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ORIGINAL ARTICLE

The effect of undulating periodized plyometric training on power, sprint, and agility performance

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ABSTRACT

BACKGROUND: The purpose of this study was to investigate the effect of undulating periodized plyometric training on power, sprint, and agility performance. Forty-eight amateur male soccer and futsal players volunteered.

METHODS: The pretest included the measurement of squat jump height, countermovement jump height, the Wingate anaerobic test, 20 m sprint test, and Illinois agility test. After the pretest, the subjects were randomly assigned into four groups: a) traditional periodization, b) daily undulating periodization, c) weekly undulating periodization, and d) control. The training program consisted of six weeks, three sessions per week. The volume load of the training programs was matched among groups.

RESULTS: Significant improvement was shown with all periodization models in jumping height, Wingate peak power, sprint, and agility performance. Wingate average power was significantly increased with traditional and weekly undulating periodization. There was no significant difference among the periodization models of plyometric training in Wingate average power. The peak and average power from the jump significantly increased with daily undulating and weekly undulating periodization compared to the control group. Furthermore, daily undulating periodization had a significant increase compared to traditional periodization in jumping peak and average power. In addition, no periodization model had significant effects on minimal power and fatigue index.

CONCLUSIONS: Except for the jumping power, there were no significant differences among the periodization models of plyometric training in the measured variables. Total volume load of plyometric training is more important than the variation of training volume and intensity in order to gain explosive functions.

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Plyometric training is a very popular form of physical training in healthy and special patient individuals to improve performance and rehabilitation.[1] This kind of training includes movements that use a stretch-shortening cycle (SSC) such as jumping and throwing medicine balls. In a review article, which was included studies from 1966 to 2009, the results of most research showed improvement in power, muscular strength, sprint, agility, and neuromuscular adaptations. Other studies have reported no improvement or slight improvement of these variables.[1] These discrepancies may be due to a lack of specified periodization in the plyometric training program. In the majority of studies conducted on plyometric training, different periodization patterns are used. Some studies have used the traditional periodization. In this model of periodization, overload principle is applied by an increase in training volume during a training period, while the intensity of sessions remains constant throughout the whole training program.[2, 3] Linear periodization used by some studies,[4, 5] which is characterized by gradual increases in training intensity between microcycles, with simultaneous reductions in training volumes. However, in most of the research, non-periodization or traditional periodization have been used.[6-8]

Periodization is the manipulation and systematic variation of the training process for developing training adaptation and avoiding maladaptation and plateau phases in training responses.[9] There are different models of periodization. Researchers mostly use the traditional or linear periodization and nonlinear or undulating periodization. Linear periodization is mainly used for sports that have one or two training goals, and athletes need one or two peaks in their performance during an annual cycle (such as track and field). Nonlinear periodization was mainly developed for sports with an extended competition season and multiple training goals, in which athletes need to keep close to their peaks for all competitions during a prolonged period (such as soccer and volleyball).[9] There is no convincing evidence showing the superiority of nonlinear periodization over linear periodization. However, some studies that have investigated the effect of periodization models in resistance training have reported more improvement and adaptation in maximum strength [10, 11] and lower body muscular endurance [10] with nonlinear periodization compared to linear periodization. It is possible that the nonlinear periodization of resistance training led to greater neural adaptations due to the constant change in the motor unit recruitment.[11] It seems that nonlinear periodization of resistance training is more appropriate than traditional periodization because it avoids overtraining due to its greater flexibility within microcycles, possible reduction in fatigue, minimization of poor effects on technique and skill acquisition, and possible decrease in the risk of injury.[12]

Since plyometric training is a form of resistance training, it must follow the principles of progressive overload. Typically, as intensity increases, volume decreases.[13] Few studies have investigated the effects of periodization models in plyometric training.[4, 5] Ebben *et al.* (2010) investigated the effects of linear periodized plyometric training on countermovement jump (CMJ) height and jump power and reported a 25% increase in the CMJ height and an 11–14% improvement in the jump power. Plyometric training is mostly used by strength and conditioning coaches in team sports such as soccer, rugby, basketball, and hacky.[14] Strength/power training such as plyometric training is especially used in the in-season phase of training cycles. On the other hand, the aim of using undulating periodization is to develop or maintain high levels of strength/power for the remainder of the pre-season and throughout the in-season weight training program.[15] It seems necessary to design undulating periodization for plyometric training in team sports. To our knowledge, no study has evaluated the effects of the nonlinear or undulating periodization model of plyometric training on physical fitness indices. These indices include anaerobic power, sprinting, and agility. Therefore, the purpose of this study was to investigate the effect of six weeks of plyometric training with different periodization models, including daily undulating (DUP), weekly undulating (WUP), and traditional periodization (TP), on anaerobic power, jumping, sprinting, and agility performances in male athletes.

Materials and methods

Experimental design

To our knowledge, no previous studies have examined the effect of the undulating periodization model in plyometric training. This is the first study that compares the different periodization models such as DUP, WUP, and TP in plyometric training. In this study, equated volume load (sets × repetitions × intensity) used by all training groups. Forty-eight amateur soccer and futsal players voluntarily participated in this research. Dependent variables included jump height, jump power, power from Wingate anaerobic test, 20 m sprint, and agility. In this study a pre-to posttest-randomized design used and subjects were randomly assigned to either a control or a training group. The training groups completed six weeks of periodized plyometric training in addition to their regular soccer and futsal training. In the control group, the subjects continued their routine soccer and futsal conditioning programs. Twenty-four soccer players and 24 futsal players randomly placed in four groups, and all groups were matched according to their physical activity in a week and relative peak power.

Subjects

Forty-eight amateur male soccer and futsal players volunteered. However, only 36 subjects could accomplish this research protocol. The players had a minimum two-year history of continuous training in their sport. None of the players had a history of plyometric training. Resistance training was banned for the duration of the study. All subjects filled out a consent form to participate in the research, which was approved by the Research Ethics Board of Hakim Sabzevari University. Afterwards, height and body mass were measured according to the instructions of the *Anthropometric standardization reference manual.*[16] Anthropometric and descriptive characteristics of the subjects are presented in Table I.

Testing

After the subject's familiarization with testing and training protocols, pretests were performed in three sessions including jumping tests, a Wingate anaerobic test, and sprint and agility tests. At the beginning of each session, a warm-up was performed for 10 minutes. Forty-eight hours after the last training session, a posttest was performed. The tests and tools used for data collection are described below.

Jumping performance

In this study, squat jump (SJ) and CMJ were used for measuring jumping performance. The subjects performed three trials for each jump with 60 seconds rest between trials, and five minute breaks between jumps. In the SJ test, subjects began from the squat position (knee angle 90°) with their hands on their hips and jumped upward as high as possible.[17] CMJ was performed similar to SJ except that these jumps were performed from a standing position with fast downward.[17] The best performance was recorded for further analysis. Jumping height was measured from flight time [18] with an infrared system (Ergo jump, made in Hakim Sabzevari University, Iran). This device has a higher correlation coefficient (r=0.94) with jumping height measured by a motion analysis system (Simi Reality Motion Systems, Germany). The interaclass correlation coefficient (ICC) for this device was 0.97.

Jumping power

Explosive power of leg extensor muscles or peak power was calculated from CMJ with the Johnson and Bahamonde formula.[19] In addition, the average power was calculated from the following formula. The relative power was obtained from dividing the absolute power (W) on weight (kg) and used for analysis.

$$\text{Peak power (W)} = 78.5 \times \text{VJ (cm)} + 60.6 \times \text{mass (kg)} - 15.3 \times \text{height (cm)} - 1308$$

$$\text{Average power (W)} = 41.4 \times \text{VJ (cm)} + 31.2 \times \text{mass (kg)} - 13.9 \times \text{height (cm)} + 431$$

TABLE I.—*Anthropometric and descriptive characteristics of subjects.*

Variables	Groups				*P* value
	DUP (n=9)	WUP (n=9)	TP (n=10)	CON (n=8)	
Height (cm)	173.4 (6.7)	182.8 (5.9)	177.5 (5.7)	173.3 (5.2)	0.30
Weight (kg)	64.6 (8.4)	73.8 (10)	66.8 (9.1)	71.3 (9.7)	0.16
Age (years)	20.2 (2.9)	21.3 (1.9)	21.9 (2.8)	23 (2.2)	0.17
Mean activity per week (hours)	7.1 (0.9)	7.2 (0.9)	7.8 (0.7)	7.1 (1.75)	0.47
Peak power (W)	582.1 (66.1)	655.2 (75.2)	609.8 (99.4)	695 (156.4)	0.13

DUP: daily undulating; WUP: weekly undulating; TP: traditional periodization; CON: control.

Wingate Anaerobic Test

The lactic anaerobic power output was measured by a 30-second Wingate test. At the beginning, subjects performed a 5-minute warm-up by unloaded pedaling on an ergometer cycle. Then, loading was determined by computer based on 0.075 of individual body mass. Participants began pedaling on a Monark ergometer cycle (Model 894E, Varberg, Sweden) with a sign of an examiner. When the rate of revolutions per minute (RPM) reached 120, weight discs were released and a 30-second test was performed. After completing the test, the computer calculated peak, average, and minimum power. A fatigue index (FI) was determined using peak and minimal power as the following formula:[20]

$$FI= [(\text{peak power}- \text{minimal power}) / (\text{peak power})] \times 100$$

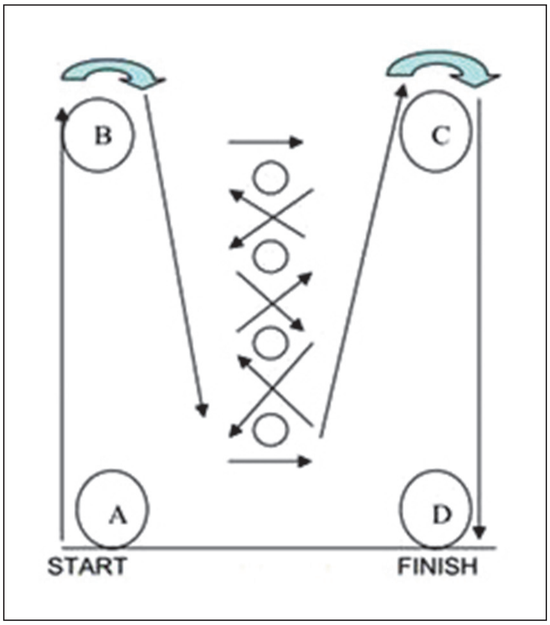

Figure 1.—Illinois Test.

Sprint

The subjects' sprinting ability was measured by 20 m sprint test.[21] After warm-up, subjects began the test from a standing position with examiner command. Then, the subjects accelerated as quickly as possible through the 20 m distance from the starting line. The examiner recorded the time with a stopwatch (Q&Q, Model HS43. Japan). Participants performed this test in three trials, and the best performance was used for statistical analysis. ICC for the times recorded by the examiner was 0.87.

Agility

In the present study, agility was measured by the Illinois test.[3] The test was performed as illustrated in Figure 1. Four cones were placed in the corners of the test area (10 m long x 5 m wide). Cone A marked the start point. Cones B and C were placed at the turning spots. Cone D was placed at the finish point. In addition, four cones were placed in the center of the testing area at 3.3 m apart. The test began with subjects lying face down and with a "go" command.[3] The examiner recorded the time between the start and finish point with a stopwatch. The subjects performed two trials with a 5-minute rest interval, and the best performance was used for data analysis. ICC for the times recorded by the examiner was 0.86.

Training program

A training program was performed for six weeks at three sessions per week. In each session, the subjects had to do a 10-minute standard warm-up and cool-down. The first group used TP. In this model, the training intensity was constant in all sessions, and the principle of progressive overload was applied two weeks once by an increase in training volume (Table II). Participants in the second group used DUP periodization. Intensity and volume of training alternately changed in each session of the week, and the principle of progressive overload was applied two weeks once by an increase in training volume (Table III). Participants in the third group used WUP periodization. Intensity and volume of training alternately changed every week, and the principle of progressive overload was applied three weeks once by an

TABLE II.—*Traditional periodization protocol.*

Exercise	Week (1,2)	Week (3,4)	Week (5,6)	Intensity
Cone hops	2 × 10	2 × 10	3 × 10	Low
Squat jump	2 × 10	2 × 10	2 × 10	Low
Tuck jumps	2 × 7	3 × 7	3 × 7	Moderate
Box jumps	2 × 7	3 × 7	4 × 7	Moderate
Depth jump	1 × 7	2 × 7	2 × 7	High
Single-leg vertical jump	1 × 7	2 × 7	3 × 7	High
Volume load	780	1,248	1,518	Total volume load= 3,546

TABLE III.—*Daily undulating periodization protocol.*

Exercise	Week (1,2)			Week (3,4)			Week (5,6)			Intensity
	S1	S2	S3	S1	S2	S3	S1	S2	S3	
Cone hops	3 × 10	-	-	4 × 10	-	-	5 × 10	-	-	Low
Squat jump	3 × 10	-	-	4 × 10	-	-	5 × 10	-	-	Low
Skipping	3 × 10	1 × 10	-	4 × 10	3 × 10	-	5 × 10	3 × 10	-	Low
Tuck jumps	2 × 10	2 × 10	-	4 × 10	3 × 10	-	5 × 10	3 × 10	-	Moderate
Box jumps	-	2 × 10	-	-	3 × 10	-	-	4 × 10	-	Moderate
Barrier jumps	-	2 × 10	2 × 10	-	3 × 10	3 × 10	-	4 × 10	3 × 7	Moderate
Depth jump	-	-	1 × 10	-	-	2 × 8	-	-	3 × 8	High
Single-leg vertical jump	-	-	1 × 10	-	-	2 × 8	-	-	3 × 8	High
Pike jump	-	-	1 × 10	-	-	2 × 10	-	-	3 × 8	High
Volume load		780			1,252			1,516		Total volume load= 3,548

TABLE IV.—*Weekly undulating periodization protocol.*

Exercise	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Intensity
Cone hops	3 × 10	-	-	4 × 10	-	-	Low
Squat jump	3 × 10	-	-	4 × 10	-	-	Low
Skipping	3 × 10	3 × 10	-	4 × 10	3 × 10	-	Low
Tuck jumps	2 × 10	2 × 10	-	3 × 10	3 × 10	-	Moderate
Box jumps	-	2 × 10	-	-	3 × 10	-	Moderate
Barrier jumps	-	2 × 10	2 × 10	-	3 × 10	3 × 10	Moderate
Depth jump	-	-	1 × 10	-	-	2 × 10	High
Single-leg vertical jump	-	-	2 × 10	-	-	3 × 10	High
Pike jump	-	-	2 × 10	-	-	3 × 10	High
Volume load			1,470			2,070	Total volume load= 3,540

increase in training volume (Table IV). In the training groups, jumps were performed with maximal effort. The heights of barriers, cones, and boxes were selected equal. The rest interval between sets and series was 60 seconds and 2 minutes, respectively.

Volume load equitation

In the plyometric training, volume was calculated based on the total number of sets and repetitions. For lower-body plyometrics, the number of foot contacts or distance covered determined the training volume. Plyometric training intensity is often determined based on the exercise complexity, loading, speed, and the size and height of the boxes or barriers used.[13, 14] In the present study, the intensity of plyometrics was determined from the table mentioned in *ACSM's foundations of strength training and conditioning* book.[14] The volume load of each session was calculated by multiplying the intensity and volume (number of set × number of repetition × intensity).[22] Due to an inverse relationship between intensity and volume, as intensity increases, volume must be reduced.[13, 14] For quantifying the total volume load, we multiplied by low-, moderate-, and high-intensity plyometrics in 1, 2, and 3 coefficients, respectively. By doing so, we applied the inverse relationship that exists between intensity and volume.

Statistical analysis

The normality of data distribution and homogeneity of variance were tested using the Shapiro–Wilk and Levene's tests, respectively. To compare the variables among the four groups, one-way analysis of covariance (ANCOVA) and LSD post hoc tests were used. Within-group changes were analyzed using paired t-test. The significance level in all analyses was set at $p \leq 0.05$. Percent change was calculated as follows: (posttest mean - pretest mean)/(pretest mean) × 100.

Results

The mean and standard deviation of between-group and within-group changes of variables are presented in Table V. The height of SJ and CMJ significantly increased in TP, DUP, and WUP compared with the pretest scores and the control group ($p \leq 0.05$). There was no significant difference among the periodization groups. The DUP and WUP significantly increased the peak and average power of jumping compared with the pretest and the control group ($p < 0.05$). The DUP group also had a significant increase compared to the TP group in peak and average power of jumping ($p < 0.05$).

The WAnT peak power significantly increased in TP, DUP, and WUP compared with the pretest and the control group ($p < 0.05$). There was no significant difference among the periodization groups. The TP and WUP significantly increased the WAnT average power compared with the pretest and the control group ($p < 0.05$). The DUP group only had a significant increase compared to the pretest ($p < 0.05$). No significant differences were found for minimal power and FI.

The TP, DUP, and WUP groups significantly decreased the 20 m sprint time compared with the pretest and the control group ($p < 0.05$). Furthermore, the TP, DUP, and WUP groups

Table V.—*Intragroup and intergroup changes of variables.*

Variables	Test	TP	DUP	WUP	CON
SJ height (cm)	pre	32.1±5.1	29.9±3.7	30±4.2	33±5.4
	post	35.2±3.4 †*	33.4±3.3 †*	33.4±4.5 †*	32.9±5.6
CMJ height (cm)	pre	37.9±6.1	35.9±3.7	35±3.6	38.8±4.9
	post	41.2±5.4 †*	40.7±3.1 †*	39.5±3.9 †*	40.9±4.9 †
Jump peak power (w/kg)	pre	45.3±6.9	43.1±4	44.2±3.5	47.4±5.85
	post	49.4±6.2 †	49.2±3.6 †*‡	49.2±3.2 †*	49.9±5.6 †
Jump average power (w/kg)	pre	24.5±4	23.7±2.5	24.1±1.7	25.8±2.8
	post	26.6±3.7 †	26.9±2.2 †*‡	26.7±1.6 †*	27.1±2.6 †
WAnT peak power (w/kg)	pre	9.1±1.2	9 ±1	8.9±1.4	9.8±1.4
	post	10.1±0.9 †*	9.8±1.1 †*	9.7±0.4 †*	9.5±1.8
WAnT average power (w/kg)	pre	6.8±0.7	6.7±0.5	6.7±0.6	7.1±0.6
	post	7.2±0.5 †*	6.9±0.3*	6.9 ±0.8 †*	6.8±0.8
WAnT minimal power (w/kg)	pre	3.8±0.8	4±0.7	4±0.9	3.5±0.3
	post	4±0.6	3.9±0.5	4.3±0.5	3.6±0.5
Fatigue index (%)	pre	57.4±8.5	54.4±9.6	54.4±12.4	60.6±9
	post	60±7.4	58.2±8.4	54.9±7.4	56.5±13.7
20 m sprint time (s)	pre	3.5±0.1	3.5±0.1	3.5±0.2	3.5±0.1
	post	3.1±0 †*	3.1±0.1 †*	3.1±0.4 †*	3.4±0.2
Agility time (s)	pre	16.6±0.3	16.8±0.6	16.8±0.3	16.7±0.5
	post	16.2±0.5†*	16.5±0.5†*	16.5±0.4 †*	16.8±0.5

DUP = Daily undulating, WUP = Weekly undulating, TP = Traditional periodization, CON= Control
*Significantly different (p≤0.05) from control group.
† Significantly different (p ≤0.05) from pretest.
‡ Significantly different (p≤0.05) from TP group.

significantly decreased the Illinois agility time compared with the pretest scores and the control group ($p < 0.05$). There was no significant difference among the periodization groups in both sprint and agility.

Discussion

The purpose of this study was to investigate the effect of different periodization models in plyometric training, especially undulating periodization, on power, sprint, and agility performances. The results of this study demonstrated that the TP, DUP, and WUP groups significantly improved the SJ and CMJ height, WAnT peak and power, and sprint and agility performance. No significant difference was observed among the periodization models of plyometric training. The DUP and WUP significantly increased the peak and average power of jumping, while the DUP group had also a significant increase in these variables in comparison with the TP group. This study is the first to investigate the effect of undulating periodization in plyometric training. Only two previous studies (Ebben *et al.*, 2010; Petushek *et al.*, 2011) have investigated the effect of periodized plyometric training, particularly linear periodization.[4, 5] Ebben *et al.* (2010) demonstrated that periodized plyometric training produced a 25.0% increase in CMJ height, and jump peak power increased by 11.6–14.3% from pre- to post-training. In the present study, the DUP and WUP groups showed a 13.9% and 12.9% improvement, respectively, in CMJ jump height compared with a 9.2% increase in the TP group. Furthermore, the DUP and WUP groups demonstrated a 14.4% and 11.4% improvement, respectively, in jump peak power in comparison with the TP group (9.5% increase). The reason for the greater improvements in the DUP and WUP groups compared with the TP group may be related to more and stable fluctuations in nonlinear periodization that result in more motor unit recruitment and muscle fiber excitability.[12]

Most traditional and non-periodized programs in previous studies conducted in plyometric training demonstrated increased jump height,[7, 21, 23] jump power,[23-25] sprint,[7, 20] and agility[3, 20, 26] performance. However, a number of previous studies demonstrated no significant increase in jump height, power, sprint, and agility performance. Improvement in these variables similar to previous studies on plyometric training may be related to improvement in neuromuscular adaptations. These adaptations increase the number of motor unit recruitments and firing rate,[1, 24] improvement in motor unit synchronization,[24] inhibition of neuronal protection mechanisms, excitability of motor units and neural activity of agonist muscles,[27] and muscle cross-sectional area and muscle fiber size.[25]

Lack of any improvement in power, jump height, sprint, and agility performance in pervious traditional and non-periodized programs in plyometric training might be related to low volume load in these studies. Particularly, these studies have applied low intensity plyometrics, a lower number of jumps per session, and short training program duration. A lower training load reduces recruitment of motor units and, therefore, causes a lack of neuromuscular adaptation.[28]

The WAnT power had a significant improvement with DUP, WUP, and TP compared with the control group and the pretest scores. There were no significant differences among the periodization models of plyometric training. Furthermore, minimal power and FI did not show significant change in all three periodizations of plyometric training. Pienaar and Coetzee (2013) investigated the effect of four weeks of plyometric training on the WAnT power and showed a significant improvement in peak and average power. Only average power had a significant increase in comparison with the control group. FI did not cause a significant change, which is similar to the results of the present study.[20] According to Pienaar and Coetzee (2013), no significant change in peak power may be related to the short rests between sets in their study. In the present study, a rest interval between sets was 60 seconds, while it was 30 seconds in their study. Therefore, a shorter rest interval may be causes more improvement of power endurance than peak power. Another reason for the lack of improvement in peak and average power in their study may be the short training period (four weeks).

The lack of significant change in jump height, WAnT power, sprint, and agility with different periodizations of plyometric training in the present study may be related to equated volume load among the training groups. On the other hand, according to the results of studies conducted to investigate the effects of linear and nonlinear periodization in resistance training in trained and untrained subjects, it seems that more trained and elite athletes had a better response to nonlinear periodization than beginner and amateur athletes.[11, 22, 29] In addition, the initial weeks of resistance training (approximately eight weeks) and type of periodization (e.g., linear, nonlinear, and nonperiodization) may not be important factors in the strength gain of different individuals (e.g., moderately trained and untrained).[22, 30]

Conclusions

According to our findings, there were no significant differences among periodization models of plyometric training in the variables, except for the jumping power. It seems that the total volume load of training is more important than the variation of training volume and intensity within a periodized program in plyometric training for gaining explosive power. Few studies have examined the effect of periodized plyometric training. More research is guaranteed to verify the effect of training periods of eight weeks and longer in the muscular performance of athletes with different levels of activity.

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