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# LOW AND MODERATE PLYOMETRIC TRAINING FREQUENCY PRODUCES GREATER JUMPING AND SPRINTING GAINS COMPARED WITH HIGH FREQUENCY

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## ABSTRACT

The purpose of this study was to examine the effect of 3 different plyometric training frequencies (e.g., 1 day per week, 2 days per week, 4 days per week) associated with 3 different plyometric training volumes on maximal strength, vertical jump performance, and sprinting ability. Forty-two students were randomly assigned to 1 of 4 groups: control ( $n = 10$ , 7 sessions of drop jump (DJ) training, 1 day per week, 420 DJs), 14 sessions of DJ training ( $n = 12$ , 2 days per week, 840 DJs), and 28 sessions of DJ training ( $n = 9$ , 4 days per week, 1680 DJs). The training protocols included DJ from 3 different heights 20, 40, and 60 cm. Maximal strength (1 repetition maximum [1RM] and maximal isometric strength), vertical height in counter-movement jumps and DJs, and 20-m sprint time tests were carried out before and after 7 weeks of plyometric training. No significant differences were observed among the groups in pre-training in any of the variables tested. No significant changes were observed in the control group in any of the variables tested at any point. Short-term plyometric training using moderate training frequency and volume of jumps (2 days per week, 840 jumps) produces similar enhancements in jumping performance, but greater training efficiency (~12% and 0.014% per jump) compared with high jumping (4 days per week, 1680 jumps) training frequency (~18% and 0.011% per jump). In addition, similar enhancements in 20-m-sprint time, jumping contact times and maximal strength were observed in both a moderate and low number of training sessions per week compared with high training frequencies, despite the fact that the average number of jumps accomplished in 7S (420 jumps) and 14S (840 jumps) was 25 and 50% of that performed in 28S (1680 jumps). These observations may have considerable

practical relevance for the optimal design of plyometric training programs for athletes, given that a moderate volume is more efficient than a higher plyometric training volume.

**KEY WORDS** optimal volume, plyometric, drop jump, maximal force, velocity, training efficiency

## INTRODUCTION

Vertical jumping constitutes an integral component of explosive performance in several athletic activities. Plyometric training has been advocated as an appropriate approach for sports that require explosiveness and vertical jumping ability enhancement. Coaches and researchers attempt to identify the proper handling of program variables in plyometric training, including the intensity, frequency, and volume of exercise to achieve high levels of jump performance. For increased improvement in vertical jump, it is believed that it is necessary to systematically increase the stress-related overload placed on the body during plyometric training. One of the ways to do this is increase training volume because it has been proposed that the effect of the work performed partially depends on the total number of repetitions or jumps. There are several ways to program the volume of the treatment. Some studies use different numbers of sessions per week (i.e., 1–5 sessions per week) (6,24), whereas others combine the total number of training sessions (i.e., between 6 and 10 sessions (5), between 15 and 20 sessions (25,30), or >25 sessions (7)). Various jumping training volumes (i.e., 400–650 jumps (1,39), 650–900 jumps (8), 900–1150 jumps (33), or 1150–1700 jumps (32,34)) have also shown improvements in jumping performance (e.g., countermovement jump (CMJ), drop jump (DJ), long jump). Previous strength training studies (9,10) concluded that junior experienced lifters respond with a greater improvement in performance with a moderate training volume and a moderate volume of high relative training intensity compared with low and high volumes of training. Unfortunately, the optimal jumping training volume stimulus for the development of jumping and sprinting ability and the

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effectiveness of stimuli within the training process have not been satisfactorily resolved.

Decreased strength and explosive (i.e., jumping ability) performance (7–12%) have been demonstrated after short periods (4–12 weeks) of training cessation (11–14). On the contrary, other studies have shown that previously untrained or recreationally trained athletes can maintain or experience only a slightly decrease in their neuromuscular performance during short periods (i.e., 2–3 weeks) of training cessation (18,23,28). Kraemer et al. (23) observed that recreationally trained men can maintain jump performance during short periods of no training (6 weeks). Recently, Andersen et al. (2) reported that 3 weeks of resistance training cessation led to increased velocity and power of maximal unloaded limb movement in previously untrained subjects, but isokinetic maximal strength reverted to pretraining levels. However, to the best of the authors' knowledge, little is known about the impact of short-term training cessation (7 weeks) after a periodized plyometric training program in active physical education students.

In the present study, we hypothesized that a higher training frequency (i.e., number of sessions per week) with a higher level of plyometric training volume and controlling other variables such as jumping technique (type of jump) and training intensity (height of jump) could advance the knowledge of the effects of different jumping training volumes on the performance of athletes. It is critical, therefore, for a well-prepared athlete and practice coach to know training volume manipulation strategies to enhance optimal training adaptability and avoid overtraining. In view of these considerations, the purpose of this study was to examine the effect of 3 different plyometric training frequencies (e.g., 1 day per week, 2 days per week, 4 days per week) associated with 3 different plyometric training volumes on maximal strength, vertical jump performance, and sprinting ability. A secondary purpose was to examine the impact of 7 weeks of no training after 7 weeks plyometric training on maximal and explosive strength performance.

**METHODS**

**Experimental Approach to the Problem**

This study was designed to address the question of how 3 different plyometric training frequencies and volumes affect

vertical jump and sprint gains, and maximal dynamic and isometric force, as well as the impact of 7 weeks of cessation of training after a 7-week plyometric training program. To do this, we compared the effects of 7 weeks of plyometric treatment in 4 groups of subjects with a different total number of plyometric training sessions. Some initial tests were executed before the plyometric treatment started. The initial tests were completed in 3 days (Monday, Wednesday, Friday) as part of a regular testing program. After the initial measurements, subjects were randomly assigned to 1 of 4 groups: control ( $n = 10$ , 7 sessions of DJ training, 1 session per week, a total of 420 DJs), 14 sessions of DJ training ( $n = 12$ , 2 sessions per week, 840 DJs), and 28 sessions of DJ training ( $n = 9$ , 4 sessions per week, 1680 DJs). The control group did not train. Before the initiation of the training periods, the subjects in all the groups were instructed about the proper execution of all the exercises to be done during the training period for all training regimens. The training protocols only included only DJ from 3 different heights (20, 40, and 60 cm). None of the subjects had performed plyometric exercises before. All training sessions were supervised. Every subject in the experimental groups performed the plyometric exercises at 10:00 am. The subjects were instructed to avoid any strenuous physical activity during the duration of the experiment and to maintain their dietary habits for the whole duration of the study.

**Subjects**

This study involved a group of 42 active physical education students between the ages of 21 and 26 with no plyometric training experience (Table 1). None of the subjects had any background in regular strength training or competitive sports that involved any kind of jumping exercises during the treatment.

Exclusion criteria included subjects with potential medical problems or a history of ankle, knee, or back pathology in the 3 months preceding the study; subjects with medical or orthopedic problems that compromised their participation or performance in this study or any lower extremity reconstructive surgery in the past 2 years or unresolved musculoskeletal disorders; and subjects who were taking and had previously taken anabolic steroids, growth hormone, or related performance-enhancement drugs of any kind. However, individuals were not eliminated if they had been taking vitamins,

**TABLE 1.** Initial characteristics of the experimental groups (mean  $\pm$  SD).

Group	Age (years)	Height (cm)	Body mass (kg)	Body fat (%)
Control ( $n = 10$ )	23.6 $\pm$ 2.7	180.3 $\pm$ 3.6	78.56 $\pm$ 6.2	9.45 $\pm$ 3.7
7 sessions ( $n = 10$ )	22.4 $\pm$ 1.1	174.7 $\pm$ 7.2	75.60 $\pm$ 5.4	8.64 $\pm$ 3.8
14 sessions ( $n = 12$ )	23.1 $\pm$ 3.1	176.6 $\pm$ 4.9	80.10 $\pm$ 9.1	8.88 $\pm$ 3.5
28 sessions ( $n = 10$ )	21.8 $\pm$ 1.3	175.5 $\pm$ 4.4	72.68 $\pm$ 7.4	9.68 $\pm$ 2.8

minerals, or related natural supplements (other than creatine monohydrate). All subjects were carefully informed about the experiment procedures and about the possible risk and benefits associated with participation in the study and signed an informed consent document before any of the tests were performed. The study was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee of the responsible department. This study was performed between October and December.

#### **Anthropometric Characteristics and Testing Procedures**

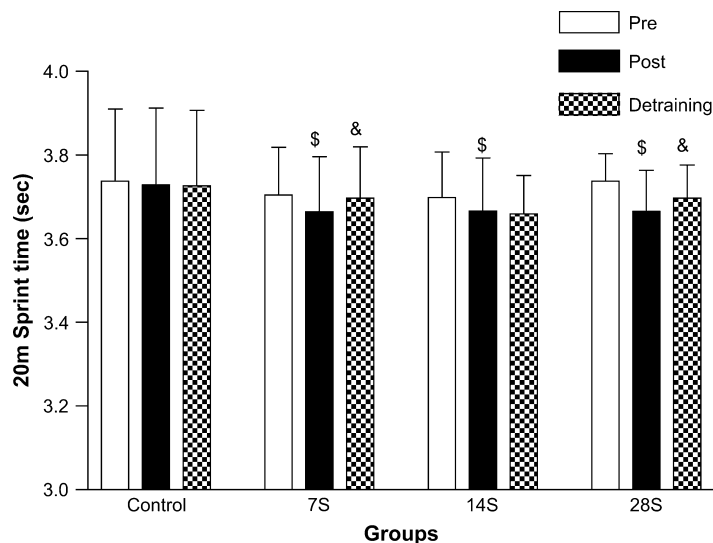
Height was measured using a wall-mounted stadiometer (Seca 222, Terre Haute, IN) recorded to the nearest centimeter. Body mass was measured to the nearest 0.1 kg using a medical scale. The percentage of body fat was estimated using the skinfold method of Pollock et al. (21). The subjects were carefully familiarized with the test procedure of voluntary force and power production during several sub-maximal and maximal actions a few days before the measurements were taken, and the tests were also done previously for control training purposes. The subjects also completed several explosive type actions to become familiar with the action required to move different loads rapidly and with the jump technique. In addition, several warm-up muscle actions were recorded prior to the actual maximal and explosive test actions. All tests to determine the force, power, and velocity values were carried out before, after, and following 7 weeks of rest of the 7 weeks of plyometric treatment. The performance tests were completed in 3 days. On day 1, the following tests were completed: measurement of height, body mass, and percentage of body fat, CMJ for vertical distance (in centimeters), and DJ (from 20, 40, and 60 cm) vertical. On day 2, the isometric maximal strength test and the 1RM test were completed. On the last day, performance testing was carried out for 20-m distances. The 20-m sprint test was regularly done to assess the acceleration phase of the sprint for the 100-m sprinter. Additionally, care was taken to allow sufficient rest between all tests to limit the effects of fatigue in subsequent tests.

*Countermovement Jump.* A CMJ was used in order to maximize stretch-shortening cycle activity and to assess explosive strength of the lower extremity muscles. The CMJ test was performed using an electronic contact mat system (Globus Tester, Codogne, Italy). Jump height was determined using an acknowledged flight-time calculation (4). During the CMJ, the subject was instructed to rest his hands on his hips while performing a downward movement followed by a maximal effort vertical jump. All subjects were instructed to land in an upright position and to bend the knees following landing. Three trials were completed, and the best performance trial was used for the subsequent statistical analysis.

*Drop Jump.* The subjects performed a DJ from a 20-, 40-, and 60-cm high platform, using an electronic contact mat system

(Globus Tester; Globus Italia, Codogne, Italy). Jump height was determined using an acknowledged flight-time calculation (4). The subjects were instructed to place their hands on their hips and step off the platform with the leading leg straight to avoid any initial upward propulsion ensuring a drop height of 20, 40, and 60 cm. They were instructed to jump for maximal height and minimal contact time. The subjects were again instructed to leave the platform with knees and ankles fully extended and to land in a similarly extended position to ensure the validity of the test. Four basic techniques were stressed: (i) correct posture (i.e., spine erect, shoulders back) and body alignment (e.g., chest over knees) throughout the jump; (ii) jumping straight up with no excessive side-to-side or forward-backward movement; (iii) soft landing including toe-to-toe heel rocking and bent knees; and (iv) instant recoil preparation for the next jump. Phrases such as “on your toes,” “straight as a stick,” “light as a feather,” “shock absorber,” and “recoil like a spring” were used as verbal and visualization cues during the DJs. The instructions given to the subjects were (a) “jump as high as you can” and (b) “jump high a little faster (shorter ground contact time) than your previous jump.” The first instruction was intended to maximize jumping height regardless of the ground contact time. The second instruction was intended to maximize jumping height with limited ground contact time. Three repetitions were executed from each height with 10–15 seconds of rest between trials. Three trials were completed, and the best performance trial was used for the subsequent statistical analysis. The intraclass correlation coefficient (ICC) was 0.97 (0.96–0.98) for 20-cm DJs, 0.93 (0.90–0.94) for 40-cm DJs, and 0.90 (0.88–0.92) for 60-cm DJs.

*Maximal Dynamic Strength (1 RM).* A bilateral leg press test was selected to provide data on maximal dynamic strength through the full range of motion of the muscles involved. Maximal strength of the lower extremity muscles was assessed using concentric 1RM leg press action. Bilateral leg press tests were completed using standard leg press equipment (Gervas Sport, Madrid, Spain), with the subjects assuming a sitting position (about 120° flexion at the hips, 80° flexion at the knees, and 10° dorsiflexion) and the weight sliding obliquely at 45°. A manual goniometer (Q-TEC Electronic Co. Ltd., Gyeonggi-do, Korea) was used at the knee to standardize the range of motion. On command, the subjects performed a concentric leg extension (as fast as possible) starting from the flexed position (85°) to reach the full extension of 180° against the resistance determined by the weight. Warm-up consisted of a set of 10 repetitions at loads of 40–60% of the perceived maximum. Thereafter, 5–6 separate single attempts were performed until the subject was unable to extend the legs to the required position (19). The last acceptable extension with highest possible load was determined as 1RM. The rest period between the actions was always 2 minutes.

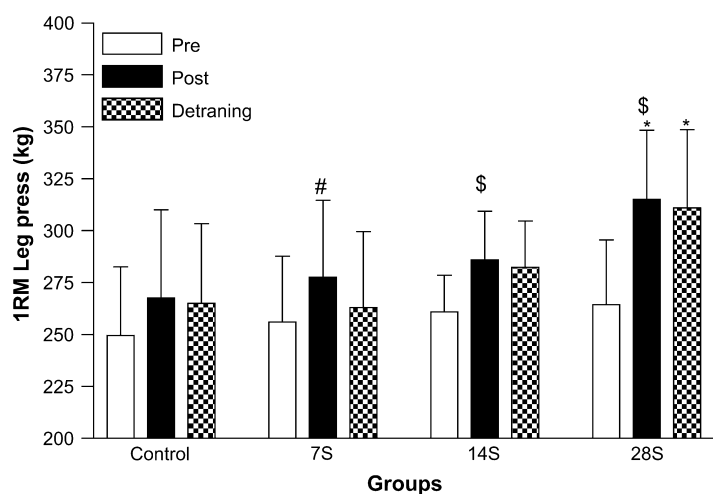


**Figure 1.** The 20-m sprint time performance for the 7-, 14-, and 28-session and control groups at pre-training, post-training, and after 7 weeks of detraining. \$ Significant difference from the corresponding pretraining value ( $p < 0.05$ ). & Significant difference from the corresponding posttraining value ( $p < 0.05$ ).

**Maximal Isometric Strength.** Isometric maximal strength of the lower extremity muscles were assessed using standard leg press equipment (Gervas Sport), with the subjects assuming a sitting position (about 110–112° flexion at the knees [full extension = 0°]). A manual goniometer (Q-TEC, was used at the knee to standardize range of motion. Warm-up consisted of a set of 10 repetitions at loads of 40–60% of the perceived

maximum. On command, the subjects forcefully exerted their maximal isometric knee extension force against the platform. The subjects were instructed to exert their maximal force as fast as possible during a period of 5 seconds. A dynamometer (Globus Tester) was used to determine the peak force. Torque signals were converted from analog to digital at a sampling rate of 100 Hz (Cambridge Electronic Design, Cambridge, UK) and analyzed by computer (Packard Bell, London, UK). The rest period between each maximal contraction was always 3 minutes. Three trials were completed, and the best performance trial was used for the subsequent statistical analysis.

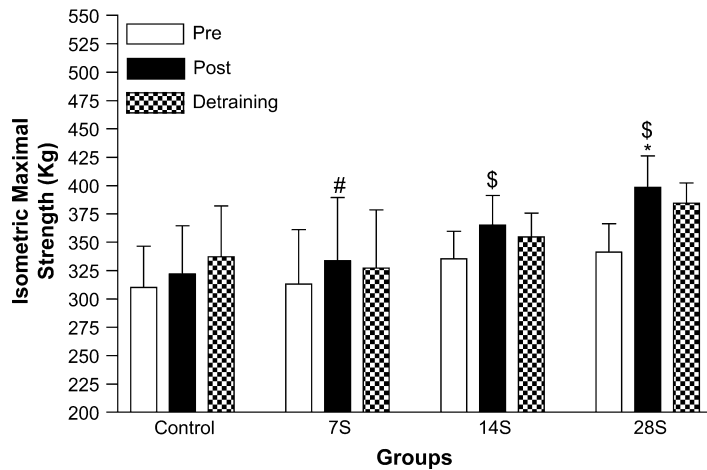
**20-m Sprint Time.** Sprint times were recorded for 20-m distances. The 20-m sprint test was conducted indoors on a synthetic running surface. For all sprint tests, the subject started using a crouch start and commenced sprinting with a random sonorous sound. Infrared beams were positioned at the sprint distance to be measured with photoelectric cell (DSD-Sport SPEED 2.2, León, Spain). Subjects were given 2 practice trials performed at half speed after a thorough warm-up to familiarize themselves with the timing device. Three trials were completed, and the best performance trial was used for the subsequent statistical analysis. Three minutes of rest were permitted between 20-m trials. Times were reported to the nearest 0.01 second.



**Figure 2.** Maximal strength (1 repetition maximum) concentric leg press (in kilograms) performance for the 7-, 14-, and 28-session and control groups at pre-training, post-training, and after 7 weeks of detraining. \* Significant difference from the control group ( $p < 0.05$ ). # Significant difference with 28-session group ( $p < 0.05$ ). \$ Significant difference from the corresponding pretraining value ( $p < 0.05$ ).

**Treatment**

The plyometric training took place 1 day per week for the first experimental group (7S), 2 days per week for the second experimental group (14S), and 4 days per week for the third experimental group (28S) during 7 weeks of treatment. Each session lasted 30 minutes and consisted of the following components: 10 minutes of standard warm-up (5 minutes submaximal running at



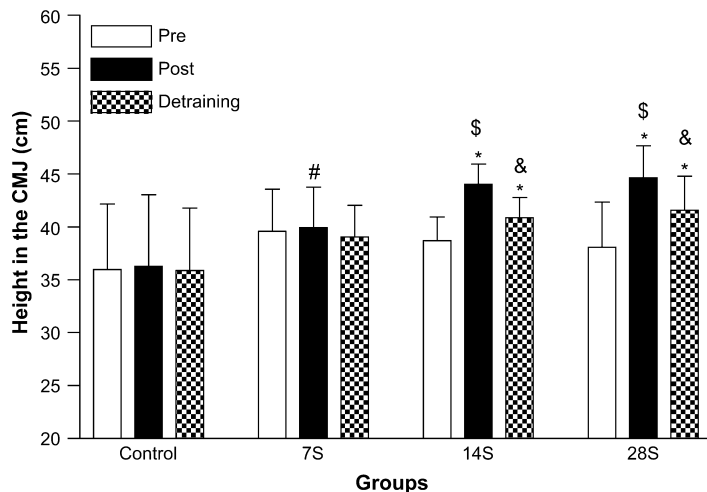
**Figure 3.** Isometric maximal strength performance for the 7-, 14-, and 28-session and control groups at pre-training, post-training, and after 7 weeks of detraining. \* Significant difference with the control group ( $p < 0.05$ ). # Significant difference with the 28-session group ( $p < 0.05$ ). \$ Significant difference from the corresponding pretraining value ( $p < 0.05$ ).

9 km·h<sup>-1</sup> and several displacements, stretching exercises for 5 minutes, and 2 submaximal exercises of jump (20 vertical jumps, 10 long jumps), 15 minutes of plyometric work, and 5 minutes of stretching exercises. The plyometric exercises consisted only of DJs, with a total of 60 DJs per session (2 series of 10 jumps from a box of 20 cm, 2 series of 10 jumps from a box of 40 cm, and 2 series of 10 jumps from a box of 60 cm).

time. These instructions were intended to maximize jumping height with limited ground contact time.

#### Statistical Analyses

Descriptive statistics (mean  $\pm$  SD) for the different variables were calculated. The training-related effects were assessed using a 2-way analysis of variance with repeated measures (groups  $\times$  times). When a significant  $F$  value was achieved, Scheffé post hoc procedures were performed to locate the pairwise differences between the means. The  $\alpha$  level was set at  $p \leq 0.05$ .



**Figure 4.** Height in the countermovement jump (CMJ) (in centimeters) performance for the 7-, 14-, and 28-session and control groups at pre-training, post-training, and after 7 weeks of detraining. \* Significant difference with the control group ( $p < 0.05$ ). # Significant difference with the 28-session group ( $p < 0.05$ ). \$ Significant difference from the corresponding pretraining value ( $p < 0.05$ ). & Significant difference from the corresponding posttraining value ( $p < 0.05$ ).

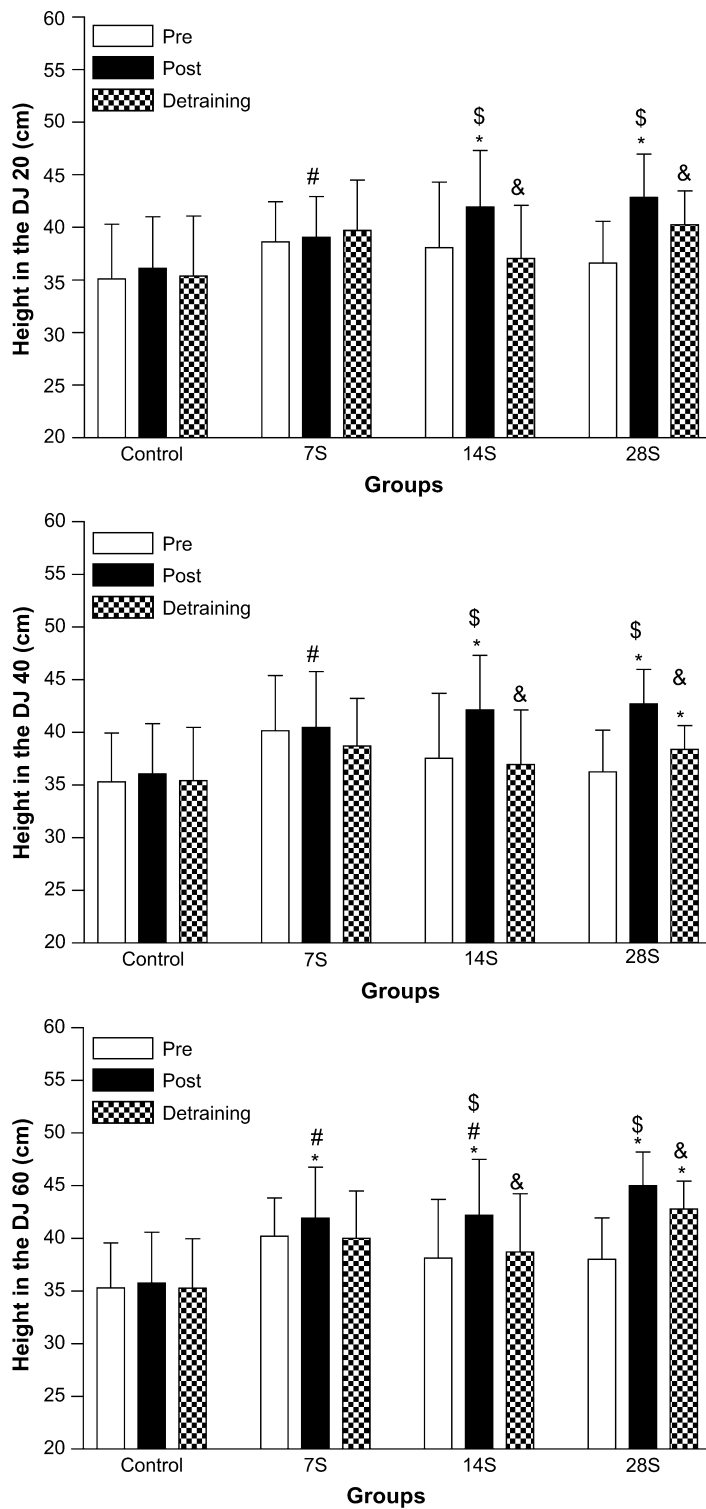
The rest period between each series was 1 minute. The total number of DJs for each experimental group was as follows: 7S (420 DJs), 14S (840 DJs), and 28S (1680 DJs). No training was performed by the control group. This group carried out the same testing protocols as the other groups. The training was performed on an athletic mat of 3 cm. This is a very important aspect in plyometric training due to its high harm index. The subjects were instructed to place their hands on the hips and step off the platform with the leading leg straight to avoid any initial upward propulsion ensuring a drop height of 20, 40, and 60 cm. They were instructed to jump for maximal height and minimal contact

#### RESULTS

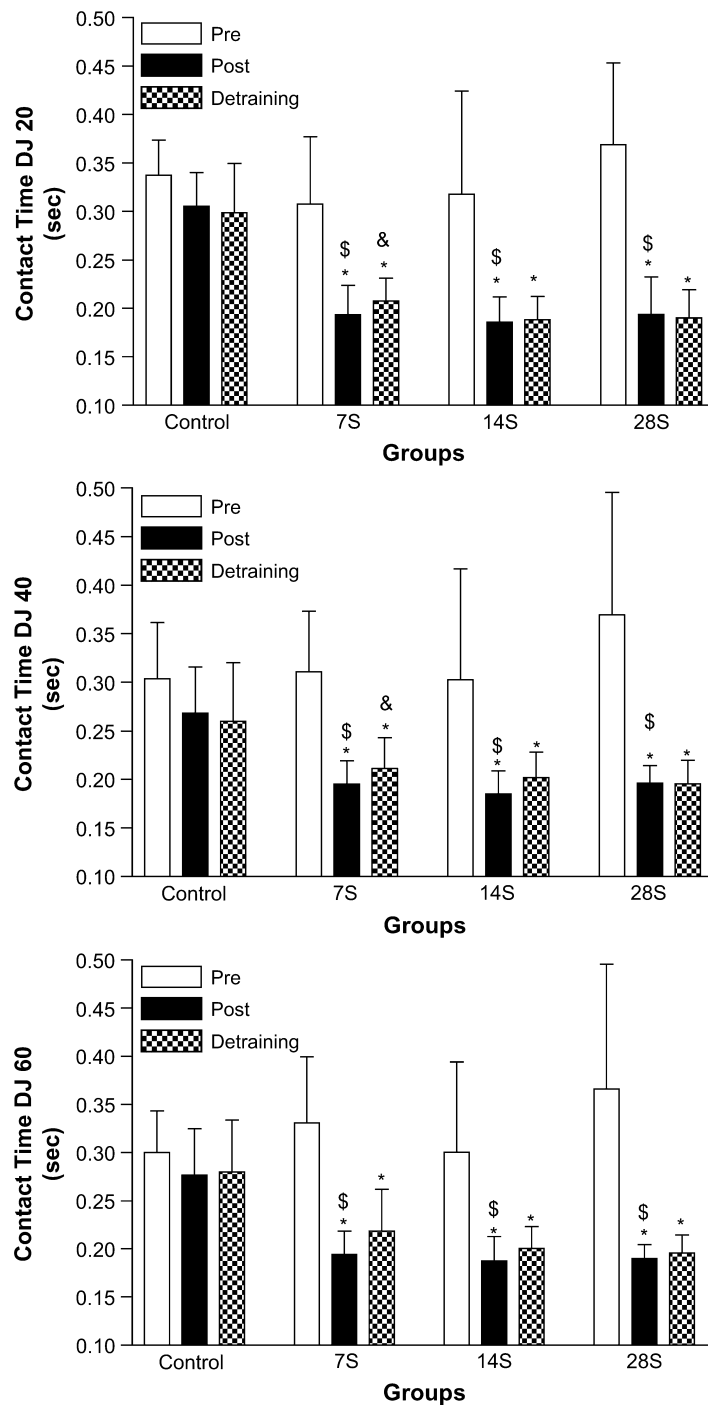
At the beginning of the training program, no significant differences were observed among the groups in the pretraining 20-m sprint time, maximal dynamic and isometric strength, and height in CMJs and in 20-cm DJs, 40-cm DJs, and 60-cm DJs. Moreover, no significant changes were observed in the control group in any of the variables tested in any point.

#### 20-m Sprint Time

During the 7 weeks of training, statistically significant decreases ( $p < 0.05$ ) occurred in



**Figure 5.** Height in the 20-cm drop jump (DJ) (A), 40-cm DJ (B), and 60-cm DJ (C) performance for the 7-, 14-, and 28-session and control groups at pre-training, post-training, and after 7 weeks of detraining. \* Significant difference with the control group ( $p < 0.05$ ). # Significant difference with the 28-session group ( $p < 0.05$ ). \$ Significant difference from the corresponding pretraining value ( $p < 0.05$ ). & Significantly difference from the corresponding posttraining value ( $p < 0.05$ ).



**Figure 6.** Contact time in the 20-cm drop jump (DJ) (A), 40-cm DJ (B), and 60-cm DJ (C) for the 7-, 14-, and 28-session and control groups at pre-training, post-training, and after 7 weeks of detraining. \* Significant difference with the control group ( $p < 0.05$ ). # Significant difference with the 28-session group ( $p < 0.05$ ). \$ Significant difference from the corresponding pretraining value ( $p < 0.05$ ). & Significant difference from the corresponding posttraining value ( $p < 0.05$ ).

20-m sprint time in all experimental groups (1.92, 1.07, and 0.89% in 28S, 14S, and 7S, respectively). No significant differences were observed after training in the magnitude of the changes among all treatment groups. During the

experimental period, the average training efficiency in 7S (0.002% per jump) was higher than that for the 14S group (0.001% per jump) and 28S group (0.001% per jump) in 20-m sprint time (Figure 1).

### Maximal Isometric and Dynamic Strength

Maximal 1RM leg press and isometric strength significantly increased ( $p < 0.05$ ) in the 28S and 14S groups, whereas no significant changes were observed in the 7S group. No significant differences were observed in the magnitude of the increase in 1 RM leg press and maximal isometric strength at 7 weeks between the 28S group (19.11 and 13.81%, respectively) and the 14S group (10.23 and 8.39%, respectively). Significant differences ( $p < 0.05$ ) were observed in the magnitude of the increase between the 28S and 7S groups (8.9 and 6.9%, respectively). During the experimental period, average training efficiency in 7S (0.0199% and 0.0155% per jump, in 1 RM leg press and maximal isometric strength, respectively) was higher than in the 14S group (0.0121% and 0.0099% per jump) and 28S group (0.0113% and 0.0082% per jump) (Figures 2 and 3).

### Height in CMJ and Drop Jump

During the 7 weeks of plyometric training, statistically significant ( $p < 0.05$ ) increases were observed in height in CMJ and 20-, 40-, and 60-cm DJs in the 28S and 14S groups, but no significant changes were observed in the 7S group. No significant differences were observed in the magnitude of the increase in height in CMJs and 20-, 40-, and 60-cm DJs at 7 weeks between 28S (17.48, 16.93, 18.78, and 18.44%, respectively) and 14S (11.09, 10.10, 12.25, and 10.72%, respectively). Significant differences ( $p < 0.05$ ) were observed in the magnitude of the increase between 28S (17.48, 16.93, 18.78, and 18.44%, respectively) and 7S (0.88, 2.22, 3.31, and 3.39%, respectively). During the experimental period, average training efficiency in 14S (0.0132, 0.012, 0.0145, and 0.0127% per jump in height in CMJs and 20-, 40-, and 60-cm DJs, respectively) was higher than that for the 28S group (0.0104, 0.01, 0.0111, and 0.0109% per jump in CMJs, 20-, 40-, and 60-cm DJs, respectively) (Figures 4 and 5).

### Contact Time

During the 7 weeks of plyometric training, statistically significant ( $p < 0.05$ ) decreases were observed in the contact time in 20-, 40-, and 60-cm DJs in all experimental groups. No significant differences were observed in the magnitude of changes in contact time in 20-, 40-, and 60-cm DJs between 28S (-43.86, -40.64, and -40.94%, respectively), 14S (-36.27, -31.39, and -32.24%, respectively) and 7S (-33.91, -35.87, and -39.55%, respectively) during the 7-week plyometric treatment period. During the experimental period, average training efficiency in 7S (0.08, 0.085, and 0.094% per jump and in contact time of 20-, 40-, and 60-cm DJs, respectively) was higher than that for the 14S group (0.043, 0.037, and 0.038% per jump, respectively) and the 28S group (0.026, 0.024, and 0.024% per jump, respectively) (Figure 6).

### Detraining

After the 7-week detraining period, significant increases ( $p < 0.05$ ) were observed in 20-m sprint time in 28S (0.89%) and in

7S (0.89%) (Figure 1), whereas 1RM leg press and maximal isometric strength remained unchanged in all treatment groups (Figures 2 and 3). After detraining, no significant differences were observed in the magnitude of height decrease in CMJs and 20-, 40-, and 60-cm DJs in 28S (-5.54, -5.32, -9.28, and -10.24%, respectively), and 14S (-7.57, -6.93, -5.24, and -8.28%, respectively) (Figures 4 and 5). Significant decreases were only observed in 7S in the contact time measured in 20-, 40-, and 60-cm DJs (18.44, 20.33, and 26.33%, respectively) after 7 weeks of detraining (Figure 6).

### DISCUSSION

A novel approach in this study was to examine the effect of 3 different plyometric training frequencies associated with 3 different plyometric training volumes over 7 weeks (e.g., 1 day per week, 420 DJs; 2 days per week, 840 DJs; 4 days per week, 1680 DJs) to maximize jumping ability, maximal concentric and isometric strength, and 20-m sprint time. The primary finding of this investigation indicates that short-term plyometric training using moderate training frequency and volume of jumps (2 days per week, 840 jumps) produces similar enhancements in jumping performance, but greater training efficiency compared with high jumping (4 days per week, 1680 jumps) training frequency. In addition, similar enhancements in 20-m sprint time, jumping contact times, and maximal strength were observed performing both a moderate and low number of training sessions per week compared with high training frequencies, despite the fact that the average numbers of jumps performed in 7S (420 jumps) and 14S (840 jumps) were 25% and 50% of that performed in 28S (1680 jumps). Conceptually, the present data would indicate that increasing the number of jumps in previously moderately trained men does not appear to be the best stimulus for improving vertical jump performance during short-term training periods compared with high volumes of jumping training. In addition, 7 weeks of detraining following a 7-week plyometric training program resulted in similar decreases in 20-m sprint velocity and jumping performance in all treatment groups, whereas no further changes were observed in maximal strength. These data indicate that cessation of training may induce a greater effect on muscle power performance (20-m sprint time and jumping performance) output than on maximal strength, regardless of the prior training volume performed.

Several studies have suggested that plyometric training may enhance sprint ability because the use of stretch-shortening cycles during DJ and CMJ performance has been shown to have a significant relationship to 30- and 40-m sprint time (15,29). In agreement with other studies, the present results also showed improved sprint ability after short-term plyometric training. Over a 12-week period of non-depth jump plyometric exercises, 25-m sprint significantly improved (9%) in a group of entry-level competitive collegiate athletes (27). Similarly, a 6-week plyometric training program consisting of 4–5 horizontal and vertical plyometric drills

significantly decreased 50-m sprint time by 1.5 and 2.1% in a group of 9 athletic adult males and a group of basketball players, respectively (37). In contrast, the performance of unloaded horizontal and vertical plyometric training resulted in no significant change in 20-m sprint time in physical education students (16) or in 30-m sprint time in previously strength trained subjects (39).

To the authors' knowledge, a limited number of studies have attempted to isolate the effects of increasing number of jumps on neuromuscular performance. The magnitude of decreases in 20-m sprint time was the same in the present study for all treatment groups, despite the higher average number of jumps (up to 50%) accomplished in 14S and 28S than in 7S and that training efficiency was 1 time greater in 7S than in 14S and 28S. The results of the present study suggest that in previously active physical education students increased jumping training volume (i.e., number of sessions per week) does not produce any additional jumping performance enhancement during short-term plyometric training. Similar to previous studies (9,10), this indicates that training with high levels of demand (e.g., great jumping volume) does not appear to be a critical stimulus for 20-m sprint time enhancement and that plyometric training can be effective for sprint enhancement without performing a large number of jumps. The only minor changes observed in sprint performance gains observed in all the groups could be due to the lack of specificity in the training. It is possible that a training program that incorporates greater horizontal acceleration (i.e., skipping, jumps with horizontal displacement) or combined with strength/power training would result in the most beneficial effects.

An interesting finding in the present study was that all treatment groups increased after plyometric training maximal strength (isometric and 1RM leg press). This agrees with the results previously described that plyometric training, in the form of dynamic DJs, has been reported to enhance an individual's ability to rapidly develop force and allows for greater improvements in the maximal rate of force development (5,22). Performing DJs involves the rapid development of maximal force during the eccentric phase of motion. It has been previously reported that the body experiences tremendous impact forces during foot contact with ground in vigorous locomotion. Maximal vertical ground reaction force values as high as 14.4 times body weight (BW) have been reported (31) for single-leg landing from a double back somersault. Stacoff et al. (35) showed that the first peak of the vertical component of ground reaction forces ranged from 1000 to 2000 N, whereas the second peak values ranged from 1000 to 6500 N in landing after a volleyball block jump. McNitt-Gray (26) demonstrated that the maximal vertical ground reaction forces for training gymnastics were 3.9, 6.3, and 11 times BW for landing from heights of 32, 72, and 128 cm, respectively. Horita et al. (17) reported values of 3628 N, demonstrated that the maximal vertical ground reaction forces were 4.7 times BW for landing

from heights of 50 cm. Vitasalo et al. (36) also reported vertical reaction forces of 4.7 and 5.8 times the BW landing from a height of 40–80 cm. Thus, one may speculate that the muscle force stimulus experienced by previously physically active or moderately trained individuals during plyometric training can be effective for maximal strength development.

The magnitude of increases in vertical jump was the same for both 14S and 28S training groups, despite the fact that the average number of jumps accomplished in 14S (840 jumps) was 50% of that performed in the 28S (1680 jumps), and training efficiency was slightly greater in the 14S than in 28S. This agrees with the results of previous studies (9,10) that junior experienced lifters respond with a greater improvement in performance with a moderate training volume and a moderate volume of relatively high training intensity compared with low and high volumes of training. These results also suggest that there is a minimal training volume threshold after which further increases in volume are no longer advantageous. Furthermore, these results do not support the notion of "the more, the better" because previously physically active subjects in the context of a short-term plyometric training cycle of 7 weeks can only optimize jumping performance training by 50% or by a high volume jumping program (e.g., 28 sessions of plyometric training (1680 DJs) performed 4 sessions per week during a 7-week training period).

Similar enhancement in jumping contact time was observed performing both a low number of jumps compared with moderate and high training volumes, but the 7S group (low volume) obtained a greater training efficiency, despite the fact that they performed fewer jumps. The results showed a decrease of more than 40% (between 165 and 175 milliseconds from 368.67 to 193.89 milliseconds). Decrease in contact time during DJs seem to indicate an improvement in stretch-shortening contraction performance, likely to be determined by the utilization of potential energy stored in the series elastic component during muscular lengthening, and higher moments, power output, and leg stiffness values are produced (3). Bosco et al. (4) demonstrated that myoelectric potentiation, presumably originating from stretch reflexes, could also play an important role in the enhancement of contact time during a DJ. Walsh et al. (38) determined that the maximal vertical force values increased with a decrease in contact time and concluded that the maximal power output is produced with a contact time interval between 160 and 170 milliseconds. The results of the present study indicate that a low number of jumps could be sufficient to improve jumping technique and contact time values.

The underlying mechanisms responsible for the attenuated performances observed when relative plyometric training frequency and volume were further increased (28S training program) are unknown but could be related to a complex state of overreaching or overtraining (9,10). However, whether such different responses when plyometric training volume and frequency are altered are mediated by biochemical and

neuroendocrine mechanisms is beyond the scope of the present data.

These findings should be interpreted within the context of the study and the population examined (moderately trained subjects). Whether altering several training variables (e.g., increasing the number of training sessions per week or distributing the high-intensity plyometric training in several daily sessions using longer term resistance training programs or resuming over the next cycle) and/or improving recovery methods elicit similar adaptations in the present population warrants further investigation. In addition, it is possible that more experienced subjects or less trained subjects may have a different response pattern to changes in training frequency and volume. In addition, it is possible that genetically gifted trained subjects (i.e., sprinters and jumpers) can tolerate greater relative training volumes and obtain further increases in performance. More studies are required to optimize jumping and sprinting ability and the effectiveness of stimuli within the training process in both experienced and elite athletes.

A limited number of studies have examined the impact of short-term (7 weeks) detraining after a plyometric training period on maximal strength and explosive performances (e.g., jumping and sprint time). A major finding of the present study was that detraining resulted in a greater decrease in muscle power output (e.g., vertical jump) (5–10%) than in maximal strength (1–5%). In contrast, other studies have shown that previously untrained or recreationally trained athletes can maintain or experience only a slightly decrease in their neuromuscular performance during short periods (i.e., 3–6 weeks) of training cessation (18,23,28). The discrepancy between the present study and previous studies may be related to the impact from the power training history (20,23). Thus, explosive gains after a short-term plyometric training period appear to be lost at a greater rate than strength after detraining. To what extent preferential decreases in muscle power occur during the early phase of detraining (i.e., 3 weeks) may be related to preferential atrophy of type II muscle fibers (18) or with reductions in neural drive (2) remains to be elucidated.

### PRACTICAL APPLICATIONS

Although the optimal amount of jump for a plyometric treatment program continues to remain speculative, the results of the present study suggest that short-term plyometric training using a moderate volume of jumps (840 jumps) produce similar enhancements in jumping performance, but greater training efficiency compared with training using a high volume of jumps (1680 jumps). In addition, similar enhancements in 20-m sprint time, jumping contact times, and maximal strength were observed by performing both a moderate and low number of jumps compared with high training volumes. In addition, 7 weeks of detraining following a 7-week plyometric training program may induce a greater effect on muscle power performance (20-m sprint time and

jumping performance) output than on maximal strength, independently of the previous training volume performed. These results do not support the notion of “the more, the better” because previously physically active subjects in the context of a short-term plyometric training cycle of 7 weeks can optimize jumping performance training to only 50% or less of the volume performed with high training frequency and volume of jumps (i.e., 28 sessions of plyometric training [1680 jumps]). By doing so, one could obtain similar explosive jumping enhancement with a smaller risk of muscular and articulation overload. We suggest that in the context of moderately trained subjects, these observations may have important practical relevance for the optimal design of plyometric training programs for athletes, given that a moderate volume is more efficient than performing a higher plyometric training volume. To what extent the present results are also applicable to more experienced trained athletes or other type of sports needs to be further examined.

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