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# Evaluation of Plyometric Exercise Training, Weight Training, and Their Combination on Vertical Jumping Performance and Leg Strength

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**ABSTRACT**

The purpose of this study was to compare the effects of 3 different training protocols—plyometric training, weight training, and their combination—on selected parameters of vertical jump performance and leg strength. Forty-one men were randomly assigned to 1 of 4 groups: plyometric training ($n = 11$), weight training ($n = 10$), plyometric plus weight training ($n = 10$), and control ($n = 10$). Vertical jump, mechanical power, flight time, and maximal leg strength were measured before and after 12 weeks of training. Subjects in each training group trained 3 days per week, whereas control subjects did not participate in any training activity. Data were analyzed by a 2-way ($4 \times 2$) analysis of variance (repeated-measures design). Results showed that all training treatments elicited significant ($p < 0.05$) improvement in all tested variables. However, the combination training group produced improvements in vertical jump performance and leg strength that were significantly greater than improvements in the other 2 training groups (plyometric training and weight training). This study provides support for the use of a combination of traditional and Olympic-style weightlifting exercises and plyometric drills to improve vertical jumping ability and explosive performance in general.

***Key Words:*** stretch-shorten cycle, power training, flight time, leg strength

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## Introduction

Vertical jumping constitutes an integral component of explosive performance in numerous athletic activities. As such, jumping ability is crucial in the execution of many athletic skills, such as rebounding in basketball, spiking in volleyball, and high jumping. Therefore, it is important to determine the parameters involved in vertical jumping and develop them through proper training regimens.

Several factors have been established as major determinants of vertical jumping performance; these include force developed by the hip, knee, and ankle joints, the rate of force development (muscle power) produced by these muscles (32), and the neural coordination of the movement (32). The extent to which jumping performance can be improved by training seems to depend on subjects' strength status before the initiation of the training program. Specifically, it has been shown that subjects of a low-strength profile exhibited substantial increments in their jumping ability following training (2, 8, 21), whereas previously strength-trained subjects experienced limited increase in their jumping score after additional training (27). Despite the fact that vertical jumping performance seems to depend on leg strength, a low correlation between leg strength and vertical jumping performance has been obtained ($r = 0.35$ and $r = 0.40$) on 2 occasions (24, 34), but this may be due to the way leg strength was assessed (dynamic vs. static measurement) and the speed of movement adapted during the measurement (4).

Jumping is a complex multijoint action that demands not only force production but also a high power output. Numerous investigators have underlined the significance of maximal rate of force development in the improvement of explosive jumping performance (9, 27, 39). Plyometric training has been advocated for sports that require explosiveness and increased vertical jumping ability by the athletes.

Plyometric or stretch-shortening cycle exercises are those that are characterized by rapid deceleration of the body followed almost immediately by rapid acceleration of the body in the opposite direction (35). Plyometric exercises evoke the elastic properties of the muscle fibers and connective tissue in a way that allows muscle to store energy during the deceleration phase and release that energy during the acceleration period (5, 6, 14, 20, 26, 30, 43). The end result is that muscles are trained under tensions greater than those achieved by conventional slow-speed resistance training (28). Therefore, plyometric training has been recommended for sports that rely on generation of high power output. Researchers and practitioners assumed that these characteristics of plyometric exercises would facilitate significant gains in muscle strength and power and therefore optimize jumping performance. Despite the support for plyometrics in improving power (6, 11, 12, 17, 18, 23), their effectiveness in improving jumping performance is less clear. Specifically, most studies revealed that plyometric training resulted in increased vertical jumping performance (2, 3, 11, 14, 18), although some studies indicated otherwise (2, 10, 37, 45), and one study showed improvement of vertical jumping performance only after 18 months of plyometric training (13).

Weight training has been able to improve vertical jumping performance in most cases by 2–8 cm (or by 5–15%) (2, 3, 10, 11, 45), with lighter more explosive lifts being more effective than the heavier and slower lifts (27, 45). The comparison of plyometric exercises and weight-training protocols has produced controversial results. Plyometric protocols have been shown to be more effective (44), equally effective (2, 3), or less effective (25, 44) than weight training in improving vertical jumping ability. Furthermore, 2 other studies showed that plyometric training was no more effective than isokinetic training (10) or flexibility training alone (40).

The combination of plyometric exercises and weight training increased (2, 8, 10) or maintained unaffected vertical jumping performance (25). Adams et al. (2) suggested that this combination may provide a more powerful training stimulus to vertical jumping performance than either weight training or plyometric training alone. However, Clutch et al. (21) did not reach similar conclusions.

It seems that researchers have not come to an agreement about the relative effectiveness of plyometric training compared with weight training or the combination of both in the development of vertical jumping ability. It seems likely that different durations of training periods, different training status of the subjects, or different training designs (i.e., training loads or volumes or exercises) might have caused the discrepancy in the results of previous studies. Therefore, the purpose of the present investigation was to determine how selected variables of vertical jumping performance, namely, leg power, jumping height, flight time, ground time, and leg strength, are affected by a typical 12-week plyometric training program, a typical 12-week weight-training program, and 12-week training program that combines plyometric exercises and weight training.

**Table 1.** Descriptive data of subjects' characteristics.

| Group* | $n$ | Height (cm) | Weight (kg) | Age (y) |
|---|---|---|---|---|
| Control | 10 | 181 ± 1.5 | 80.8 ± 3.1 | 20.5 ± 1.8 |
| PT | 11 | 178 ± 2.1 | 83.4 ± 4.8 | 21.1 ± 2.5 |
| WT | 10 | 180 ± 1.9 | 85.0 ± 2.7 | 20.9 ± 2.4 |
| PWT | 10 | 178 ± 3.0 | 79.9 ± 2.2 | 20.1 ± 1.4 |

* PT = plyometric training; WT = weight training; and PWT = plyometric plus weight training.

## Methods

### *Subjects*

Forty-one healthy men (20.7 ± 1.96 years of age) volunteered to participate in this study (subjects' characteristics are given in Table 1). Although subjects could be classified as untrained (they did not participate in organized weight or other types of training), they were able to lift at least 1.5 times their body weight in the squat exercise. (Those who were not able to lift that amount of weight were discharged from the study.) Subjects received all necessary information about the study's procedures in oral and written form. Each subject completed a medical history form (special care was given to hypertension and orthopedic status screening), a training background questionnaire, and a written informed consent form. The study was approved by the university's institutional review board and conformed to requirements set by the American College of Sports Medicine.

### *Data Acquisition*

Each subject underwent measurements of vertical jumping performance, leg power, flight time, and maximal leg strength. Pretesting was conducted in 4 sessions 1 week before initiation of the training period. The first session included an introduction of the testing protocols to the subjects. The second session included measurement of vertical jumping performance and flight time. In the third session, leg strength was determined. During the fourth session, leg power was measured. There was a 24-hour pause between testing sessions. Identical measurements were performed in the same order 4 days following the completion of the training period.

### *Vertical Jump Height*

Vertical jump height was measured by the stand and reach test (41). A vertical jump board marked in centimeters was used. A vertical jump test was completed from a 2-footed standing position without a step into the jump. Subjects were allowed to use their hands as they desired. Three test jumps were completed, and the highest of these was recorded. This test was selected because it has high validity (0.80) and reliability (0.93) coefficients (38) and because it allows arm movement and a squat motion before the jump, such as those performed in sports.

### *Measurement of Jumping Mechanical Power*

Jumping mechanical power was obtained by use of the Vertical Jump Test by Bosco et al. (15). This test was preferred because it takes advantage of the potential for using elastic energy storage in addition to chemical-mechanical energy conversion. The test has been shown to have high validity (compared with the Wingate test, 0.87) and reliability (test-retest, 0.95) coefficients (15). The test calculates mechanical power both for 15- and 60-second jumping intervals. The 15-second jumping interval was selected, since it reflects real jumping conditions in sports performance and exhibits a high validity coefficient when compared with the Wingate power test (0.87) (15). A Dekan Automatic Performance Analyzer was used. Two switch mats for the timer were placed side by side and connected by a Y adapter to the timer (''start on break contact'' input). The timer was triggered by the feet of the subject at the moment of release from the platform and stopped at the moment of touch down. Thus, the flight time of the subject during the jump was recorded. This method of flight time calculation assumes that the positions of the jumper on the platform were the same in takeoff and landing. The error of measurement, when compared with film analysis, has been reported to be approximately $\pm$ 2% (30). If several jumps are performed, the timer is summing the respective flight times of the single jumps. To standardize the knee angular displacement during the contact phase, the subject was required to bend the knees to about 90°. Furthermore, to avoid unmeasurable work output, horizontal and lateral displacements should be minimized, and the hands were required to be kept on the hips throughout the jump (15). Jumping frequency was visually counted and recorded manually by 2 testers for 15 seconds. The average power output during the trial was computed as follows:

$$\text{Power (W)} = \frac{9{,}8 \times \text{total flight time (sec)} \times 60}{4 \times \text{number of jumps} \times (60 - \text{total flight time})} \qquad (1)$$

### *Measurement of Flight Time*

The Dekan Automatic Performance Analyzer, which was selected to measure jumping mechanical power, was used for the measurement of flight time and ground time. Subjects performed 3 single jumps, and the time they remained in the air was recorded (the best flight time of the 3 was recorded). Ground time was defined as the amount of time subjects were in contact with the ground between successive jumps. Ground time was selected for measurement as an indication of the time delay between the eccentric and concentric phase of the jump (42). Subjects had to execute maximal jumps for 15 seconds. To standardize the knee angular displacement during the contact phase, subjects were required to bend the knees to about 90°. The following formula (15) was used to calculate ground time:

$$\text{Tc (s)} = \text{Total Time} - \text{Total Flight Time (for Number of Jumps)}/n \qquad (2)$$

### *Measurement of Leg Strength*

Leg strength was assessed by 2 weightlifting tests: the 1RM (1 repetition maximum) squat and 1RM leg press tests. Bilateral leg press tests were completed using standard leg press equipment (Universal, Irvine, CA), with the subjects assuming a sitting position (about 120° flexion at the hips, 100° flexion at the knees, and 10° dorsiflexion) and the weights sliding vertically. During the lifts, the subjects extended their hips and knees, with ankle plantar flexion to about 10°. The subjects' 1RM weight was determined within 2–5 lifts, using weight increments selected by the subjects.

In the squat 1RM test, subjects executed the traditional back squat exercise following the NSCA guidelines for the execution of this particular test. However, a manual goniometer was used at the knee to standardize range of motion. Subjects started the squat exercise at 30° of knee flexion, descended to 90°, and then forcefully returned to the starting position by extending both knees and hips and plantar flexing at the ankles. Testers alerted the subjects when the starting and finishing positions were attained.

### *Training Protocols*

After the initial measurements, subjects were randomly assigned to 1 of 4 groups: control ($n$ = 10), plyometric training ($n$ = 11), conventional weight training ($n$ = 10), and combination of plyometric plus weight training ($n$ = 10). The control group did not train. All other 3 training groups trained for 12 weeks 3 days per week. Before the initiation of the training periods, subjects of all groups were instructed about the proper execution of all the exercises to be used during the training period for all training regimens. The training protocols included only leg exercises. None of the subjects had used plyometric exercises before. The training programs were designed to overload the leg muscles involved in vertical jumping motion. All training sessions were supervised.

*Weight Training Protocol.* Traditional leg exercises were used. Barbell squats, leg presses, leg curls, and standing calf raises were used as core exercises in the first 8 weeks, whereas jump squats (with a barbell), cleans, snatches, and push presses were used as core exercises in the last 4 weeks, supplemented by front and side lunges, step ups, sitting calf raises, and dead lifts in all 12 weeks of training. During the first 2 weeks, training intensities (average weight lifted or percentage of 1RM lifted, 2 sets at $1 \times 12$ and $1 \times 10$) and volumes (repetitions × weight lifted) were kept relatively low (weight lifted corresponded to approximately 70% of 1RM) to accommodate subjects with the training protocol. In the remaining training period, intensity for the core exercises was maintained between 80 and 95% of each subject's 1RM, whereas supplementing exercises were performed constantly at 70–80%. The first training day of the week included high-intensity ($2 \times 6$, $1 \times 4$, $1 \times 2$), the second day intermediate-intensity ($2 \times 10$, $2 \times 8$), and the third day low-intensity ($4 \times 12$) exercises. Supplementing exercises were performed at $1 \times 12$, $1 \times 10$, and $1 \times 8$. Increases in training weight were adjusted carefully to ensure that the subjects were able to complete the required sets and repetitions. (If a subject was perceived to be using too little weight, adjustments were made.)

*Plyometric Training Protocol.* Plyometric exercises included squat jumps, jumps over cones and bench, repeat triple jumps, single- or double-leg hops, alternate leg bounds, depth jumps, and box jumps. Training intensity and volume was kept low (up to 80 foot contacts with low-intensity drills, while technique was given special attention) during the first 2 weeks to avoid injuries and have subjects adjusted to this new (to them) type of training. During the remainder of the training period (10 weeks), the first training day of the week included high intensity of about 220 foot contacts, the second included moderate-to-high intensity of about 150–170 foot contacts, and the third day included low-to-moderate intensity of about 120 foot contacts. However, box jumps and depth jumps were introduced in the sixth week of training, and the height of boxes varied, depending on the training day and the week within the program (started with 30 cm and reached a high of 80 cm).

*Plyometric Plus Weight Training Program.* The combined program consisted of a weight-training regimen in conjunction with a plyometric routine that included exercises used in the 2 protocols separately as described above. The 2 protocols were performed on the same day, with weight training taking place 180 minutes after the plyometric exercise program. The training intensities followed the same progression as the ones used in the plyometric and weight-training groups.

### *Statistical Analyses*

A factorial, 2-way ($4 \times 2$, 4 treatments by 2 times of measurement) analysis of variance (repeated-measures design) procedure was used to test for statistically significant differences on all criterion variables across time. Following a statistically significant $F$ ratio, a Newman-Keuls post hoc technique was used to clarify the interaction. The 0.05 level was adopted as the probability level of significance throughout the analysis. Data are presented as mean ± *SE*.

## Results

Means and *SEs* for vertical jump height, jumping mechanical power, flight time, and leg strength (in leg press and squat tests) are listed in Table 2. The combination training group exhibited significantly ($p < 0.05$) better performance than the plyometric training and the weight-training groups in vertical jump height, jumping mechanical power, and flight time. However, in leg press– and squat-measured leg strength, the combination group presented significantly ($p < 0.05$) higher improvement compared with the plyometric training group but not compared with the weight-training group.

## Discussion

The purpose of this study was to determine if plyometric training alone or in combination with weight training can enhance selected variables of vertical jumping performance. The results indicate that long-term plyometric training is capable of improving vertical jumping ability, but its combination with weight training is even more beneficial.

The effectiveness of plyometric training in improving explosive performance has been supported by most training studies in the field during the last 2 decades (11, 14, 25, 30). Despite its wide use in athletics and the specific guidelines given regarding its use, more studies are needed to evaluate its effectiveness, especially compared with other conventional training methods such as weight training or its combination with them. Combination of different training methods will promote all qualities of muscle power and strength.

Several previous investigations have failed to find that plyometric training is significantly more effective than other training methods in improving vertical jumping ability (21, 25, 28, 33, 35). Furthermore, previous research that used a combination of plyometric and weight training found either increased (2, 8, 10) or unaffected vertical jumping performance (25). Other investigators (21, 33) found that the combination of plyometric and weight training is equally effective to plyometric or weight training. Results of the present study indicate otherwise. This combination training provided the most powerful stimulus in improving various parameters of vertical jumping ability.

In contrast to previous studies, results of the present study indicate that all treatments produced pro-

**Table 2.** Means ± *SEs* between pretraining and posttraining for all dependent variables for the 3 groups.*

| Group | VJH (cm) | Power (W/kg) | FT (ms) | GT (ms) | Leg press (kg) | Squat (kg) |
|---|---|---|---|---|---|---|
| Control ($n$ = 10) | | | | | | |
| Pre | 54.5 ± 1.5 | 44.8 ± 3.8 | 528 ± 10.01 | 333 ± 2.8 | 191.5 ± 5.8 | 128.5 ± 4.1 |
| Post | 54.9 ± 1.9 | 45.1 + 3.5 | 533 ± 10.09 | 333 ± 3.6 | 194.2 ± 6.4 | 130.2 ± 3.8 |
| PT ($n$ = 11) | | | | | | |
| Pre | 52.9 ± 2.4 | 46,5 ± 6.9 | 515 ± 10.45 | 344 ± 4.1 | 202.9 ± 8.3 | 132.4 ± 6.4 |
| Post | 58.9 ± 2.3†‡§ | 58.4 ± 7.4†‡§ | 578 ± 10.31†‡§ | 277 ± 3.2†‡§ | 221.3 ± 7.3†‡§¶ | 148.8 ± 6.6†‡§¶ |
| WT ($n$ = 10) | | | | | | |
| Pre | 58.1 ± 1.4 | 46.5 ± 4.0 | 522 ± 12.39 | 343 ± 4.5 | 189.8 ± 9.3 | 133.0 ± 4.4 |
| Post | 63.5 ± 1.8†‡‖ | 58.0 ± 4.0†‡‖ | 566 ± 12.19†‡‖ | 290 ± 4.8†‡‖ | 217.5 ± 7.4†‡¶ | 161.9 ± 3.3†‡¶ |
| PWT ($n$ = 10) | | | | | | |
| Pre | 58.8 ± 3.0 | 43.0 ± 4.6 | 508 ± 20.53 | 341 ± 2.9 | 133.0 ± 8.9 | 125.0 ± 4.5 |
| Post | 67.4 ± 2.8†‡§‖ | 59.9 + 5.0†‡§‖ | 597 ± 21.44†‡§‖ | 258 ± 2.7†‡§‖ | 216.5 ± 7.6†‡§ | 161.1 ± 3.4†‡§ |

* VJH = vertical jump height; FT = flight time; GT = ground time; PT = plyometric training; WT = weight training; PWT = plyometric plus weight training.
† Significant difference between pretraining and posttraining ($p < 0.05$).
‡ Significant difference with the control group ($p < 0.05$).
§ Significant difference between the PT and PWT groups ($p < 0.05$).
‖ Significant difference between the WT and PWT groups ($p < 0.05$).
¶ Significant difference between the PT and WT groups ($p < 0.05$).

found improvement in vertical jumping performance and leg power. However, the combination training treatment evoked the most significant changes in these variables. The discrepancy between these results and results of previous investigations might be attributed to several reasons. First, the training experience level of the study subjects might offer one explanation. Subjects in the present study were novices in plyometric training in contrast to subjects in previous investigations. However, they were strength trained enough to be able to sustain plyometric training loads. One needs to be weight trained to enjoy positive adaptations to plyometric training. The second explanation is the nature of the training protocols used in the present study and previous investigations. The present study used a large variety of plyometric and weight-training exercises compared with previous studies. During the first phase of training, the weight-training protocols used general strength training exercises (i.e., squats) aimed at increasing maximal strength of the lower limb muscles. During the last stage of training, special strength exercises (i.e., snatches, cleans, jump squats) were used to convert maximal strength to power as it relates to jumping (7). This special type of strength training exercises are characterized by a more forceful and rapid execution, generation of a higher power output, and loss of foot contact with the ground (7). In plyometric training protocols, several exercises were used, ranging from bounds and hops to drop jumps. Another difference between the present study and previous ones is the model used to provide the training stimulus to subjects. Training intensity, volume, and exercise selection followed the principle of progressive overload, starting with lower intensities, single-joint exercises, and less complex exercise techniques and progressing to higher intensities, multijoint exercises, and more complex techniques. Intensity varied within a single week. Training programs focused on developing basic strength and exercise technique initially, maximal strength later, and finally transition of maximal strength to power.

Plyometric training resulted in a slightly better improvement than weight training in vertical jump performance, but it was not statistically significant. These results are in agreement with previous findings, indicating that these 2 methods are equally effective in improving jumping performance (1, 3). Lately, weight-training protocols have been modified by incorporating more dynamic and explosive movements aimed toward power development. Such weight-training protocols have been found to be very effective in improving mechanical power in movements requiring explosiveness (31, 45).

Even though plyometric and weight training each increased flight time and decreased ground time significantly, it is their combination that caused the greatest gains in these 2 parameters. It has been suggested that the increased efficiency of plyometric movements and generally in stretch-shortening cycle exercises is due to the fact that previous stretching decreases the time in which positive work is done during the subsequent shortening (16, 17, 20). Part of the positive work measured does not derive from chemical energy transformation but from recoil of tense elastic elements (20). If the time delay between the stretch and the concentric contraction is too long, the energy stored dissipates as heat (18). In the present study, results showed that combination training decreased ground time or the amortization phase between jumps (thereby decreasing the time that the feet were in contact with the ground between jumps). This adaptation might have occurred because of a better utilization of the stored elastic energy, resulting in a higher jump and increased flight time (and thus reduced ground time). Mechanical power results followed the same trend between groups. Interestingly, maximal strength as measured in leg press was improved more by weight training than by plyometric training, whereas maximal strength as measured by the squat exercise was equally increased by the 2 treatments. This finding probably is related to the nature of the plyometric and weight-training exercises used.

Another interesting note is that, despite the fact that subjects in the combination group performed plyometric and weight training on the same day, their performance was not impaired. NSCA and others (22, 36) do not recommend performing heavy strength and plyometric training on the same day, with the exception of track and field athletes, who might benefit from ‘‘complex training.’’ In the present study, there was enough rest between sessions to allow recovery of the neuromuscular and metabolic systems of the subjects. Plyometric training was performed first to ensure that subjects would perform the plyometric drills with the proper technique and full explosiveness.

However, some extraneous variables might have confound the results of this study. It is very difficult to control the total work performed in each training session so that subjects in all groups handle the same amount of total work. Total workload was not equated between groups. Authors followed a traditional training scheme in each treatment based on the periodization model. There is a possibility that subjects in the combination training group were exposed to a higher training stimulus than subjects in the other groups. It would be very interesting if future studies made an attempt to equate workloads between groups when comparing different training methods.

Therefore, the results of this study indicate that both plyometric and weight training are able to improve selected variables of vertical jumping performance. However, it is their combination that produced the greatest improvement on these selected variables of vertical jumping performance.

## Practical Applications

The results of this study provide insight into several aspects of vertical jump training and into training for improvement of athletes' explosiveness. First, very important parameters of vertical jumping performance can be improved significantly by either plyometric or weight training separately. However, strength and conditioning professionals must notice that in this study the combination of plyometric and weight training was significantly more beneficial in increasing vertical jump height and other related variables. Therefore, strength professionals must be able to incorporate both elements in their training regimens. Second, weight training must incorporate special exercises, that is, exercises (such as power jumps, snatches, pulls, power cleans, and push presses) that focus on power development once strength levels have been improved. Third, intensity and training volume followed the progressive overload principle in the present study. Intensity and volume of training built up, gradually allowing subjects to adjust effectively, especially subjects who followed the plyometric training protocols. Variation of intensity within each week of training seems to have helped subjects who participated in all training groups. Fourth, despite the fact that execution of plyometric training and weight training is not generally recommended on the same day, the present study indicates that this might not be true if adequate recovery is allowed in between. Fifth, it seems that 12 weeks is adequate for improvement of vertical jumping if the training protocols maintain the appropriate intensity and volume. Sixth, in this study, 3 days of training per week was proven an effective training frequency for vertical jump training. However, this cannot be accomplished during the in-season period. Such training protocols should be incorporated in the preseason or postseason training periods. Seventh, the results of this study concern individuals relatively inexperienced in jump training. It is possible that advanced athletes in power sports would not exhibit the same magnitude of improvement with the training protocols used herein. It is possible that more advanced athletes need a different manipulation of training intensity and volume and selection of exercises.

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