FORCE, VELOCITY, AND POWER ADAPTATIONS IN RESPONSE TO A PERIODIZED PLYOMETRIC TRAINING PROGRAM

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This study assessed kinetic, kinematic and temporal adaptations to the countermovement jump in response to a 6 week periodized plyometric training program. Twenty recreationally active women were randomly assigned to a plyometric training or control group. Testing consisted of 3 maximal countermovement jumps on a force platform prior to and after the six weeks of training. A two-way repeated measures ANOVA was used to assess differences between pre- and post-testing sessions and between groups. Post-test eccentric and concentric velocity, power and jump height were significantly greater ($p < 0.05$) in the training group. Periodized plyometric training is effective for increasing jump height, and augmentations are likely due to enhanced eccentric velocity.

KEY WORDS: ground reaction forces, stretch-shortening cycle, program design

INTRODUCTION: Jumping ability is important for many athletic events. Plyometric training subjects have consistently demonstrated improvements in jumping performance (Markovic, 2007; De Villarreal et al., 2009). However, the specific kinetic, kinematic and temporal characteristics associated with improved jump height remain equivocal.

Jump height has been shown to be correlated with power and velocity (Dowling and Vamos, 1993) and is increased by countermovement jump training (Cormie et al., 2009). Specifically, power and velocity curve analyses have revealed higher values throughout the concentric and eccentric phases, as a result of countermovement jump training (Cormie et al., 2009). To better understand the jump height augmentation of the countermovement jump, the eccentric phase must be investigated.

Studies have shown the influential role of acutely reducing the duration of the amortization phase and increasing the eccentric speed, to increase the subsequent performance (Ham et al., 2007; Moran and Wallace, 2007; Wilson and Flanagan, 2008). More specifically, increased countermovement depth and eccentric velocity have been shown to be a positive adaptation of plyometric training (Cormie et al., 2009). This previous study, however, failed to include women and to implement Matveyev's model of periodization into the training program (Matveyev, 1966).

Therefore the purpose of this study was to explore the kinetic, kinematic, and temporal adaptations in response to a 6 week periodized plyometric training program for women. By quantifying kinetic, kinematic and temporal factors resulting from plyometric training, practitioners will gain insight into how increases in performance are manifested. This information may lead to the manipulation of training methods to enhance jump performance.

METHODS: Twenty subjects were randomly assigned to either a non-training control or a plyometric training group. Ten women served as controls (mean ± SD; age = 19.50 ± 1.18 years; height = 1.63 ± 0.065 m; body mass = 61.70 ± 9.90 kg). Ten women served as training subjects (mean ± SD; age = 19.00 ± 0.82 years; height = 1.68 ± 0.067 m; body mass = 62.72 ± 9.22 kg). All subjects provided informed written consent and the study was approved by the institution review board.

Warm-up prior to the testing and training sessions consisted of three minutes of low intensity cycling on an ergometer followed by dynamic stretching exercises as well as 5 countermovement jumps of increasing intensity. Five minutes of rest were provided prior to beginning the testing and training.

The plyometric training group trained twice per week with 48- to 96- hours recovery between training sessions for 6 weeks. The program was periodized by decreasing volume and increasing intensity based on previous recommendations (Potach and Chu, 2008). Volume was reduced from 100 foot contacts early in the program to 60 foot contacts upon cessation of training. Intensity was based on previous research examining kinetic variables of various plyometric exercises (Jensen and Ebben, 2007). Subjects rested 15 seconds between single jumps and 30 seconds between sets which was based on the previous recommendations of work to rest ratios of at least 1:5(Read and Cisar, 2001; Potach and Chu, 2008).

All training and control group subjects refrained from physical activity during the 6 week training period, as determined by subject activity logs. Subjects participated in one pre- and one post-training testing session consisting of three maximum countermovement jumps with arm swing performed on a force platform (BP6001200, AMTI, Watertown, MA, USA). Vertical ground reaction force (GRF) was sampled at 1000Hz, real time displayed, and saved with the use of computer software (BioAnalysis 3.1; AMTI, Inc.) for later analysis. Velocity was determined by subtracting body weight from the force-time curve, dividing by body mass, and integrating with respect to time using the trapezoidal rule (Dowling and Vamos, 1993). Power was determined by multiplying the GRF without body weight by velocity. The beginning and end of the eccentric phase was identified with methods previously used (Hori et al., 2009). The time in air (TIA) method was used for calculating jump height derived from the force platform (Aragón–Vargas, 2000). Concentric peak force, velocity and peak power were determined as the maximum values obtained during the concentric phase of the countermovement jump. Eccentric peak force was determined as the maximum force during the eccentric phase. Peak eccentric velocity was determined as lowest velocity value during the eccentric phase. Temporal variables such as eccentric and concentric duration were also assessed. These variables have been chosen due to their previously assessed importance to jump performance (Dowling and Vamos, 1993; Cormie et al., 2009).

All data were evaluated with SPSS 17.0 (IBM Corp., Chicago, IL, USA) using a two-way repeated measures ANOVA to assess the interaction and main effects for jump height, eccentric and concentric duration, time to peak force and take off, peak eccentric and concentric force and velocity, and peak power between pre- and post-testing sessions as well as between training and control groups. Significant interactions and main effects were further analyzed using paired-samples *t*-tests to identify specific differences in the outcome and performance variables pre- and post-testing. Assumptions for linearity of statistics were tested and met. Statistical power (*d)* and effect size (η_p^2) are reported. The a priori alpha level was set at $p \leq 0.05$.

RESULTS: Analysis of variance revealed significant interactions for jump height ($p \leq 0.001$, $d = 0.992$, $\eta_p^2 = 0.55$). There were no other significant interactions for the variables assessed ($p > 0.05$). However, results revealed significant main effects for pre- and post- testing: jump height ($p \leq 0.001$, $d = 1.00$, $\eta_p^2 = 0.74$), peak eccentric velocity ($p = 0.006$, $d = 0.85$, $\eta_p^2 = 0.36$), peak concentric velocity ($p = 0.022$, $d = 0.66$, $\eta_p^2 = 0.26$), peak power ($p = 0.005$, $d = 0.85$, $\eta_p^2 = 0.36$) and body mass ($p = 0.023$, $d = 0.65$, $\eta_p^2 = 0.25$). Paired-samples *t*-tests for the training group revealed that all of the aforementioned variables were different from pre-testing values with the exception of body mass ($p \leq 0.05$). Paired-samples *t*-tests for the control group revealed that all post-testing values were not different from pre-testing values ($p > 0.05$). The mean, standard deviation, and percent increase for the outcome and performance variables of the training group are shown in Table 1. Because follow up analyses of the control group variables revealed no significant differences, pre- and post-testing, only training group data are reported.

Table 1. Training group pre- and post-training outcome and performance variables (n=10).

Outcome and performance variables	Pre-training		Post-training		Percent Increase (%)
	Mean (SD)	CV(%)	Mean (SD)	CV(%)	
Jump Height(m)	0.24 (0.04)	16.67	0.29 (0.03)	10.34	20.83*
Ecc Duration(s)	0.62 (0.13)	20.97	0.64 (0.10)	15.63	3.23
Con Duration(s)	0.33 (0.06)	18.18	0.34 (0.06)	17.65	3.03
Time to Pk Force(s)	0.81 (0.18)	22.22	0.83 (0.13)	15.66	2.47
Time to Take Off(s)	0.95 (0.18)	18.95	0.98 (0.13)	13.27	3.16
Pk Ecc Force(N)	502.07 (144.54)	28.79	505.24 (202.36)	40.05	0.63
Pk Con Force(N)	702.04 (147.54)	20.96	731.54 (107.84)	14.74	4.2
Pk Ecc Velocity(m/s)	−0.78 (0.14)	−17.95	−0.99 (0.12)	−12.12	−26.92*
PkConVelocity (m/s)	2.36 (0.19)	8.05	2.50 (0.19)	7.6	5.93*
Pk Power (W)	134.37 (308.70)	22.98	1500.83 (167.37)	11.15	11.72*

Ecc = Eccentric; Con = Concentric; Pk = Peak; *Significant difference ($p \leq 0.05$) between pre-test and post-test

DISCUSSION: Six weeks of periodized plyometric training enhanced peak eccentric and concentric velocity, peak power and jump height by 26.92%, 5.93%, 11.72%, and 20.83%, respectively. Investigation of the eccentric phase adaptations provide insight into the underlying mechanisms responsible for the increased jump height.

Peak eccentric velocity was the only eccentric variable affected by the periodized plyometric training program. Research suggests that acutely decreasing ground contact or eccentric time will lead to greater return of elastic energy and thus enhanced performance (Wilson and Flanagan, 2008). The present study revealed that while eccentric velocity improved, eccentric duration was unaffected by training, but performance was enhanced. Other temporal variables including concentric duration, time to peak force, and time to take off, were also unaffected by plyometric training.

The increase in eccentric velocity augmented the peak concentric velocity and power and consequently, jump height, but not force. Previous research revealed similar increases in eccentric and concentric velocity, power and no change in peak force in response to countermovement jump training (Cormie et al., 2009). Despite similar changes to countermovement jump kinetics and kinematics, jump height was increased by 20.83% in the present study compared to 13.5% in the study using countermovement jump training (Cormie et al., 2009).The present greater increase in peak eccentric velocity and ultimately jump height could have been due to progressing the intensity of the exercises (depth jumps) that result in higher negative velocities compared to the countermovement jump. Thus, other factors such as training status, plyometric exercise type, intensity, and volume likely contributed to the present improvement in jump height.

The 5.0cm increase in jump height for women is higher than the average 2.82cm increase found by meta-analyses (De Villarreal et al., 2009). Training status has been suggested to be a factor in plyometric training adaptations (Markovic, 2007) however, De Villarreal et al., suggested that plyometric training gains seem to be independent of fitness level (De Villarreal et al., 2009).

The type of plyometric exercises incorporated into a program ultimately dictates the exercise intensity (Jensen and Ebben, 2007; Potach and Chu, 2008). Thus, plyometric exercise type can be manipulated to follow the periodization model. In fact, the periodized program used in the present study progressed from low intensity exercises such as line and cone hops to depth jumps and bounding movements, which have been shown to be of high intensity (Jensen and Ebben, 2007). Furthermore, the magnitudes of the changes in jump height from the periodized program are unique considering the short duration of the training program.

The present study demonstrated that a 6 week program periodized from 100 to 60 foot contacts per session was sufficient for jump height adaptations, compared to previous recommendations for programs to be longer than 10 weeks consisting of 50 foot contacts per session (De Villarreal et al., 2009). Tapering or reducing the volume towards the end of the training program likely decreased fatigue, which influenced the significant improvement in jump height over few weeks (Matveyev, 1966).

It is noted that performing follow up analyses without a significant interaction may increase Type I error, however, previous research suggests that jumping performance is influenced by many kinetic, kinematic, and temporal variables, thus finding significant differences in individual predictor variables might be problematic (Dowling and Vamos, 1993).

Analysis of the eccentric phase and velocity of the countermovement jump provided insight into the manifestations of jump height increases in response to training. Additionally, the manipulation of program design variables and implementation of Matvyev's model of periodization influenced the eccentric and concentric phases and jump height during the countermovement jump.

CONCLUSION: Eccentric velocity was enhanced by 26.92% through periodized plyometric training which influenced the increases in concentric phase velocity, power and ultimately jump height by 5.93%, 11.72%, and 20.83%, respectively. This study highlights the importance of implementing periodization in plyometric program design by increasing intensity based on previous recommendations and decreasing volume by reducing the foot contacts over time.

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