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The effect of linear and daily undulating periodized resistance training on the neuromuscular function and the maximal quadriceps strength

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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abstract

Background: The purpose of this study was to investigate the effects of 9 weeks' resistance training utilizing a daily undulating periodization (DUP) program versus a linear periodization (LP) program on concentric and isometric muscle strength and neuromuscular function of the quadriceps muscle.

Material and methods: 30 male subjects (age = 21.7 ±2.5 yr, body mass = 71.4 ±11.9 kg, height =1.77 ±0.09 m) participated in the study. Subjects were randomly divided into DUP and LP training groups. Both the DUP and LP training group performed leg press exercise 3 times per week. Volume and intensity were equated for each training program. However, the periodization type was different between the two groups. Additionally, the maximal isometric voluntary contraction (MIVC) of the quadriceps muscle and the associated electromyography (EMG) activity were recorded before and after 9 weeks of the DUP and LP training programs.

Results: The DUP training program resulted in a greater increase (50.1% ±10.1) in quadriceps isometric strength compared with the LP training program (35.5% ±7.3; $F = 7.6$, $p < 0.025$). Accordingly, EMG activity of the quadriceps muscle after 9 weeks of the DUP training program was significantly larger than that observed after the LP training model ($F = 7.5$, $p < 0.05$).

Conclusions: Resistance training using a DUP program is more effective than a LP program to elicit neuromuscular activity and muscle strength.

Key words: electromyography, periodization, resistance training, muscle strength.

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INTRODUCTION

Manipulating resistance training variables has been widely used to develop maximum muscle strength [1, 2]. Many styles of resistance training are utilized today, and periodization has been a popular method applied to resistance training [3]. Periodization is an organization of training in which training variables could be manipulated to enhance the ability of skeletal muscle to produce force. Training variables such as the number of repetitions per set, the number of sets, exercise intensity, training sessions per week, and the velocity of exercise, effect on the force-generating capacity of the skeletal muscle [4]. Previous studies have frequently manipulated these training variables to increase the force-generating capacity of skeletal muscles. For example, Ratamess et al. [5] suggested that high intensity–low volume exercise programs are more effective than high volume–moderate intensity programs to enhance muscle strength. Accordingly, Mazani et al. [6] reported that high-speed training with heavy workload–low repetition resulted in a greater increase in maximal concentric quadriceps strength compared with high-speed training with low workloads–high repetition. The increased muscle force after resistance training has been attributed to neuromuscular adaptations at the level of the neuromuscular junction, spinal cord and motor cortex [7, 8]. Aagaard et al. [9] observed increases in the evoked V-wave (first volitional wave) amplitude and H-reflex responses during maximal muscle contraction after strength training, most likely due to the enhanced neural drive in the corticospinal pathways and increased excitability of motor neurons.

Many types of periodization protocols can manipulate training variables to optimize muscle adaptation and force development. Linear periodization (LP) and the nonlinear or daily undulating periodization (DUP) training program have been widely used to improve muscle strength. Linear periodization is characterized by gradual increases in training intensity and decreases in volume, with these changes being made approximately every four weeks [3]. A nonlinear periodization program is characterized by more frequent alterations in intensity and volume, performed on a weekly or daily basis [10]. Due to differences in training characteristics between the linear and nonlinear periodization program (e.g., frequency and exercise order), differences in mechanical stresses can be imposed [4, 5], which in turn may result in differences in neuromuscular adaptation and subsequent force development. However, neuromuscular responses to DUP and LP training programs have received relatively little attention. Thus, the primary purpose of this study was to compare the change in dynamic and isometric maximal strength after LP and DUP training programs and to determine whether this change in muscular strength is associated with the change in neuromuscular adaptations. Muscle strength and neuromuscular activity of the quadriceps muscle were simultaneously measured before and following the 9 weeks' LP and DUP training programs.

MATERIAL AND METHODS

SUBJECTS

30 healthy male subjects with no history of knee injury (age = 21.7 ±2.5 yr, body mass = 71.4 ±11.9 kg, height = 1.77 ±0.09 m) were recruited for the study. Subjects were excluded if they reported dietary supplement use and/or any medication use for hypertension and psychiatric condition. Subjects were

randomly divided into two groups, a linear periodization training group (N-15), and a daily undulating periodization training group (N-15). All subjects were right leg dominant and were not involved in the regular exercise of their knee extensor muscles for at least one year before the experiment. The study was conducted in accordance with the Declaration of Helsinki, approved by the Local Ethics Committee (BU 1607-2017), and written informed consent was obtained from all subjects prior to inclusion.

Measurements

Warm-up: Subjects warmed up both legs on a bicycle ergometer (LC4, Monark Exercise AB, Sweden) for 10 min and performed light stretching to prevent knee joint injury during the experiment.

Maximal quadriceps strength: One repetition maximum test (1RM) was used to determine the maximal quadriceps strength. 1-RM was determined by having the subjects perform one repetition at each successive load using leg press on a weight-training machine (Universal Gym). The subject lifted the load from the starting position (90° knee extension) to the finish position (180° full knee extension) in a controlled maneuver using the dominant leg. The load was increased in 1- to 5-kg increments with a 30-s break between each attempt. Each subject was required to be able to lift his maximum load in a smooth, controlled motion.

Maximal isometric quadriceps strength: A load cell was used to measure maximal isometric quadriceps strength. The subject sat comfortably on a chair fixed with a belt at the hip and with the right knee in 90° flexion. A strap, connected by a chain to a load cell, was attached to the ankle to measure knee extension isometric force. Force was provided to the subject as visual feedback on an oscilloscope. The subject performed three 5-second maximal isometric voluntary contractions (MIVC) of knee extension each separated by 2-min rest. During each MIVC, verbal encouragement was provided to exceed the previous force level. The highest MIVC value was considered as the reference value.

Surface EMG recordings: Surface EMG signals were recorded from quadriceps of the dominant leg during maximal isometric voluntary contractions of the knee extension. Surface electrodes (Ag-AgCl electrodes, Ambu Neuroline, conductive area: 28 mm^2) were placed in bipolar configuration (interelectrode distance: 2 cm) at a position equal to 10% of the distance between the medial border, superior border, and lateral border of the patella and anterior superior iliac spine; corresponding to the vastus medialis (VM), rectus femoris (RF), and vastus lateralis (VL) muscles, respectively [11]. A reference electrode was placed around the right ankle. Surface EMG signals were amplified (EMG amplifier, EMG16, OT Bioelettronica, Torino, Italy, bandwidth 10–500 Hz), sampled at 2048 Hz and stored after 12-bit A/D conversion. To assess the amplitude of muscle activation during the maximal isometric voluntary contraction, the average rectified values (ARV) of individual muscles were calculated over 200-ms windows within 5-s. The peak ARV obtained from 200-ms windows was considered as a representative value [12]. The ARV values were averaged over three muscles to obtain one representative value.

Training protocol

Subjects performed leg press exercise 3 times per week. Unilateral leg press exercise was performed through 90° to 180° of the knee extension (180° = full extension). Like previous studies, a cadence of 2/1/3 was considered for the leg exercise [21]. The timing of the lifting, lowering and lockout phases of the exercise, was established using a sound metronome (SEIKO Big). The metronome emitted an audible stimulus at a frequency of 1 Hz per second. Subjects were asked to maintain a cadence of 2 during the concentric phase, 1 during the lockout and 3 during the eccentric phase, in time with the metronome. The LP group performed 3 sets of 12-RM (%65-1RM) during weeks 1–3, 3 sets of 8 RM (%75-1RM) during weeks 4–6, and 3 sets of 6-RM (%85-1RM) during weeks 7–9. The DUP group changed the training volume and intensity every exercise day: 3 sets of 12-RM (%65-1RM), 3 sets of 8-RM (%75-1RM), and 3 sets of 6-RM (%85-1RM) repeated continuously for 9 weeks. %RM was calculated by multiplying the percentage by 1RM. Repetitions were performed at a constant pace of 1 repetition every 3 seconds. 90-second rest was given between each set. Moreover, training intensity (RM), training sets and repetitions were equated for both LP and DUP training program during the 9-week training program [3]. Differences between groups were calculated to ensure that the only difference between the two types of training programs was the order in which the training volume and intensity were adjusted. All sessions were supervised individually by the same experimenter.

Statistical analysis

One-way repeated-measures ANOVA was applied to analyze the maximal isometric quadriceps strength before and after 9 weeks' LP and DUP resistance training. A one -way repeated-measures ANOVA was also applied to analyze the maximal concentric quadriceps strength before and after 9 weeks' LP and DUP training program. Two-way repeated-measures ANOVA was used to assess EMG ARV during the maximal isometric voluntary contraction of knee extension with the testing session (pre-training and post-training) and training groups (LP and DUP) as the factor. Pairwise comparisons were performed with the Student–Newman–Keuls post hoc test when ANOVA was significant. Finally, the Pearson correlation coefficient was used to assess the relationship between changes in EMG variables and the maximal isometric quadriceps strength across the testing session. The significance level was set at $p < 0.05$ for all statistical procedures. Results are reported as mean and standard division (SD) in the text and standard error (SE) in the figure.

Results

Total Volume: The paired sample t-test revealed that the total weight lifted by the DUP training group (71.476 ±21.579 kg) was not significantly different from the LP training group (73.171 ±22.165 kg) during the 9-week training program ($t = 1.25$, $p > 0.05$).

Muscle function: Maximal isometric quadriceps strength increased significantly for both LP and DUP training groups from the pre-training to post-training session ($F = 14.1$, $p < 0.0001$, Fig. 1). Maximal concentric quadriceps strength measured after 9 weeks' LP (mean ± SD; 197.7 ±18.6 kg) and DUP resistance training (226 ±23.4 kg) were also significantly greater than those observed for the LP (103.3 ±15.5 kg) and DUP group (113 ±16.7 kg) at the pre-training condition ($F = 16.6$, $p < 0.0001$, Fig. 2). Additionally, a significant interaction was observed between the training group and the testing session ($F = 7.6$, $p < 0.025$), in which the DUP training group showed a higher percentage increase in the maximal concentric and isometric quadriceps strength after 9 weeks' resistance training ($p < 0.05$, Fig. 1 and 2).

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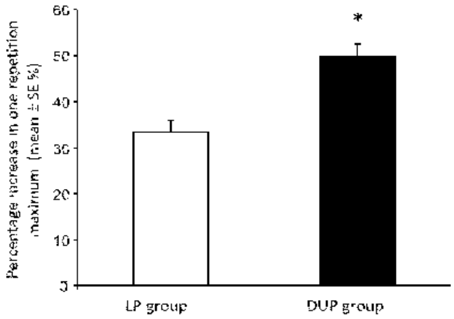

Fig. 1. Percentage increase in one repetition maximum (1RM) leg press (mean ±SE, %, n = 15 subjects) after 9 weeks' DUP and LP training program

(*) indicates that the percentage increase in 1RM leg press for the DUP training group was significantly higher than for the LP group (p < 0.05).

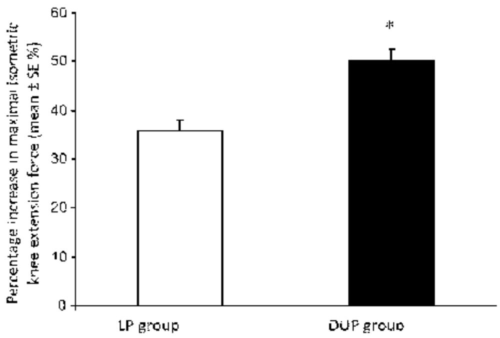

Fig. 2. Percentage increase in MVC (maximal isometric knee extension force; mean ±SE, %, n = 15 subjects) after 9 weeks' DUP and LP training program

(*) indicates that the percentage increase in isometric force for the DUP training group was significantly higher than for the LP group (p < 0.05).

EMG: EMG ARV measured during maximal isometric voluntary contraction was significantly increased after 9 weeks of resistance training for both the LP and DUP training groups ($F = 11.9$, $p < 0.001$). The increased EMG ARV was dependent on the interaction between the training group and the testing session ($F = 7.5$, $p < 0.05$), with a higher percentage increase identified for the DUP group compared with the LP group ($p < 0.05$, Fig. 3).

Correlation between EMG and quadriceps strength: A significant correlation was observed between changes in the maximal isometric quadriceps strength (change from the pre-training to the post-training sessions) and changes in EMG ARV (change from the pre-training to the post-training sessions). Change in the maximal isometric quadriceps strength and change in EMG ARV were positively correlated ($R = 0.65$, $p < 0.003$, Fig. 4), indicating that the increased maximal isometric quadriceps strength at post-training condition was partially associated with increased muscle activation.

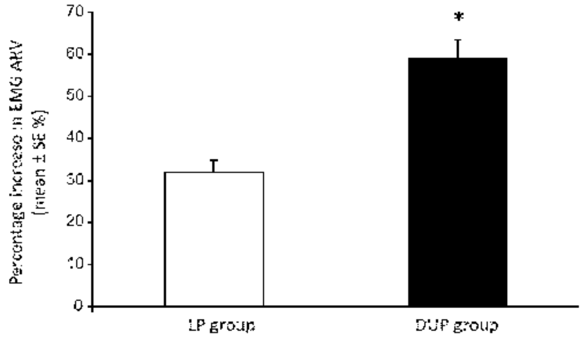

Fig. 3. Percentage increase in in the average rectified value of EMG
(mean ±SE, %, n = 15 subjects) during maximal isometric contraction of quadriceps muscle after 9 weeks' DUP and LP training program

(*) indicates that the percentage increase in ARV for the DUP training group was significantly higher than for the LP group (p < 0.05).

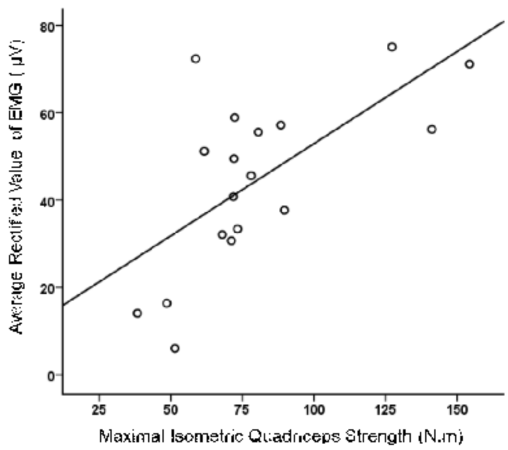

Fig. 4. Scatter plot of the change in the average rectified value of EMG (average for all muscles and training groups) versus change in the maximal isometric muscle (average for all training groups) from pre-training to the post-training condition.

The changes in the maximal isometric force and in ARV were significantly correlated (p < 0.003; r = 0.65). The positive correlation indicates that variation in the maximal force of the quadriceps muscle was partially a result of changes in muscle activation.

DISCUSSION

The results demonstrated that both the DUP and the LP training programs brought a significant increase in muscle strength and neuromuscular activity of the quadriceps, with a higher increase identified for the DUP as compared to the LP training group.

Muscle strength: Like in previous studies, the maximal concentric and isometric quadriceps strength was significantly increased after 9 weeks' LP and DUP resistance training [3, 13], most probably due to the enhanced neural drive and cortical excitability [7, 9]. However, the DUP training group showed a higher increase in 1RM and the maximal isometric force as compared to the LP training group. In agreement with these results, previous studies also showed that the DUP program was more effective than the LP program to increase muscle strength [3, 13, 14], most likely due to more frequent alterations in training intensity.

EMG activity: Accordingly, the EMG amplitude of the quadriceps muscle during the maximal voluntary isometric contraction performed after 9 weeks' LP and DUP resistance training was significantly larger than in the pre-training condition. The increased EMG amplitude observed after strength training can be attributed to the increased motor unit discharge rate and/or motor unit recruitment to produce maximal tension [15, 16]. For example, previous studies have frequently reported that an increase in muscle force following strength training was associated with significant changes in the motor unit discharge rate [17] muscle fiber conduction velocity [18] and the rate of force development [19]. The altered motor unit activity after strength training may be related to both supraspinal and spinal adaptations (e.g., increased central motor drive, elevated motoneuron excitability, and reduced presynaptic inhibition) [7, 8, 9].

DUP vs. LP training program: The main findings of this study showed that manipulating exercise parameters has significant effects on strength gain and neuromuscular activity, which is in agreement with previous studies [20, 21]. In the present research, we found that the DUP training program using a combination of volume (3 sets × 6–8–12 repetitions) and intensity (65%, 75%, and 85% 1RM) resulted in a higher increase in quadriceps strength and EMG activity as compared to the LP training program.

In agreement with our findings, others studies also reported a greater increase in muscle strength after DUP training program. Rhea et al. [3] demonstrated that the DUP training program on a daily basis was more effective in eliciting strength gains than the LP training program with alteration being made approximately every four weeks. Similarly, Prestel et al. [14] showed that undulating periodized strength training induced higher increases in maximal strength than the linear model in strength training men. A study conducted by Miranda et al. [13] demonstrated that periodized resistance training could be an efficient method for increasing the strength and muscular endurance in trained individuals, and the DUP group presented a superior effect size in muscular maximal and submaximal strength when compared to the LP group.

The superiority of the DUP training program in increasing muscle strength of the upper and lower limbs has also been frequently reported in other studies [22, 23] that may be related to the unique characteristics of DUP training-induced adaptation at the level of the neuromuscular junction, spinal cord and/or motor cortex. For instance, in the current study, we found that EMG amplitude rate of increase during maximal isometric contraction of the quadriceps muscle after the DUP training program was significantly larger than that observed after the LP training program. A greater increase in EMG amplitude observed after the DUP training program may indicate that the DUP training program on a daily basis is more effective in eliciting neuromuscular activity than LP training program. A higher EMG amplitude observed after DUP training program may be explained by more frequent alterations in intensity and volume on a daily basis. Since skeletal muscle is frequently exposed to greater muscle tension during the DUP training program, this type of exercise program may be most effective for recruiting fast twitch motor units. Fast twitch motor unit is characterized by a higher firing rate and conduction velocity and is considered to produce a larger EMG amplitude and muscle tension [15, 24]. It has been reported that the recruitment threshold of fast twitch motor unit can be reduced following the high-intensity training program. For example, previous studies reported an increase in motor unit firing rate of the skeletal muscle as a result of frequent exposure to a high-intensity training program [17, 18]. Additionally, more frequent alterations in intensity and volume during the DUP training program may result in a greater cortical excitability [25] and therefore can enhance neural drive from a higher motor center to muscle fibers, which in turn produce larger EMG activity during the maximal voluntary contraction.

CONCLUSIONS

In summary, resistance training using the DUP program is more effective than the LP program to elicit neuromuscular activity and muscle strength, most probably due to more frequent alterations in intensity and volume on daily basis.

TRAINING CONSIDERATION

Manipulating training variables has been commonly used to optimize maximum muscle strength and neuromuscular function of the skeletal muscle, particularly for those sports that require explosive movements. The result of this study showed that resistance training using the DUP program is more effective than the LP program to elicit neuromuscular activity and muscle strength. The knowledge gained from this study may be relevant for designing exercise training to improve neuromuscular function and strength gain.

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