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The Influence of Plyometric Training Volume Varied by Exercise Sets on Lower-Body Explosive Power

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Abstract Training volume and the number of sets for developing lower body explosive power are important considerations for plyometric training. The purpose of this study was to compare training volume differing in number of sets in a 8-week program on field-based measures of lower-body explosive power. We hypothesized plyometric training would enhance lower body explosive power in a dose-dependent manner in which a 4-set program would result in greater power improvements than a 2-set program. Seventy-two recreational exercisers were randomly assigned to one of 3 groups: 2-set, 4-set or non-plyometric control. Controls exercised *ad libitum* with the exception of any plyometric exercise. Training by experimental groups included weighted static jumps (SJ) and countermovement jumps (CMJ) using heavy and light loads, under a supervised and periodized program for 3 d/wk over 8 wks. Heavy loads were ramped up by 10% of one-repetition maximum (1RM) each week starting from 60% of 1RM, followed by a light load of 30% of 1RM for 8 repetitions for the first 4 wks of training. During the last 4 wks, the heavy loads were ramped down by 10% of 1RM each week starting from 90% of 1RM. The executed repetitions for the heavy loads for each week and each work-out day were periodized from 4 to 50 repetitions. Lower-body power was measured before and after using a commercial-available contact mat that recorded the ground reaction forces. The dependent variables were vertical jump height (H) and power (PW) of SJ and CMJ. One-way analyses of variance with paired post-hoc analysis on mean post-pre differences were employed to determine significant effects ($p < 0.05$). Improvement in SJ-H ($p = 0.0099$), SJ-PW ($p = 0.0208$), CMJ-H ($p = 0.0037$), CMJ-PW ($p = 0.0037$) were all greater in 4-set group when compared to 2-set and control groups. The 2-set group did not differ from the control in any of the dependent variables. Plyometric training does not always improve explosive power. A periodized resistance plyometric program varied by exercise sets demonstrated that a greater training volume is necessary for developing lower-body explosive power. An effective way to increase plyometric training is to increase the number of sets.

Keywords Complex resistance training, Athletic power development, Training volume, Plyometric exercise

1. Introduction

Development of lower-body explosive power is important for virtually every sport [1-5]. Effective plyometric training can lead to rapid improvements in explosive power [1, 6, 7]. When done incorrectly, fatigue, may lead to incorrect technique, unnecessary exposure to injury overreaching and overtraining [6, 8-11]. Establishing a training volume for explosive power development is a complex task and the best approach is often debated among strength and conditioning coaches [3, 8, 12], for both short [13] -and long-term power improvements [14].

Training volume can be altered in a number of ways: varying reps in a set, resistance in rep, number of sets, and frequency of training [8, 15-18]. Several investigators have examined the number of sets for resistance training to develop strength [10, 14, 19, 20]. Set number has also been studied with plyometric training for developing power [1, 21]. However, training volume varied by set number has not been investigated for resistance-loaded plyometric training in novice athletes.

The purpose of this study was to determine the effects of resistance plyometric training programs of 2 or 4 sets on lower-body jumping power among adults engaged in competitive team or individual sports. We chose training and testing activities commonly used to develop lower-body power in athletes [1, 3, 11, 22]. Our objective was to better understand the dose-response relationship between resistance plyometric training and power-related outcomes that might help coaches to develop prudent and effective plyometric training programs for improving lower-body explosive power. We hypothesized plyometric training would enhance lower body explosive power in a dose-dependent manner in which a 4-set program would result in greater power improvements than a 2-set program.

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2. Study Overview

Volunteers were recruited to participate in an 8–week program in order to test plyometric training volume, adjusted by exercise sets, on the development of lower-body explosive power. Plyometric training consisted of either 2 or 4 sets of static jump (SJ) and countermovement jump (CMJ) at a frequency of 3 sessions per week. Explosive power was measured by jump height (H) and power (PW), as determined from ground reaction forces, using in both types of jumps. All plyometric training and testing was conducted at the Olympic Aqua Center and the Sport and Exercise Science Lab in Rethymnon, Crete, Greece.

2.1. Participants

This study was limited to healthy male members of the Olympic Aqua Gym Centre between 18 and 40 years of age. Participants were recruited by flyers and word of mouth.

Participants had previous resistance training experience and were working out on a regular basis; however, these individuals did not have previous formal plyometric training experience nor where these individuals currently undergoing any training specifically designed to develop power in the lower body. Participants were asked to refrain from independent training to improve lower-body explosive power until they had completed the study. After providing volunteers with a thorough explanation of the procedures and risks, all volunteers read and signed a consent form that was approved by Sheffield Hallam University Ethics Board and was consistent with the guidelines set forth in the Declaration of Helsinki.

2.2. Preliminary Procedures

Participants completed a physical activity readiness medical examination questionnaire (PARmed-X) [23] and underwent a medical evaluation by a registered physician in order to screen for physical conditions that would preclude safe participation in this study.

Before the initiation of the study, participants were asked to complete two instructional training sessions, to teach them proper and safe techniques, to determine one-repetition maximum (1RM) and those who failed to perform an 1RM value of squat at least 1.5 times their body mass were excluded from the study. Training of SJ and CMJ was completed using an Olympic-sized bar with Olympic free weights on a fixed vertical plane and a power rack Smith machine (Life Fitness, UK LTD, Queen Adelaide, Ely, Cambs). The Smith-machine restricts the participant's movement in the vertical plane; thereby, securing a balanced movement and increased safety.

On the first day, training techniques were explained and demonstrated. Participants practiced the plyometric maneuvers for the SJ and CMJ and demonstrated that they could perform each correctly. Baseline measurements were obtained during the second session, which occurred at least 24hrs after the first session.

Prior to the baseline measurements, participants were required to complete a 5-min warm-up of cycling on a stationary bicycle (Life Fitness, UK LTD, Queen Adelaide, Ely, Cambs) at 100 Watts and 60 to 80 rpm followed by light static and dynamic lower-body stretching exercises.

The SJ and CMJ were selected as the most direct assessment of lower body explosive power. Both jumps were executed according to guidelines set forth by the National Strength and Conditioning Association and the American College of Sports Medicine position stands [8, 9, 24, 25].

The beginning position for the SJ began with the knees flexed at 90° without prior counter movement. Technique was checked to ensure that thighs were parallel with the ground and feet were placed shoulder-width apart with arms positioned at the level of the waist. Participants were asked to jump vertically without any preparatory movement as explosively as they could to reach their maximum height and land in the squat initial position.

The CMJ began with participants in a comfortable upright stance with feet shoulder-width apart and arms positioned at the level of the waist. Participants were asked to begin their jump with a preparatory countermovement to a knee flexion of 90° followed by an upward explosive vertical jump in order to reach their maximum height and land in the initial upright stance.

All testing factors were standardized for each individual and controlled as closely as possible for time of day, length of time between last activity period, warm-up and identical body position. Vertical SJ height (SJ-H), CMJ height (CMJ-H), SJ lower-body power (SJ-PW) and CMJ (CMJ-PW) were assessed using the Newtest Powertimer® (Newtest, Oy, Oulu, Finland) apparatus contact mat. The contact mat consists of a piezo-electric mat and a timer. By timing take-off and landing, the apparatus computes the flight time and height, estimates power using body weight and flight time. Jump height for both SJ and CMJ was calculated based on Sayers *et al*. [26] equation where:

$$\text{Jump height (cm): } = 9.81 \text{ x Flight time}^2/8$$

Power for both SJ and CMJ was also calculated based on Sayers *et al*. [26] where:

$$\text{Power (W)} = 60.7 \cdot \text{jump height (cm)} + 45.3 \cdot \text{body mass (kg)} - 2055$$

Participants performed a 1RM squat test to determine lower-body strength and to calculate the relative 1RM loads used for exercise training. Post-testing occurred using the same protocols and procedures after at least 2 days of rest following completion of the 8-wk intervention.

2.3. Training

Participants in the control group were free to continue resistance and cardiorespiratory exercise activities during the 8-week period with the exception that they had to avoid performing any structured plyometric exercises. Participants in both experimental groups trained 3 days per week, on

Monday, Wednesday and Friday, while the weekends were designated as rest days. These daily changes (on-days, off-days) were designed to provide frequent changes in neural stimulation, while allowing sufficient time for recovery and the prevention of detraining effects [7, 8, 19, 22, 27]. Participants in both experimental groups were prohibited from performing other strength and power development exercises for the lower body during the span of the 8-wk study.

Training sessions took place either in groups or individually depending on time factors and personal needs. All training sessions were supervised, carefully timed and executed.

Each session was preceded by a warm-up similar to the previously described for baseline measurement testing. This was followed by a specific squat warm-up consisting of an 80% half squat of 1RM and 5 repetitions. Participants were instructed to perform all jumps at a maximal effort and to exaggerate the knee flexion during the landing phase so as to maximize the eccentric component imposed to the knee extensors [8, 13, 27, 28]. Participants were regularly encouraged to perform each set as rapidly as possible, without compromising proper technique.

All the exercises were individualized based on the baseline 1RM squat. The SJ and then a CMJ were performed with less weight to promote high-velocity contractions and with more weight to promote low-velocity contractions. The exercise type, exercise intensity, rest periods, speed of movement, training sessions per week, compliance and attendance, where controlled through the periodized training program (table 1).

In order to facilitate a standardized cool-down, all sessions ended with 10 minutes of cycling on a stationary bicycle at 100 Watts and 60-80 rpm and 15 minutes of light stretching exercises of the lower body and relaxation [2, 7, 9, 10, 27, 28]. All sessions lasted ~ 20 minutes for the 2S group and ~ 45 minutes for the 4S group.

2.4. Statistical Analysis

An *a priori* power analysis was performed, to determine the appropriate sample size using average of two samples. The following information was used: $\alpha = 0.05$, power (β) = 0.7. The anticipated effect size (ES) was based on data obtained from a previous study by Kotzamanidis *et al.* [4], in which a significant change of 1.99 ± 2.9 cm in squat jump height was recorded with plyometric training. The sample size was calculated to be 23 per group for one-tailed testing.

The independent variable was group affiliation (i.e., control, 2-set, 4- set). The dependent variables were changes in SJ-H, CMJ-H, SJ-PW, and CMJ-PW that occurred in 8-week of resistance plyometric training.

Distributions of all dependent variables were checked for the assumption of normality using the Kolmogorov-Smirnov and Shapiro-Wilks tests. No significant departures from normality were found.

Mean changes were computed by subtracting baseline measures from post-training for body mass index (BMI) and all dependent variables. Homogeneity of variances between groups for change variables was established via Levene's Test. Differences between the 2 -sets, the 4 - sets and the control group were analyzed using multiple 1 X 3 analysis of variance (ANOVA). Tukey post-hoc analyses were performed when global significance was determined. A comparison-wise alpha level was set at 0.05.

In order to be able to determine the magnitude of our treatment effects in strength training and to compare our results with the literature, ES was calculated as the difference between pre-and post-training means divided by pre-training standard deviations [29, 30].

$$ES = [(\text{Mean } 2 - \text{Mean } 1)/ SD]$$

All statistical analyses were performed by JMP ® software (JMP, Version 9.0.0. SAS Institute Inc., Cary, NC, 1989-2013).

Table 1. Plyometric Training Program

Week	1	2	3	4	5	6	7	8
1^{st}-3^{rd} set				1RM % load				
	60	70	80	90	90	80	70	60
				Repetitions				
Monday	15	15	12	12	8	12	15	8
Wednesday	12	12	10	10	6	10	12	6
Friday	10	10	8	8	4	8	10	4
2^{nd}-4^{th} set				1RM % load				
	30	30	30	30	30	30	30	30
				Repetitions				
Monday	8	8	8	8	8	8	8	8
Wednesday	8	8	8	8	8	8	8	8
Friday	8	8	8	8	8	8	8	8

Periodized training program for experimental groups. Rest intervals were standardized to 5 min.

3. Results

Our cohort included 72 participants who were randomly assigned to one of three groups: 2-set group, 4-set group, and non-plyometric control group (C). No significant differences were observed for body weight and BMI. Descriptive characteristics are presented in Table 2.

Improvements in SJ-H ($p = 0.0099$), CMJ-H ($p = 0.0037$), SJ-PW ($p = 0.0208$), and CMJ-PW ($p = 0.0037$) were significantly greater in the 4-set group versus the 2-set and control groups. Changes in the 2-set group did not differ from the control group for any of the dependent variables. This pattern was similar for SJ-H, CMJ-H, SJ-PW and CMJ-PW normalized for body weight [e.g., (post-training variable/post-training body weight) – (pre-training variable/ pre-training body weight)].

Small to moderate effect sizes (0.14 to 0.24) were determined for the 4-set group. Effect sizes are reported in Table 4.

Table 2. Physical Characteristics Before and After 8 Weeks of Exercise

	Before			**After 8 weeks**		
	C (n=23)	2-set (n=24)	4-set (n=25)	C (n=23)	2-set (n=24)	4-set (n=25)
Age (yr)	28.7 (4.7)	24.4 (5.9)	30.7 (5.3)			
Height (cm)	180.8 (8.0)	176.7 (6.6)	180.2 (7.9)			
Weight (kg)	93.7 (16.4)	75.0 (9.4)	94.2 (11.8)	93.7 (15.7)	74.9 (9.4)	94.3 (12.2)
BMI (kg/m^2)	28.6 (4.2)	24.2 (2.6)	25.8 (3.1)	28.4 (4.4)	24.3 (2.6)	25.8 (3.2)

All values are means ± (SD). No significant change occurred in any group over 8-weeks

Table 3. Performance Changes with Plyometric Training

	C (n=23)	**2-set (n=24)**	**4-set (n=25)**	**Sig.p - value**
Δ-SJ-H (cm)	-0.6 (1.9)	-1.0 (4.4)	1.5* (1.9)	0.009
nΔ-SJ-H	-0.01 (0.02)	-0.01 (0.03)	0.02* (0.02)	0.019
Δ-CMJ-H (cm)	-0.4 (2.8)	-2.0 (4.4)	1.2* (1.8)	0.004
nΔ-CMJ-H	-0.01 (0.04)	-0.03 (0.05)	0.01* (0.02)	0.015
Δ-SJ-PW (Watt)	-33.7 (149.0)	-67 (160.4)	90.4* (182.2)	0.021
nΔ-SJ-PW	-0.39 (1.36)	-0.89 (1.42)	0.92* (1.47)	0.030
Δ-CMJ-PW (Watt)	-23.5 (169.1)	-126.9 (163.6)	71.7* (145.2)	0.004
nΔ-CMJ-PW	-0.32 (1.42)	-1.65 (1.44)	0.74* (1.19)	0.007
Δ-Weight (kg)	0.1 (2.0)	-0.1 (0.9)	0.0 (2.8)	0.969
Δ-BMI (kg/m^2)	-0.3 (1.5)	0.1 (0.8)	0.0 (0.7)	0.431

Δ = post – pre-training. nΔ = post - pre-training difference normalized for body weight. All values are means ± (SD). * = significant difference from 2-set group ($p < 0.05$ for all)

Table 4. Effect Sizes

	2-set		**4-set**	
	(n=24)	**95% CI**	**(n=25)**	**95% CI**
Effect Size SJ-H (cm)	-0.16	[0.03,-0.06]	0.24	[0.07,0.02]
Effect size CMJ-H (cm)	-0.29	[0.00,-0.08]	0.17	[0.06,0.01]
Effect size SJ-PW (Watt)	-0.12	[0.01,-0.04]	0.17	[0.04, 0]
Effect size CMJ-PW (Watt)	-0.20	[0, -0.05]	0.14	[0.03, 0]

ES = [(Mean 2 – Mean 1) / SD] at 95% CI = Confidence Intervals [29, 30]

4. Discussion

The purpose of this study was to compare the effects of training volume, adjusted by the number of exercise sets, on development of lower-body explosive power. The 4-set group exhibited significant improvements in jump height and power performance for both static and CMJs. These data indicate that, among healthy adults, lower-body power is increased with higher plyometric volume [20]. Our results do not directly support a dose-response relationship, with greater doses producing greater responses (presumably up to a certain point), since the 2-set group did not produce any difference above control.

The 2-set group did not differ significantly from the control group. Therefore, it would appear that a plyometric training volume, at least greater than what was introduced in the 2-set group, is needed to observe results that exceed those that can be obtained through regular participation in physical activity or a program not specifically addressing improvement of power in the lower extremities. In fact, based on the small effect sizes for our 4-set group, an even greater plyometric volume is likely necessary for further development of explosive power. Our present findings, including modest effect sizes, suggest that the volume achieved with 4 sets of plyometric training may represent a threshold for inducing noticeable improvements in lower body explosive power, although we do not have evidence to directly validate such a claim. Indeed, according to Rhea's proposed scale for determining the magnitude of effects sizes in strength training research [30], the effect of our 4-set intervention is classified as trivial for developing lower-body explosive power (table 4.)

Markovic [6], in his meta-analysis, reports ES from 26 studies conducted from 1966-2006 that examined whether plyometric training improves vertical jump height. The majority of this research pertained to non-athletes and the intervention time varied from 4 to 24 weeks. The reported ES ranged between -0.4 and 2.8 for vertical jump height. In another meta-analysis authored by de Villarreal *et al.* [11] plyometric training elicited an average ES of 0.84 for the plyometric training group and an average increase of 3.9 cm in vertical jump height. We observed an average increase 1.4 cm in vertical jumping ability and ES between -0.29 and 0.24. Our results appear to be in agreement with Markovic [6] but somewhat less effective than results analyzed by de Villarreal *et al.* [11].

de Villarreal *et al.* [11], in their meta-analytic report an ES = 0.54 and 3.2 cm increase in SJ and an ES=0.54 and 2.91 cm increase in CMJ. They state that plyometric training seems to be effective for improving the vertical jump height (7% increase), but there are no differences in ESs among different combinations of plyometric training among programs with and without added resistance. However, plyometric training variables (e.g. training program design, program duration training volume and intensity) and characteristics of the groups being studied (e.g. age, training level, familiarity with the plyometric training) are widely-thought to influenced the development of explosive power [11]. The relative short duration of the plyometric training and the novice-to-advanced level of adult athletes may have led to smaller ESs compared to those reported in the related literature [11].

Ramirez – Campillo *et al*. [15] examined the effects of different volumes and training surfaces during 7 weeks of plyometric training on performance enhancement and in maximal strength in actions requiring fast SSC actions, suggested that high training volume leads to significant increase compared to moderate volume [15]. Marshall *et al.* [21], examined the effects of 6-weeks of squat exercise at 80% of 1RM using one, four or eight sets of repetitions twice per week. Their results support resistance prescription in excess of 4-sets for faster and greater strength gains as compared to 1-set training.

Some have proposed that plyometric exercises that utilize resistances from 60 to 90% of 1RM are too challenging and risky and therefore a pre-conditioning level must exist prior to any engagement in plyometric training. First, we screened our participants for their ability to squat with a 1RM that equals around 1.5 times their body weight as a safety barrier. Next, we applied a progressive non-linear periodized resistance plyometric stimulus on a Smith-machine for enhancing lower-body explosive power. The intervention addressed coaches' time constraints, the availability of equipment [8] and injury risk, as no training-related injuries were reported.

Weight control (as reflected in the BMI) was also examined in the present study but showed no differences between groups. Stable BMI measurements in all groups suggests that the gains in strength and power performance observed in the 4-set group were solely due to intermuscular and intramuscular and factors and not due to changes in body mass.

4.1. Study Limitations

It is important to underscore that the participants in the control group were not sedentary but rather regularly active exercisers. Therefore, the effectiveness of the 2-set and 4-set group was not evaluated against a no-exercise standard but rather against a physical activity that did not incorporate a stretch shorten cycle component.

Our results cannot be extrapolated to untrained – or to highly trained athletes individuals because differential outcomes between trained and untrained have been reported when studying the effects of the same exercise program [10, 19, 20]. Our protocol would be suitable for resistance exercisers or local league athletes who aim to increase their lower-body power due to large heterogeneity of our sample.

Another limitation is the relatively short duration of our training intervention. A training volume of more than 10 weeks, with more than 20 sessions, with more than 50 jumps per session is thought to be necessary for improving explosive power in the lower body performance [11]. Although we demonstrated modest improvements in lower body power with a program of similar volume but less duration, perhaps a longer duration with either the 2-set or 4-set interventions would have resulted in greater achievement. We implemented a program in which we maintained the same number of sets but we alternated the relative resistances in a pyramid design [11, 17, 22]. Alternative approaches that can address dose-response relationships by utilizing intensity, repetitions and/or duration would be useful for understanding the application of resistance plyometric training [10, 11].

The results of the study are limited by the characteristics of the assessments of lower body explosive power. We utilized a commercially-available power mat to estimate explosive power. These mats are easier to use in an applied setting when compared to kinematic equipment used in biomechanical laboratories; however, the mats are less reliable than kinematic cameras and digitizing equipment. We incorporated commonly-used assessments of lower body explosive power (e.g., SJ and CMJ). However, it is widely-recognized that these field-based tests may not directly translate to sports-specific explosive power or improved athletic performance.

5. Conclusions

5.1. Practical Applications – Importance of Findings

Lower-body power development is an important factor for many athletic maneuvers [22]. The present results supports the evidence regarding the efficacy of plyometric programs composed of larger number of sets [12, 17, 18, 22]. Of course, several training strategies can be used to enhance lower body power performance [11], but the findings of this study suggesting that 4 sets, for 8 weeks and 3 times per week are enough for modest improvements in jumping performance. This can serve as a guide to coaches when they are planning their training schedules for adult athletes.

5.2. Directions for Future Research

Our results apply to a resistance plyometric program. We do not know if a light plyometric program without an external resistance application, consisting only of weight-bearing jumps will elicit the similar results. The depth of squatting for CMJ training is not well-defined. Whether or not a lower or higher adjustment will produce similar results has not been determined. Alternative approaches that can address the relationships between sets, repetitions, intensity (resistance), and frequency will help us to understand the efficacy of plyometric training beyond our knowledge of training volume thresholds. Characterizing the influence of these training variables in elite athletes is, likewise, of obvious interest.

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