarding the effectiveness of the undulating model as compared with the linear model (3, 4, 16). Fleck and Kraemer also suggest investigating the specific combination of variables that will elicit maximum gains in strength (4).

Methods

Research Approach

The purpose of this study was to examine a more intensive approach to undulating periodization than that used by Baker et al. (2) by altering volume and intensity on a daily basis. To our knowledge, this study is the first to compare LP and DUP. It is also important to note that many previous periodization studies have failed to equate training volume and training intensity between groups. Failure to do so makes it impossible for researchers to attribute differences in strength gains to the program design or to differences in volume or intensity between groups. In the present study, volume and intensity were equated for both groups throughout the training program to attribute any outcomes to the differences in periodization. Maximal strength in the bench press and the leg press was designated as the dependent variable and method of periodization (LP and DUP) was set as the independent variable.

Subjects

Twenty men (age 21 $\pm$ 2.3 years) were recruited from college weight-training classes. Subjects gave their informed consent to participate in the study, which was approved by an Institutional Review Board before beginning the research. Subjects filled out questionnaires evaluating their prior strength-training experience. All subjects reported participating in a strength-training program (at least 2 days per week) for a minimum of 2 years before beginning the study. Each subject reported that he had been following a program equivalent to LP during the previous 2 years. Subject characteristics are listed in Table 1.

Testing

Subjects participated in 6 instruction/training sessions before the pretest to ensure proper technique and comprehension of the testing process. The 1RM was used as a measure of pretraining strength of the upper and lower body using the bench press and leg press. Bench press testing and training were performed on a standard free-weight bench press station. The Cybex incline leg press machine was used for lower body testing and training. To obtain reliable baseline strength values, the pretraining 1RM values were performed on 3 separate occasions separated by several days. A high interclass correlation was found between the second and third 1RM trials ($R = 0.99$). The greatest 1RM from the last 2 trials was used in the statistical analysis as the baseline measure. All 1RM testing was conducted on the same equipment with identical subject–equipment positioning overseen by the same trained investigator according to guidelines set forth by the American College of Sports Medicine (1). Subjects were required to warm up and perform light stretching before performing approximately 10 repetitions with a relatively light resistance for each exercise. 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 to 5 attempts. Strength testing was repeated after weeks 6 and 12 of resistance training.

Statistical analysis of both bench press and leg press baseline data demonstrated that no significant differences between groups ($p > 0.05$) existed in strength at baseline. This ensured that both groups began the study at comparable levels.

Training Protocol

After testing, subjects were randomly divided into 2 groups (LP or DUP) and began a 12-week training program on the leg press and bench press. Subjects trained 3 days per week, with each session lasting approximately 40 minutes. Each subject performed a 10-minute aerobic warm-up and stretching exercises before beginning each workout. A warm-up set was also performed on each lift with light resistance and involved approximately 10 repetitions. Both leg press and bench press lifts were performed during the same training session with random assignment of order for each session. Subjects also performed abdominal crunches (3–4 sets of 15–25 repetitions), biceps curls (3 × 8–12 RM), and lat pull-downs (3 × 8–12 RM). Subjects were prohibited from performing any other strength-building exercises during the 12-week program.

The training volume and intensity were altered differently for each group (see Table 2). However, both volume (total reps performed) and intensity (RM) were equated among the groups. This was done to control for differences in training volume or intensity. Therefore, the only difference between the training programs was the order in which subjects performed the workouts.

Table 2. Training program (3 workouts·week^{-1}).*

	Weeks 1–4	Weeks 5–8	Weeks 9–12
LP group†	3 sets 8RM	3 sets 6RM	3 sets 4RM
	Day 1	Day 2	Day 3
DUP group	3 sets 8RM	3 sets 6RM	3 sets 4RM

* Training volume and intensity throughout the training program identical for each group.
† LP = linear periodization; DUP = daily undulating periodization; RM = repetition maxima.

The LP group performed 3 sets of 4–8 RM (8 RM each session for the first 4 weeks, 6 RM for weeks 5–8, and 4 RM during weeks 9–12) as suggested by Stone (13). The DUP group also performed 3 sets of 4–8 RM each session. The first session of each week consisted of 8 RM sets, the second session consisted of 6 RM sets, and the third session consisted of 4 RM sets. Each session was separated by a minimum of 48 hours. This cycle was repeated for 12 weeks with 1 week of active rest (participation in physical activity with the exception of weight training) between weeks 5 and 6.

Body Composition

Body volume was determined by whole-body plethysmography (Bod Pod, Life-Measurement Instruments, Concord, CA) and converted into percent fat values using the Siri equation (5). The initial measured thoracic gas volume was entered for the posttest to ensure reliability. Subjects were required to wear a Lycra swim cap and tight fitting Lycra-Spandex bike shorts, or swimming briefs, for each trial. Bod Pod testing was performed by the same trained technician for all subjects.

Repeated circumference measures were taken using a Gulick tape measure. Circumference measures were taken at the chest and at mid-thigh (9).

Statistical Analyses

These data were analyzed using an analysis of variance with repeated measures and, where appropriate, Tukey's post hoc tests were used to determine differences among groups and across time. The level of significance in this study was set at $p \leq 0.05$.

Results

Absolute and percentage strength increases were compared between groups. Both LP and DUP groups increased strength significantly ($p < 0.05$) in both leg and bench presses over the course of the training program (T1 to T3). Mean percent increases in strength

Table 3. Strength measures across time and absolute strength increases across time.†

Group			
Bench press [kg (*SD*)]			
	T1	T2	T3
LP	83.41 (12.86)	88.41 (11.75)	94.55 (10.72)
DUP	66.59 (19.23)	73.41 (21.1)	83.41 (20.27)
Leg press [kg (*SD*)]			
	T1	T2	T3
LP	266.82 (55.38)*	296.36 (55.13)*	331.36 (68.18)*
DUP	230.23 (65.05)*	298.18 (73.77)*	350.23 (80.82)*
	% Strength increases across time		
	T1 − T2	T2 − T3	T1 − T3
Bench press (% change† [*SD*])			
LP	5.9 (4.9)*	7.3 (5.4)	14.4 (10.4)*
DUP	10.7 (7.9)*	16.2 (14.9)	28.8 (19.9)*
Leg press (% change† [*SD*])			
LP	12.0 (9.9)*	11.7 (9.2)	25.7 (19.0)*
DUP	31.0 (13.5)*	18.0 (9.1)	55.8 (22.8)*

† % Change = T2 − T1/T1; T3 − T2/T2; T3 − T1/T1. Values expressed represent group means (standard deviation). LP = linear periodization; DUP = daily undulating periodization.

* Significant differences between groups ($p < 0.05$).

for LP group were 14.37% and 25.61% for bench press and leg press respectively, compared with 28.78% and 55.78% for the DUP group. The DUP group experienced significantly greater percent gains in strength from T1 to T2 and from T1 to T3 ($p < 0.05$) compared with the LP group. Analysis of absolute strength increases demonstrated significant differences ($p < 0.05$) for leg press between T1 and T2 and T1 and T3. However, absolute increases for bench press did not reach statistical significance at any time ($p = 0.08$) (Table 3).

No significant differences were found for body composition or circumference measures.

Discussion

This study is the first study to investigate differences in strength gains between DUP and LP programs. The data from our study suggest that a daily form of undulating periodization elicits greater percentage strength gains than a linear periodized program. In terms of absolute gains, this difference only occurred in the leg press. One previous study (8) has examined DUP training; however, subjects in that study were untrained (with regard to weight training) women, and thus, may be incomparable with the current study, which used recreationally trained men. To date, there are no comparable studies for the strength increases observed in our DUP group. Future research should be done to compare the increases in strength measured in the DUP group of current study (33% and 56% in the bench press and leg press, respectively). The degree of improvement for the LP group is similar to results of other studies using similar subjects and training (2, 17).

In 1988, Poliquin (11) theorized that more frequent changes in stimulus would enhance strength gains. In his original undulated program, alterations were to be made every 2 weeks. Such a program was found to elicit similar strength gains as a LP program. The present study altered training variables on a daily basis and, as hypothesized, the DUP group demonstrated significantly more strength gains than LP.

The neuromuscular system may become accustomed to a periodized program when followed for an extended length of time, even though periodized programs are designed to avoid this plateau effect. In our study all subjects reported following a program equivalent to LP for 2 years before recruitment. Those who continued with a similar program (LP group) continued making improvements but not to the same degree as those in the DUP group. By making alterations to the periodization concept, it appears that the neuromuscular system will further adapt, eliciting even greater strength gains. It is possible that the greater strength gains demonstrated by the DUP group was a result of changing the type of periodized program rather than the greater effectiveness of DUP training itself. Further research is needed to make a determination in this regard (i.e., recruiting subjects who had been following a DUP program and then assigning 1 group to follow an LP program).

The driving mechanisms behind the increased effectiveness of DUP are not completely understood. Resistance training has been shown to result in adaptations such as muscle fiber hypertrophy-hyperplasia, muscle fiber transformation, nervous system adaptations, body compositional changes, bioenergetic adaptations, and endocrine system adaptations (3). Measuring and monitoring all such mechanisms was beyond the scope of our study. However, the body composition and circumference measures in our study found no significant changes from baseline to posttraining. Therefore, the greater strength increases observed in the DUP group were not due to body composition or hypertrophic changes. Because DUP makes more frequent changes in training stimuli, it could be speculated that this type of program places greater stress on the neurological components of the neuromuscular system. This increased stress would presumably require further adaptations from this system. It is possible that this added stress elicits greater adaptations of the neuromuscular system and therefore greater gains in strength as compared with LP. Further research including measures of nerve activity and mus-

cle samples must be conducted to investigate such speculation.

Although the current subjects were experienced strength trainers, making the results applicable to others experienced in weight training, additional research is needed to observe the effects of such a program on other populations such as inexperienced strength trainers, elite athletes, elderly populations, and women. Also, this study was relatively short in duration (12 weeks) and with relatively few subjects. Long-term studies with larger sample sizes would be valuable in examining the differences in methods of periodization.

Another possible limitation of this study involves the issue of overtraining. In weeks 10–12, subjects in the DUP began to report extended muscle soreness and fatigue, whereas the LP group did not. Although these were anecdotal reports, it may be noteworthy. Interestingly, the strength gains in the second half of the program were not significantly different between groups. It is apparent that the undulating concept was successful in eliciting greater gains in the first 6 weeks of training, but no statistical difference ($p > 0.05$) was measured in weeks 6–12 (Table 3). Without more frequent 1RM measures, it is unclear exactly when strength gains in both groups began to become more similar. Further research is needed to identify the optimal duration of a daily undulating program.

The results from this study support the use of DUP for maximizing strength compared with the traditional LP. Because of the multitude of differing combinations between program variables, there are innumerable periodized programs. More research needs to be done to determine what specific combination of variables will elicit maximum gains in strength. Future comparisons of different types of UP, especially DUP, should be conducted to attempt to identify the optimal combinations and alterations of training variables.

Practical Applications

The data from this current study suggest that DUP provides the added stress and variation necessary to elicit maximal strength gains by altering the volume and intensity of training on a daily rather than monthly basis. Anyone interested in making strength gains might benefit from this type of training, especially those that have been training regularly for an extended period of time. The DUP form of periodization may prove particularly beneficial for elite athletes by helping them avoid the plateau effect in strength gains that is often experienced by long-term weight lifters; however, further research using elite athletes would be required to determine such a benefit. Large increases in strength without large gains in muscle mass, as experienced by the DUP group, may also benefit athletes in sports such as wrestling, competitive weight lifting, and boxing who attempt to curtail weight gain to participate in specific weight classes.

Program directors, coaches, trainers, athletes, and anyone participating in DUP training should be aware of and attempt to avoid overtraining, which may accompany such a program. The optimal duration one should participate in a DUP program is not presently known, nor the optimal combination of variables that will maximize strength. However, the present study did demonstrate that over a 12-week period a DUP program elicits greater percentage strength gains than the more conventional LP program.

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