

Question: For individuals participating in resistance training, is traditional/linear periodization equal or superior to daily undulating/non-linear periodization for optimizing strength?				Date: January 2022 Searches: PubMed, PEDro, CINAHL	Abbreviations: LP – linear periodization DUP – daily undulating periodization RM – repetition maximum RCT – randomized controlled trial ME – muscular endurance	
Title, Author/Year	Purpose	Design/Subjects	Intervention(s) or Description	Outcome Measures	Results/Conclusion	Limitations/Comments
A Comparison of Linear and Daily Undulating Periodized Programs with Equated Volume and Intensity Rhea et al. 2002 ¹	To compare linear periodization (LP) and daily undulating periodization (DUP) for strength gains.	Randomized controlled trial n = 20 men age 21 ± 2.3 years with minimum 2 years of strength training experience	Both groups trained 3 days per week for 12 weeks. Total volume and intensity was equated for both groups. Each training day consisted of the same 5 exercises (bench press, leg press, crunches, bicep curl, lat pull-down). The models of periodization were only applied to the leg press and bench press exercises. LP group (n=10): Weeks 1-4 – 3x8 RM Weeks 5-8 – 3x6 RM Weeks 9-12 – 3x4 RM DUP group (n=10): Day 1 – 3x8 RM Day 2 – 3x6 RM Day 3 – 3x4 RM	1° outcomes: 1RM for bench press and leg press 2° outcomes: body composition using Bod Pod, circumference measurements Measurements were taken at baseline (T1), 6 weeks (T2), and 12 weeks (T3).	The DUP group experienced significantly greater strength improvements from T1 to T2 and T2 to T3 (p<0.05) compared to the LP group. No significant differences were found for body composition or circumference measures. <i>Conclusion:</i> In recreationally strength-trained young men, DUP elicits greater strength gains than a linear periodized program.	There was no description of the randomization process for allocation to either intervention group. The study was relatively short in duration (12 weeks), and had relatively few subjects. The results may not apply to populations who are untrained, elderly, elite athletes, or women. Additionally, subjects in the DUP group anecdotally reported extended muscle soreness and fatigue, whereas the LP group did not.
Comparison Between Linear and Daily Undulating Periodized Resistance Training to Increase Strength Prestes et al. 2009 ²	To compare the effects of LP and DP resistance training on body composition and maximal strength levels.	Quasi-experimental study n = 40 men age 21.5 ± 8.3 years with minimum 1 year of strength training experience	Both groups trained 4 days/week for 12 weeks. Both groups did the same exercises with equal mean volume and intensity. Training was divided into Session A (Mon/Thurs) and Session B (Tues/Fri) with different exercises performed on each training day. LP group (n=20): Weeks 1, 5, 9: 3x12 RM Weeks 2, 6, 10: 3x10 RM Weeks 3, 7, 11: 3x8 RM Weeks 4, 8, 12: 3x6 RM DUP group (n=20): Weeks 1, 3, 5, 7, 9, 11: Days 1 and 2: 3x12 RM Days 3 and 4: 3x10 RM	1° outcomes: 1RM for bench press, 45° leg press, and standing arm curl. 2° outcomes: body composition (using skinfold caliper) Measurements were taken at baseline, 8 weeks, and 12 weeks.	No statistically significant changes in body composition were observed within or between groups after 12 weeks. The DUP group exhibited a higher % increase than the LP group in 1RM bench press, leg press, and arm curl from pre-training to 12 weeks. However, the differences between groups were not statistically significant. <i>Conclusion:</i> DUP is an effective training program to increase max strength in	Similar to the previous study, the intervention period was relatively short, and the results only apply to resistance-trained men. Additionally, the authors state that the use of skinfolds to measure body composition may not be sensitive enough to determine changes during relatively short training periods.

			<p><i>Weeks 2, 4, 6, 8, 10, 12:</i> Days 1 and 2: 3x8 RM Days 3 and 4: 3x6 RM</p>		<p>resistance-trained young men. DUP may result in larger initial increases in strength compared to LP.</p>	
<p>Effects of Linear vs. Daily Undulatory Periodized Resistance Training on Maximal and Submaximal Strength Gains</p> <p>Miranda et al. 2011³</p>	<p>To verify the effect of LP and DUP resistance training methods on the evolution of 1RM and 8RM loads.</p>	<p>Randomized controlled trial</p> <p>n = 20 resistance-trained men age 26 ± 6 years</p>	<p>Both groups trained 4x/week for 12 weeks. Total volume and intensity was equated for both groups. The periodization models were only applied to leg press and bench press. All other exercises used 3 sets x 6-8 RM. Session A (Mon/Thurs): chest, shoulder, triceps Session B (Tues/Fri): legs, back, biceps</p> <p>LP group (n=10): Weeks 1-4 – 3x8-10 RM Weeks 5-8 – 3x6-8 RM Weeks 9-12 – 3x4-6 RM</p> <p>DUP group (n=10): Day 1 – 3x8-10 RM Day 2 – 3x6-8 RM Day 3 – 3x4-6 RM</p>	<p>1° outcomes: 1RM and 8RM for bench press and leg press</p> <p>Testing was performed at baseline and after 12 weeks.</p>	<p>Both groups showed a significant increase in 1RM and 8RM values for leg press and bench press after 12 weeks. However, there were no statistically significant differences between groups. The DUP group demonstrated a superior effect size in 1RM and 8RM loads for both leg press and bench press compared to the LP group. <i>Conclusion:</i> In resistance trained young men, DUP can elicit superior maximal strength and muscular endurance improvements compared to an LP model.</p>	<p>There was no description of the randomization process, the intervention period was relatively short, and the results only apply to resistance-trained men. There were relatively few subjects involved in this study. The authors report that nutrition and hydration were not controlled, and acknowledge this as an additional limitation of the study. Additionally, 8RM testing may be too few repetitions to measure muscular endurance.</p>
<p>Linear and Daily Undulating Resistance Training Periodizations Have Differential Beneficial Effects in Young Sedentary Women</p> <p>de Lima et al. 2012⁴</p>	<p>To verify the impact of a 12-weeks muscular endurance training of high repetitions (i.e., 15–30) with 2 different periodization models (LP vs DUP) on body composition, maximal strength, muscular endurance and cardiorespiratory fitness.</p>	<p>Randomized controlled trial</p> <p>n = 28 sedentary women age 20-35</p>	<p>Both groups performed 4 weekly sessions using the same exercises with the following split: Session A (Mon/Thurs), Session B (Tues/Fri). Mean volume and intensity were equal between groups.</p> <p>CON group (n=8): remained sedentary during the 12-week intervention</p> <p>LP group (n=10): Weeks 1, 5, 9 – 3x30 RM Weeks 2, 6, 10 – 3x25 RM Weeks 3, 7, 11 – 3x20 RM Weeks 4, 8, 12 – 3x15 RM</p>	<p>1RM and muscular endurance (ME) were tested for bench press, 45° leg press, and standing arm curl. ME was measured using highest # of repetitions as possible with 50% of 1RM until concentric failure; body composition was measured via skinfold caliper; cardiorespiratory fitness was measured using an incremental running test to obtain VO₂max.</p>	<p>Both groups showed significant decrease in body fat % and fat mass, with the LP group exhibiting greater loss than the DUP group. Both groups had a significant increase in fat-free mass. Both groups significantly increased maximal strength in all exercises, but the effect size was larger in the LP group. Both groups showed significant increase in ME, but the increase in the DUP group was significantly higher compared to LP. There</p>	<p>There was no description of the randomization process, and the intervention period was relatively short. The sample size of each intervention group was small. Also of note, the study aimed to measure maximal strength despite using a muscular endurance protocol.</p>

			<p>DUP group (n=10): <i>Weeks 1, 3, 5, 7, 9, 11:</i> Day 1 and 2 – 3x30 RM Days 3 and 4 – 3x25 RM <i>Weeks 2, 4, 6, 8, 10, 12:</i> Days 1 and 2 – 3x 20 RM Days 3 and 4 – 3x15 RM</p>	<p>Testing was performed at baseline and after 12 weeks.</p>	<p>were no statistically significant changes in VO₂max, and effect sizes were small.</p>	
<p>Systematic Review and Meta-Analysis of Linear and Undulating Periodized Resistance Training Programs on Muscular Strength</p> <p>Harries et al. 2015⁵</p>	<p>To examine all studies directly comparing linear and undulating periodized resistance training programs to determine and compare their effects on muscular strength.</p>	<p>Systematic review and meta-analysis</p> <p>n = 17 studies N = 510 subjects</p>	<p>A comprehensive search of MEDLINE, SCOPUS, and SPORTDiscus databases was conducted.</p> <p>Inclusion criteria: participants were from a nonclinical population, study compared LP program to DUP program, involved an RCT or quasi-experimental design, included a quantitative assessment of muscular strength, and published in English.</p>	<p>Meta-analysis performed in RevMan, using mean difference (MD) with 95% CI to determine effect measure for muscular strength. Meta-analysis procedure used the inverse-variance random effects model. χ^2 and I^2-index tests were used to examine statistical heterogeneity. Risk of bias was assessed using criteria adapted from the CONSORT to score each study.</p>	<p>The 16 studies comparing 1RM bench press at post-intervention were found to be moderately heterogeneous ($\chi^2 = 33.41$, $df=15$ [p=0.004], $I^2= 55\%$). The meta-analysis showed no clear effect for either LP or UP (MD=1.71 [-2.05 to 5.47] kg, Z=0.89 [p< 0.37]). The 7 studies comparing 1RM leg press at post-intervention had significant heterogeneity ($\chi^2=16.55$, $df=6$ [p=0.01], $I^2= 64\%$). No clear effect was shown for either LP or UP (MD=25.93 [-2.48 to 54.35] kg, Z=1.79 [p=0.07]). The 7 studies comparing 1RM squat at post-intervention were homogenous ($\chi^2=7.83$, $df=5$ [p=0.17], $I^2=36\%$). No effect favoring LP or UP was found (MD=-1.67 [-10.88 to 7.54] kg, Z=0.36 [p=0.72]).</p>	<p>The authors acknowledge that there may have been bias in the selection of studies since abstracts, theses, and studies published in non-peer-reviewed journals were excluded. Additionally, there was considerable heterogeneity between studies, and none of the studies adequately described the randomization of subjects. There was a high risk of bias in 4 studies (23.5%) and a medium risk in 13 (76.5%) studies. The authors heed caution when interpreting the results of the meta-analysis.</p>
<p>Effects of Periodization on Strength and Muscle Hypertrophy in Volume-Equated Resistance Training Programs: A Systematic</p>	<p>To examine the current literature to determine whether there is an effect of periodization of training volume and intensity on maximal strength and</p>	<p>Systematic review and meta-analysis</p> <p>n = 35 studies N = 1,187 subjects</p>	<p>Searches were conducted in PubMed, Scopus, and SPORTDiscus databases.</p> <p>Inclusion criteria: peer-reviewed, available in English, comparison of ≥ 1 periodized resistance training group to either non-periodized group or different periodization model,</p>	<p>4 meta-analyses were performed: 1) Δ1RM in NP vs periodized training. 2) Δ hypertrophy in NP vs. periodized training. 3) Δ1RM in LP vs UP training. 4) Δ hypertrophy in LP vs UP training.</p>	<p>LP vs UP (meta-analyses 3 and 4): 16 studies compared LP to UP (DUP, WUP, or both). Meta-analysis showed a significant effect on 1RM favoring UP (ES 0.31, 95% CI [0.02, 0.61]; Z=2.06 (P=0.04)). Subgroup analyses indicated a</p>	<p>The meta-analyses comparing UP to LP indicate moderate to high degree of heterogeneity between studies. However, sensitivity analysis in which one particular study was removed resulted in large reduction or elimination of heterogeneity levels,</p>

<p>Review and Meta-analysis</p> <p>Moesgaard et al. 2022⁶</p>	<p>muscle hypertrophy.</p>		<p>changes in maximal strength and/or muscle mass measured, equated mean volume and intensity between groups, identical training frequency, exercises, and exercise order between groups, reporting of mean, SD, SEM, and sample number, duration of at least 4 weeks</p>	<p>All meta-analyses performed using RevMan, using the inverse-variance random effects model. Between-groups ES with 95% CI used to determine effect measures. Statistical heterogeneity was assessed using χ^2 and I^2 statistics. A subgroup analysis was performed to determine if results were affected by training status of subjects.</p>	<p>moderate effect favoring UP for studies conducted on trained participants (ES 0.61, 95% CI [0.00, 1.22]; Z=1.97 (P=0.05)), whereas no effect favoring LP or UP was found for studies conducted on untrained participants (ES 0.06, 95% CI [-0.20, 0.31]; Z=0.43 (P=0.67)), indicating that training status may influence the effects of these periodization models. The meta-analysis showed no effect on muscle hypertrophy favoring LP or UP (ES 0.05, 95% CI [-0.20, 0.29]; Z=0.36 (=0.72)).</p>	<p>indicating this study may have biased the results. Also, the UP interventions involved both weekly (WUP) and/or daily (DUP) undulating periodization.</p>
--	----------------------------	--	---	--	---	--

Synthesis:

Based on the current best evidence, it appears that DUP and LP programs are both effective in improving strength. However, their uses may be applied differently in different populations. In resistance trained young men, it appears that DUP may result in greater improvements in strength compared to LP models.¹⁻³ Alternatively, in untrained individuals, LP and DUP seem to elicit similar improvements in strength.^{4,6} This may be attributable to the fact that early strength gains in untrained individuals occur rapidly due to neurophysiological adaptations, therefore they may not require daily or weekly undulations in volume and intensity in order to maximize strength.⁶ On the other hand, more advanced resistance trainers may need more frequent variations in volume and intensity in order to elicit neurophysiological adaptations and subsequent strength gains. Conversely to the other studies, the meta-analyses by Harries et al. did not find any clear effect favoring either LP or UP, although both models resulted in substantial increases in maximal strength.⁵ However, it should be noted that most of the studies included in this review included relatively short intervention periods (8-12 weeks), and there was considerable heterogeneity between studies. Additionally, the studies included a mix of trained and untrained participants, and no sub-group analysis was performed to investigate differences in outcomes between trained and untrained groups.

In most physical therapy clinics, the majority of the patient population will fall into the “untrained” category. It is also rare for a physical therapist to treat a patient for more than a few weeks, depending on their impairment. Therefore, specific periodization of interventions may not be feasible, but it also may not be completely necessary. So long as there is a gradual increase in intensity with concurrent decrease in volume over time, most patients will show adequate improvements in strength. In the rare instance that a physical therapist may treat a higher-level athlete for a prolonged period of time, then daily undulating periodization may specifically benefit those patients. The DUP model may be best utilized by sports physical therapists who work closely with advanced-level athletes and their strength and conditioning coaches.

References

1. Rhea MR, Ball SD, Phillips WT, Burkett LN. A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. *J Strength Cond Res.* 2002;16(2):250-255.
2. Prestes J, Frollini AB, de Lima C, et al. Comparison between linear and daily undulating periodized resistance training to increase strength. *J Strength Cond Res.* 2009;23(9):2437-2442. doi:10.1519/JSC.0b013e3181c03548
3. Miranda F, Simao R, Rhea M, et al. Effects of Linear vs. Daily Undulatory Periodized Resistance Training on Maximal and Submaximal Strength Gains. *J Strength Cond Res.* 2011;25(7):1824-1830.
4. de Lima C, Bualosa DA, Frollini AB, et al. Linear and daily undulating resistance training periodizations have differential beneficial effects in young sedentary women. *Int J Sports Med.* 2012;33(9):723-727. doi:10.1055/s-0032-1306324
5. Harries SK, Lubans DR, Callister R. Systematic Review and Meta-Analysis of Linear and Undulating Periodized Resistance Training Programs on Muscular Strength. *J Strength Cond Res.* 2015;29(4):1113-1125.
6. Moesgaard L, Beck MM, Christiansen L, Aagaard P, Lundbye-Jensen J. Effects of Periodization on Strength and Muscle Hypertrophy in Volume-Equated Resistance Training Programs: A Systematic Review and Meta-analysis. *Sports Med.* January 2022. doi:10.1007/s40279-021-01636-1