Comparison Between Nonlinear and Linear Periodized Resistance Training: Hypertrophic and Strength Effects

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Abstract

Simão, R, Spineti, J, de Salles, BF, Matta, T, Fernandes, L, Fleck, SJ, Rhea, MR, and Strom-Olsen, HE. Comparison between nonlinear and linear periodized resistance training: hypertrophic and strength effects. *J Strength Cond Res* 26(5): 1389–1395, 2012—The aim of this study was to investigate the effects of nonlinear periodized (NLP) and linear periodized (LP) resistance training (RT) on muscle thickness (MT) and strength, measured by an ultrasound technique and 1 repetition maximum (1RM), respectively. Thirty untrained men were randomly assigned to 3 groups: NLP ($n = 11$, age: 30.2 ± 1.1 years, height: 173.6 ± 7.2 cm, weight: 79.5 ± 13.1 kg), LP ($n = 10$, age: 29.8 ± 1.9 years, height: 172.0 ± 6.8 cm, weight: 79.9 ± 10.6 kg), and control group (CG; $n = 9$, age: 25.9 ± 3.6 years, height: 171.2 ± 6.3 cm, weight: 73.9 ± 9.9 kg). The right biceps and triceps MT and 1RM strength for the exercises bench press (BP), lat-pull down, triceps extension, and biceps curl (BC) were assessed before and after 12 weeks of training. The NLP program varied training biweekly during weeks 1–6 and on a daily basis during weeks 7–12. The LP program followed a pattern of intensity and volume changes every 4 weeks. The CG did not engage in any RT. Posttraining, both trained groups presented significant 1RM strength gains in all exercises (with the exception of the BP in LP). The 1RM of the NLP group was significantly higher than LP for BP and BC posttraining. There were no significant differences in biceps and triceps MT between baseline and posttraining for any group; however, posttraining, there were significant differences in biceps and triceps MT between NLP and the CG. The effect sizes were higher in NLP for the majority of observed variables. In conclusion, both LP and NLP are effective, but NLP may lead to greater gains in 1RM and MT over a 12-week training period.

Key Words strength training, periodization, strength testing, muscle hypertrophy

Introduction

Periodization has been applied to resistance training (RT) since the 1950s and has grown in popularity since then. Comparative studies between periodized and nonperiodized programs have been published and indicate that periodized programs result in greater strength increases compared with nonperiodized programs (1,2,9,10,12,15,16,18,19,23). Additionally, strength gains between 2 RT periodization models have been compared: linear periodization (LP) and nonlinear periodization (NLP) (9,10,12,15,16).

In LP models, initial training volume is high and intensity is low, and as training progresses through specific mesocycles, training volume decreases, whereas training intensity increases (23). The NLP initially proposed by Poliquin (14) involves a dramatic variation of training volume and intensity in shorter periods of time, occurring frequently from one training session to the next. This model was adapted by Rhea et al. (19) and termed “daily undulating periodization” to depict the large changes in volume and intensity between successive training sessions.

Some studies comparing LP and NLP have shown superior strength, power, and local muscular endurance gains with NLP (9,10,12,13,19,20), whereas other studies have shown no significant differences in these measures between the 2 periodization models (3,4,6). The greater increase in maximal strength observed with NLP has been attributed to more frequent manipulation of volume and intensity, which allows a superior stress/recovery ratio resulting in the prevention of overtraining (13,14). However, other studies (2,3) found no significant differences between the models of periodization (NLP and LP) and concluded that total work is more important to increased

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TABLE 1. Baseline anthropometric characteristics (mean ± *SD*).*

Groups	Age (y)	Height (cm)	Weight (kg)	Body fat (%)
NLP ($n = 11$)	30.2 ± 1.1	173.6 ± 7.2	79.5 ± 13.1	15.1 ± 5.1
LP ($n = 10$)	29.8 ± 1.9	172.0 ± 6.8	79.9 ± 10.6	13.8 ± 4.1
CG ($n = 9$)	25.9 ± 3.6	171.2 ± 6.3	73.9 ± 9.9	15.3 ± 6.9

*LP = linear periodized; NLP = nonlinear periodized; CG = control group.

strength than the manipulation of the variables of volume and intensity.

The majority of studies comparing LP and NLP have focused on strength gains between these 2 periodization models, although a few studies have compared fat-free mass changes using skinfold measurements. However, skinfold measurement may not be sensitive enough to determine the differences in fat-free mass or muscle thickness (MT) resulting from different RT programs. Therefore, with the goal of determining precise changes in muscle hypertrophy, the primary purpose of this study was to use an ultrasound technique to compare changes in MT resulting from NLP and LP training. A secondary purpose was to compare strength gains between these 2 training models. The hypothesis was that the NLP would show greater increases than the LP in the variables measured.

METHODS

Experimental Approach to the Problem

This study was a randomized controlled trial, in which 30 men were randomly assigned to 1 of 3 groups. One group trained using NLP, the second group trained using LP, and the third group served as a control group (CG). All the subjects began by undergoing a 2-week familiarization period for 1 repetition maximum (1RM) strength testing exercises. This was done before pretesting and the initiation of the 12-week strength training phase. After this, pretraining MT was measured using an ultrasound technique, and the 1RM tests were performed on 2 nonconsecutive days for the 4 exercises using a counterbalanced order. After pretesting, 12 weeks (2 sessions per week) of either LP or NLP training was performed. Posttesting was conducted in the same order as pretesting, and the 1RM and MT tests were performed 48 and 72 hours after the last session, respectively.

Subjects

Thirty men from the Brazilian Navy were randomly assigned to NLP, LP, or CG. No differences ($p > 0.05$) between groups in height, body mass, or percent body fat (7) were observed before training (Table 1). Study inclusion criteria for all the participants were that they (a) were physically active but had not performed RT for at least 6 months before the start of the study; (b) did not perform any other type of regular physical activity for the duration of the study, other than the prescribed RT and the regular military physical activity program, which was the same for all the participants; (c) did not have any functional limitation for the performance of the prescribed RT program or 1RM testing; (d) had no injuries or conditions that would affect the performance of the training program or the 1RM testing; and (e) had no supplemented nutrition (the military diet was the same for all the participants). The regular military physical activity program involved: local muscular endurance circuits (body weight exercises) and calisthenic exercises. Before starting the study, all the participants read and signed an informed consent form, which thoroughly explained the testing and training procedures that would be performed during the study. The

TABLE 2. Training programs (2 sessions per week).*

Groups	Phases	Training duration	Resistance training	Repetitions range	Rest length (min)
NLP	Phase 1 (weeks 1–6)	Weeks 1–2	Local muscular endurance	2 × 12–15RM	1
		Weeks 3–4	Hypertrophy	3 × 8–10RM	2
		Weeks 5–6	Strength	4 × 3–5RM	3
	Phase 2 (weeks 7–12)	Day 1	Local muscular endurance	2 × 12–15RM	1
		Day 2	Hypertrophy	3 × 8–10RM	2
		Day 3	Strength	4 × 3–5RM	3
LP		Weeks 1–4	Local muscular endurance	2 × 12–15RM	1
		Weeks 5–8	Hypertrophy	3 × 8–10RM	2
		Weeks 9–12	Strength	4 × 3–5RM	3

*LP = linear periodized; NLP = nonlinear periodized; RM = repetition maximum.

Table 3. Muscle thickness of elbow extensors and flexors for NLP, LP, and CG at baseline and 12 weeks of resistance training.*†

	MT elbow extensors		MT elbow flexors	
Groups	Baseline	12 wks	Baseline	12 wks
NLP ($n = 11$)	39.8 ± 4.9	41.5 ± 4.9‡	38.4 ± 5.8	41.9 ± 3.4‡
LP ($n = 10$)	39.2 ± 4.4	39.5 ± 7.6	36.6 ± 6.0	38.7 ± 3.9
CG ($n = 9$)	32.5 ± 4.8	32.0 ± 3.9	36.6 ± 4.6	36.5 ± 3.7

*LP = linear periodized; NLP = nonlinear periodized; MT = muscle thickness; CG = control group.
†Values are given as mean ± *SD* (mm).
‡Difference to CG.

experimental procedures were approved by the Ethics Committee of the Rio de Janeiro Federal University.

One Repetition Maximum Testing

Before pretesting and the RT phase, all the participants underwent a 2-week (2 sessions per week) familiarization period, during which the subjects performed the same exercises as used in the 1RM tests, with the aim of standardizing the technique of each exercise. The sessions were performed with 1 set of 20 repetitions, using a light weight. After the familiarization period, all the participants completed 3 familiarization sessions of the 1RM test protocol. The 1RM tests were then performed on 2 nonconsecutive days for the barbell bench press (BP), machine front lat-pull down (LPD), machine triceps extension (TE), and the straight-bar standing biceps curl (BC), using a counterbalanced order (Latin Square Design). The two 1RM test sessions were separated by 48–72 hours and were used to determine test-retest reliability. The heaviest resistance load achieved on either of the test days was considered the pretraining 1RM of a given exercise. No exercise was allowed in the period between 1RM test sessions so as not to interfere with the test-retest reliability results. The 1RM testing protocol has been previously described (22).

To minimize error during the 1RM tests, the following strategies were adopted (21): (a) standardized instructions concerning the testing procedure were given to the participants before the test; (b) the participants received standardized instructions on specific exercise technique; (c) verbal encouragement was provided during the testing procedure; and (d) the mass of all weights and bars used was determined using a precision scale. The 1RM was determined in <5 attempts, with a rest interval of 5 minutes between 1RM attempts, and a 10-minute recovery period was allowed before the start of the 1RM testing of the next exercise. After the 12 weeks of training, the 1RM tests were performed similarly to the pretraining tests to determine the strength gains.

Muscle Thickness Measurements

Muscle thickness of the right biceps and triceps muscles was assessed before and after the 12-week training period. An ultrasound technique (EUB-405, Hitachi, Tokyo, Japan)

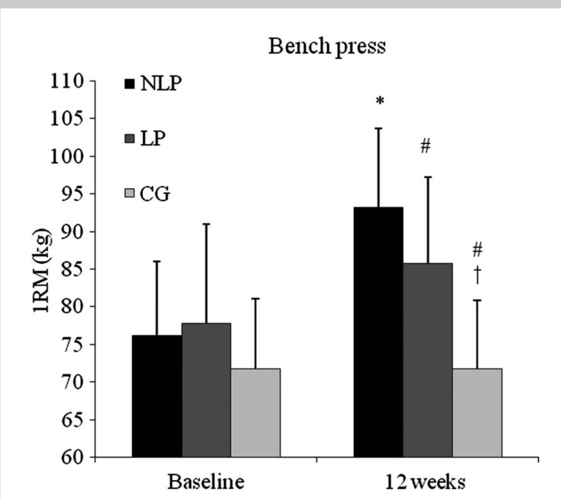

Figure 1. 1RM (Mean and *SD*) of bench press for NLP, LP and CG at baseline and at 12 weeks of resistance training. *Difference to baseline; #Difference to NLP; †Difference to LP.

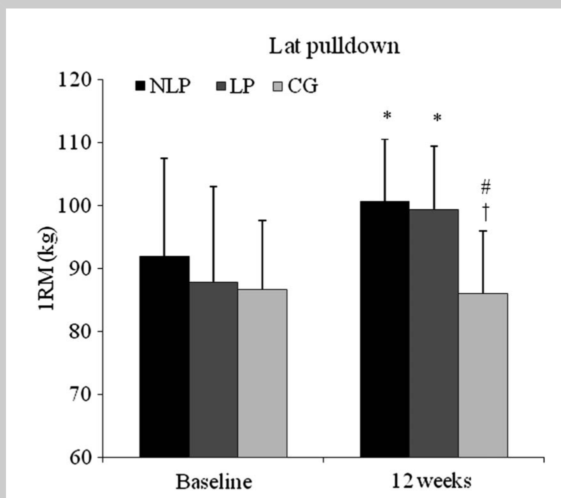

Figure 2. 1RM (Mean and *SD*) of lat pull down for NLP, LP and CG at baseline and at 12 weeks of resistance training. *Difference to baseline; #Difference to NLP; †Difference to LP.

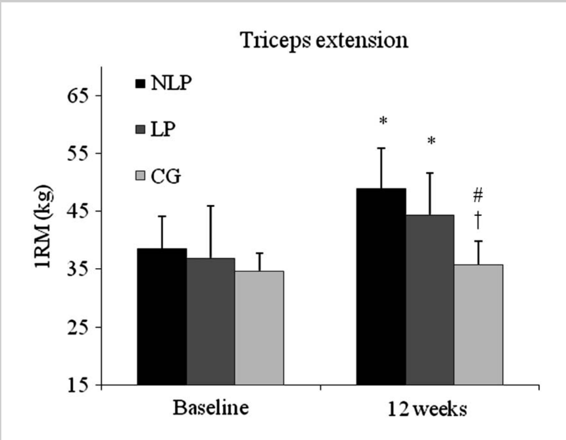

Figure 3. 1RM (Mean and *SD*) of triceps extension for NLP, LP and CG at baseline and at 12 weeks of resistance training. *Difference to baseline; #Difference to NLP; †Difference to LP.

with an electronic linear array probe of 7.5-MHz wave frequency was used to determine MT. The ultrasound probe, with the transducer coated with a water-soluble transmission gel, was oriented transversally with respect to location, and the images were recorded with the subjects sitting upright with their arms alongside the body (5,8,11). The MT was assessed at 60% of the right arm length (8,11) and was defined as the distance between the interface of the muscle tissue and subcutaneous fat to the bone. During the assessment, the evaluator had no access to the values of measure, and 2 measurements were performed for each muscle on the same day. In any cases where a difference >0.5 mm between measurements occurred, a third measurement was performed and was used for data

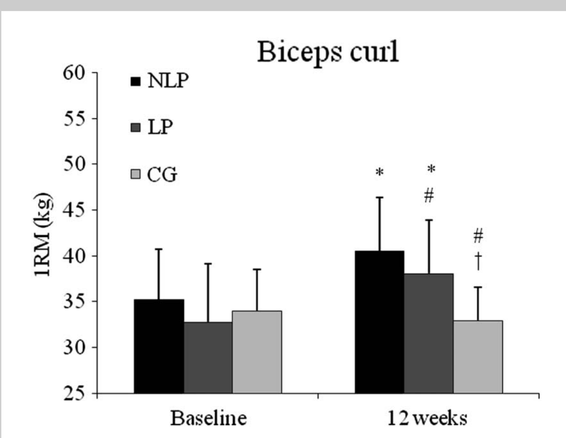

Figure 4. 1RM (Mean and *SD*) of biceps curl for NLP, LP and CG at baseline and at 12 weeks of resistance training. *Difference to baseline; #Difference to NLP; †Difference to LP.

analysis to determine the average of the 2 measures more accurately. The measurements were performed by the same investigator, an experienced technician, on all occasions. The tests were checked for reliability of measurements and showed high intraclass correlation coefficients (ICCs).

Training Procedures

After pretesting measurements, the NLP and LP groups completed the 12-week training program. The RT program consisted of the following exercise sequence: BP, LPD, TE, and BC. The CG did not take part in the RT program. The sets and repetitions of each exercise performed and the changes in training volume and intensity are described in Table 2. The NLP training program was divided into 2 phases: initially the training volume and intensity varied biweekly during 1–6 weeks and then on a daily basis during weeks 7–12. The biweekly undulation design suggested by Poliquin (14) was used for initial adaptation and identification of the different training intensities that achieve concentric failure for the prescribed repetitions of the different training zones. The LP program followed a consistent pattern of intensity and volume changes every 4 weeks. During the exercise sessions, the participants were verbally encouraged to perform all the sets to concentric failure, and the same definitions of a complete range of motion used during the 1RM testing were used to define completion of a successful repetition. There was no attempt to control the velocity of the repetitions performed. If a subject was able to perform more than the prescribed number of repetitions for all sets of a given exercise, the resistance load for that particular exercise was increased. The frequency of the training program was 2 sessions per week with at least 72 hours of rest between sessions. A total of 24 sessions were performed in the 12-week training period with all the sessions occurring between 7 and 8 AM. The training programs were performed during October, November, and December (spring-summer season). Before each training session, the participants performed a specific warm-up, consisting of 20 repetitions at approximately 50% of the resistance used in the first exercise of the training session. Adherence to the program was 100% for both training groups, and all the training sessions were supervised by an experienced strength and conditioning professional.

Statistical Analyses

The ICC was used to determine MT and 1RM test-retest reliability pretraining and posttraining. The ICC method was used based on a repeat measurement of maximal strength and MT. The statistical analysis initially involved the Kolmogorov-Smirnov normality test and the homocedasticity test (Bartlett criterion). All variables presented normal distribution and homocedasticity. An analysis of variance 2-way (3×2) was applied to compare the results for MT and 1RM tests between groups (NLP, LP, and CG), and also between baseline and 12 weeks of the RT program. The Fisher post hoc test was used for pairwise comparisons of mean values. The effect size (ES)

Table 4. One repetition maximum test and MT effect sizes and magnitudes across 12 weeks of resistance training.*

Groups	Effect size magnitude	MT elbow flexors	MT elbow extensors	Bench press	Lat-pull down	Biceps curl	Triceps extension
NLP	Effect size	0.61 Small	0.36 Trivial	1.74 Moderate	0.56 Small	0.98 Small	1.53 Moderate
LP	magnitude	0.35 Trivial	0.05 Trivial	0.60 Small	0.77 Small	0.83 Small	0.81 Small
CG		−0.03 Trivial	0.00 Trivial	0.01 Trivial	−0.05 Trivial	−0.24 Trivial	0.36 Trivial

*LP = linear periodized; NLP = nonlinear periodized; MT = muscle thickness; CG = control group.

magnitude (the difference between baseline and 12-week scores divided by the baseline *SD*) of 1RM strength, MT data, and the scale proposed by Rhea (17) for ES magnitude classification was used. T-tests were used to analyze possible differences between the total work (session × sets × load) and total volume (sets × repetitions) between trained groups. Statistical analyses were carried out with the Statistica 7.0 software (Statsoft, Inc., Tulsa, OK, USA), and the statistical significance was set at $p \leq 0.05$.

Results

There was no difference between total training volume (2,933 and 2,941 repetitions) and the total work performed (499,571 and 422,253 kg) by NLP and LP, respectively ($p > 0.05$). The MT test-retest reliability showed high ICCs at baseline for both muscles (biceps brachii, $r = 0.97$, $SEM = 0.61$; triceps brachii, $r = 0.98$, $SEM = 0.56$), and after 12 weeks of training (biceps brachii, $r = 0.93$, $SEM = 0.51$; triceps brachii, $r = 0.97$, $SEM = 0.51$). The 1RM test-retest reliability showed high ICCs at baseline for all exercises (BP, $r = 0.97$, $SEM = 0.61$; LPD, $r = 0.97$, $SEM = 0.61$; TE, $r = 0.97$, $SEM = 0.61$; BC, $r = 0.97$, $SEM = 0.61$) and after 12 weeks of training (BP, $r = 0.97$, $SEM = 0.61$; LPD, $r = 0.97$, $SEM = 0.61$; TE, $r = 0.97$, $SEM = 0.61$; BC, $r = 0.97$, $SEM = 0.61$). There were no differences ($p > 0.05$) between groups in MT or 1RM measurements at baseline.

Muscle Thickness

Table 3 presents the results for MT. The MT of NLP was significantly higher than that of CG after the 12 weeks of training ($p = 0.046$ and $p = 0.014$, for elbow extensors and flexors, respectively). There were no significant differences between baseline and posttraining MT for any group.

One Repetition Maximum

Both training groups experienced a statistically significant increase in muscular strength in LPD, BC, and TE after 12 weeks of an RT program ($p < 0.05$) (Figures 1–3). Only the NLP group increased BP 1RM after 12 weeks ($p < 0.05$) (Figure 1), but both training groups experienced a statistically significant increase in muscular strength in LPD, BC and TE after 12 weeks of a resistance training program ($p < 0.05$) (Figures 2, 3 and 4). The 1RM of NLP was significantly higher than LP for BP and BC after 12 weeks of training ($p < 0.05$) (Figures 1 and 4).

Effect Size

The ESs were higher in NLP for the majority of observed variables. The NLP group was higher than LP for the BP and TE 1RM ES. The NLP presented moderate magnitude ESs for the BP (1.74) and TE (1.53), whereas the LP group presented small magnitudes (0.60 and 0.81, respectively). Additionally, the NLP presented higher elbow flexor MT ES (0.61–small) than did the LP group (0.35–trivial) (Table 4).

Discussion

The purpose of this study was to examine the effects of different types of periodization on muscular thickness and muscle strength. Although there was no significant difference in muscle accretion between the 2 training groups, both training groups did show significant strength gains, with the NLP showing statistically significant greater strength gains than the LP group for BP and BC. The ES calculations indicate greater gains by the NLP in both 1RM and MT, with the exception of LPD, in which a greater gain with LP was indicated. Therefore, our initial hypothesis was partially confirmed.

As in this study, prior research has also found NLP to elicit superior strength gains and ES compared with LP models. Rhea et al. (19) compared the effect of LP and NLP on strength gains in previously trained individuals with a 3 sessions per week, whole-body program. The authors found significant increases in leg press and BP maximal strength after LP and NLP. However, NLP induced superior increases in maximal strength compared with LP, 55.8 vs. 25.7% for leg press, and 28.8 vs. 14.4% for BP. The main differences between the Rhea et al. (19) study and this study were that we used untrained groups, implemented an upper-body only strength program, and we also measured MT. Our findings, and those of Rhea et al. (19), were further confirmed by other studies comparing NLP and LP (12,23). Monteiro et al. (12) compared LP, NLP, and nonperiodized programs, and after 12 weeks, NLP training resulted in greater strength gains than LP and the nonperiodized training programs.

Another comparison between the effects of LP and NLP during 15 weeks of training showed that both periodization models increased maximal knee extension strength (9.8% for NLP and 9.1% for LP) with no statistically significant difference between programs (20). Although the authors used loads to improve local muscular endurance (15–25RM) and the increases in strength were similar, an increase in strength percentage and ES was observed for NLP (19).

Prestes et al. (16) found that NLP induced a greater percent increase in maximal strength for the BP, the 45° leg press, and the arm curl after 12 weeks of training compared with LP (NLP 25.08, 40.61, and 23.53% vs. LP 18.2, 24.71, and 14.15%, respectively). An interesting aspect was that after only 8 weeks, the NLP group showed significant increases in the 45° leg press and the arm curl maximal strength, which were not shown by the LP group. Moreover, NLP continued to increase maximal strength in the 45° leg press from week 8 to week 12, also not shown by the LP. Combined, these results indicate that NLP training may increase maximal strength to a greater magnitude during the first weeks of training and result in more consistent strength gains throughout the training period.

The NLP may also have superior effects on other aspects of physical health and performance when compared with LP. A recent study reported that an NLP program produced greater upper and lower body strength gains, power, and jumping capacity compared with LP in trained firemen (13). This result highlights the superiority of NLP training, in that RT professionals and coaches can adapt different intensities to the specific training goals, which would be more difficult with linear models (14). Additionally, Foschini et al. (4) showed that NLP training, compared with LP training, produced more pronounced improvements in some metabolic syndrome risks.

However, nonstatistically significant differences in strength gains between NLP and LP have also been shown. Comparing LP, weekly undulating, and NLP programs, Bufford et al. (3) showed that the percent increases in BP were 24% for LP, 17% for NLP, and 24% for weekly undulating, whereas increases in leg press were 85, 79, and 99%, respectively. No statistically significant differences between models were observed. Hoffman et al. (6) also showed no significant differences in strength gains in American football players with LP and NLP.

As previously demonstrated, earlier studies comparing different periodization models have presented conflicting findings regarding strength gains (2,3,12,13,19,23). This fact may be related to the suggestion of some authors that total work may be the most important factor to elicit training adaptations (2), whereas others claim that the manipulation of volume and intensity is the most relevant influence (23). Although both periodization models are effective in increasing upper and lower body strength, the lack of agreement indicates further study is needed.

In this sense, statistical significance may confound data interpretation, mainly when sample size is reduced and the *SD* is higher after the intervention (18). Through the calculation of the ES, it is possible to verify the modifications caused by the same treatment on independent groups or different treatments within the same group, which allows the efficacy of each method to be determined (17). According to the ES scale, NLP led to important practical outcomes, suggesting that NLP is an effective method for attaining greater strength and MT goals over a 12-week training period. The present results are in agreement with those of other studies with equated total training volume (12,13,19).

This study used ultrasound techniques, which were previously described (5,8) and were crossvalidated with (11) magnetic resonance images (gold standard method) for the assessment of muscular geometry parameters (11). Although no statistically significant differences in MT gains between NLP and LP were shown, the NLP group did present significant differences compared with CG after 12 weeks of training. Moreover, the ES reveals slight superior gains for elbow flexor MT in NLP (0.61–small) over LP (0.35–trivial). Probably, the small changes in MT for both training groups occurred because 12 weeks of the training and the training program consisting of one exercise for each muscle group were not enough to result in significant MT changes. Therefore, future studies analyzing the hypertrophic response to different periodization models with longer training periods and larger training volumes are necessary. However, until now, no other study has evaluated hypertrophy with a more accurate technique than ultrasound or magnetic resonance imaging.

In summary, the manner in which the volume and intensity are manipulated during an RT period influences the magnitude of MT and strength gains. Both LP and NLP are effective, but NLP may lead to greater gains in MT and 1RM over a 12-week training period, when performed by individuals with characteristics similar to those in our study.

Practical Applications

In light of the importance of manipulating training volume and intensity, more research on the comparison between periodization models is necessary to establish the best model specific to a particular goal. Our study suggests that, at least in trained subjects over a 12-week training period, the implementation of an NLP program may result in superior maximal strength and MT improvements compared with the classical LP model. Additionally, the NLP model variations in volume and intensity occurring from one training session to the next may reduce the "monotony" of performing repetitive training sessions and result in greater practitioner adherence. More studies comparing periodization models for different objectives and specific populations should be conducted.

References

1. American College of Sports Medicine (ACSM) Position Stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
2. Baker, D, Wilson, G, and Carlyon, R.Periodization: The effect on strength of manipulating volume and intensity. *J Strength Cond Res* 8: 235–242, 1994.

3. Bufford, TW, Rossi, SJ, Smith, DB, and Warren, AJ. A comparison of periodization models during nine weeks with equated volume and intensity for strength. *J Strength Cond Res* 21: 1245–1250, 2007.
4. Foschini, D, Araújo, RC, Bacurau, RFP, De Piano, A, De Almeida, SS, Carnier, J, Rosa, TD, De Mello, MT, Tufik, S, and Dâmaso, AR. Treatment of obese adolescents: The influence of periodization models and ACE genotype. *Obesity* 18: 766–772, 2010.
5. Fukunaga, T, Miyatani, M, Tachi, M, Kouzaki, M, Kawakami, Y, and Kanehisa, H. Muscle volume is a major determinant of joint torque in humans. *Acta Physiol Scand* 172: 249–255, 2001.
6. Hoffman, JR, Ratamess, NA, Klatt, M, Faigenbaum, AD, Ross, RE, Tranchina, NM, McCurley, RC, Kang, J, and Kraemer, WJ. Comparison between different off-season resistance training programs in division III American college football players. *J Strength Cond Res* 23: 11–19, 2009.
7. Jackson, AS and Pollock, ML. Generalized equations for predicting body density of men. *Br J Nutr* 40: 497–504, 1978.
8. Matta, T, Simão, R, de Salles, BF, Spineti, J, and Oliveira, LF. Strength training chronic effects on muscle architecture's parameters of different arm sites. *J Strength Cond Res* 25: 1711–1717, 2011.
9. Miranda, F, Simão, R, Rhea, M, Bunker, D, Prestes, J, Leite, RD, Miranda, H, de Salles, BF, and Novaes, J. Effects of linear vs. daily undulatory periodized resistance training on maximal and submaximal strength gains. *J Strength Cond Res* 25: 1824–1830, 2011.
10. Miranda, H, Simão, R, Vigário, PS, de Salles, BF, Pacheco, MTT, and Willardson, JM. Exercise order interacts with rest interval during upper-body resistance exercise *J Strength Cond Res* 24: 1573–1577, 2010.
11. Miyatani, M, Kanehisa, M, Ito, M, Kawakami, Y, and Fukunaga, T. The accuracy of volume estimates using ultrasound muscle thickness measurements in different muscle groups. *Eur J Appl Physiol* 91: 264–272, 2004.
12. Monteiro, AG, Aoki, MS, Evangelista, AL, Alveno, DA, Monteiro, GA, Piçarro Ida, C, and Ugrinowitsch, C. Nonlinear periodization maximizes strength gains in split resistance training routines. *J Strength Cond Res* 23: 1321–1326, 2009.
13. Peterson, MD, Dodd, DJ, Alvar, BA, Rhea, MR, and Favre, M. Undulation training for development of hierarchical fitness and improved firefighter job performance. *J Strength Cond Res* 22: 1683–1695, 2008.
14. Poliquin, C. Five ways to increase the effectiveness of your strength training program. *Natl Strength Cond Assoc* 10: 34–39, 1988.
15. Prestes, J, De Lima, C, Frollini, AB, Donatto, FF, and Conte, M.Comparison of linear and reverse linear periodization effects on maximal strength and body composition. *J Strength Cond Res* 23: 266–274, 2009.
16. Prestes, J, Frollini, AB, De Lima, C, Donatto, FF, Foschini, D, Marqueti, RC, Figueira Jr, A, and Fleck, SJ. Comparison between linear and daily undulating periodized resistance training to increase strength. *J Strength Cond Res* 23: 2437–2442, 2009.
17. Rhea, MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J Strength Cond Res* 18: 918–920, 2004.
18. Rhea, MR and Alderman, BL. A meta-analysis of periodized versus nonperiodized strength and power training programs. *Res Q Exerc Sport* 75: 413–422, 2004.
19. Rhea, MR, Ball, SD, Phillips, WT, and Burkett, LN. A comparison of linear and daily undulating periodized programs with equal volume and intensity for strength. *J Strength Cond Res* 16: 250–255, 2002.
20. Rhea, MR, Phillips, WT, Burkett, LN, Stone, WJ, Ball, SD, Alvar, BA, and Thomas, AB. A comparison of linear and daily undulating periodized programs with equated volume and intensity for local muscular endurance. *J Strength Cond Res* 17: 82–87, 2003.
21. Simão, R, Farinatti, PTV, Polito, MD, Maior, AS, and Fleck, SJ. Influence of exercise order on the number of repetitions performed and perceived exertion during resistance exercises. *J Strength Cond Res* 19: 152–156, 2005.
22. Simão, R, Farinatti, PTV, Polito, MD, Viveiros, L, and Fleck, SJ. Influence of exercise order on the number of repetitions performed and perceived exertion during resistance exercise in women. *J Strength Cond Res* 21: 23–28, 2007.
23. Stone, MH, Potteiger, JA, Pierce, KC, Proulx, CM,O'Bryant, HS, Johnson, RL, Stone, ME. Comparison of the effects of three different weight-training programs on the one repetition maximum squat. *J Strength Cond Res* 14: 332–337, 2000.