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A Comparison of Plyometric Training Techniques for Improving Vertical Jump Ability and Energy Production

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Reference Data
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ABSTRACT

This study was done to determine which plyometric training technique is best for improving vertical jumping ability, positive energy production, and elastic energy utilization. Data were collected before and after 12 weeks of jump training and were analyzed by ANOVA. Subjects (N = 28) performed jumps under 3 testing conditions-squat jump, countermovement jump, and depth jump-and were randomly assigned to 1 of 3 groups: control, depth jump training, or countermovement jump training. The 12-week program resulted in significant increases in vertical jump height for both training groups. The depth jump group significantly improved their vertical jump height in all 3 jumps. None of the training methods improved utilization of elastic energy. In activities involving dynamic stretch-shorten cycles, drop jump training was superior to countermovement jump training due to neuromuscular specificity. This study provides support for the strength and conditioning professional to include plyometric depth jump training as part of the athlete's overall program for improving vertical jumping ability and concentric contractile performance.

Key Words: elastic energy, depth jump, countermovement jump

Introduction

Plyometric exercises that involve stretching an active muscle prior to its shortening have been shown to enhance performance during the concentric phase of muscular contraction. Observed during the concentric phase, this enhancement has been attributed to the release of elastic energy stored in the series elastic elements of the muscle during stretch. The ability of a muscle to store and utilize elastic energy depends on the speed of the stretch, length of the stretch, force at the end of the stretch, and length of time the stretch is held (7).

The enhancement of performance by placing an active muscle on stretch has been demonstrated in both animal and human experiments (2, 6, 7). Komi and Bosco (11) compared the vertical jump performance of men and women under 3 conditions: squat jump (SJ), countermovement jump (CMJ), and depth jump (DJ). All subjects attained the greatest jump heights in the DJ condition, followed by the CMJ and SJ conditions. Men jumped higher than women, but women were better able to utilize stored elastic energy (11).

The effects of jump training on vertical jump ability have also been studied. Several researchers have found that jump height can be improved through plyometric jumps (2, 8, 11). Blattner and Noble (5) compared a DJ training group, an isokinetic training group, and a control group. They found both the DJ and isokinetic groups jumped significantly higher than the controls. Clutch and colleagues (9) compared CMJ training to DJ training when combined with weight training. They found no significant differences between the DJ and CMJ training groups, as both groups improved their vertical jump ability by 8.4 cm after 4 weeks of training.

Despite the large number of plyometric studies, few training studies have directly compared the effectiveness of plyometric DJ training to CMJ training. Dursenev and Raevsky (10) felt that depth jumps from 2 meters or higher were superior for improving muscle strength. Brown et al. (8) found significant improvement in vertical jump height following a 12-week DJ training program in male basketball players when compared to controls. Other researchers found that DJ training increased vertical jump ability in subjects who were participating in an activity that required jumping, and that any form of jump training increased vertical jump height in subjects whose activity did not require jumping (4, 9). These same authors found no significant difference in the vertical jump ability of subjects who trained with CMJ vs. those who trained with DJ.

However, we are unaware of any research that has directly compared the effects of CMJ vs. DJ training for improving energy production as well as vertical jump ability. Therefore the primary purpose of this study was to determine whether DJ training was superior to CMJ training for improving vertical jump ability. A secondary purpose was to determine whether changes in jumping ability could be attributed to positive or negative elastic energy.

Methods

Subjects and Procedures

Subjects were 14 male and 14 female college students. Descriptive characteristics were as follows:

	Height (cm)	Weight (kg)	Age (yrs)
Controls			
M (n=5)	175.50 ± 17.68	65.74 ± 5.65	20.20 ± 2.27
F (n=5)	165.40 ± 4.05	52.68 ± 7.82	19.40 ± 2.19
CMJ Group			
M (n=4)	182.34 ± 5.85	63.92 ± 7.62	19.00 ± 1.00
F (n=3)	166.40 ± 1.01	49.60 ± 4.15	19.67 ± 1.15
DJ Group			
M (n=5)	178.54 ± 8.45	73.16 ± 10.79	20.04 ± 1.34
F (n=6)	169.72 ± 6.56	57.40 ± 7.26	20.00 ± 2.53

The subjects were not participating in any competitive sport or recreational activity that involved jumping; however, all undertook 20-30 minutes of aerobic exercise 3 times a week. Subjects with potential medical problems or history of ankle, knee, or back pathology within the 3 months preceding the study were excluded. Subjects were then randomly assigned to 1 of 3 groups: Control group, CMJ training group, or DJ training group. The controls continued to perform their regular aerobic exercise.

Testing. Pretests were conducted before and after 12 weeks of plyometric training. Prior to testing, all subjects underwent a 5-min warm-up on a cycle ergometer followed by standard stretching exercises. They then performed 3 maximal vertical jumps with hands on hips, in random order, for each of the following conditions: CMJ, DJ, and SJ. Although none trained with the SJ, it was tested in order to determine elastic energy utilization.

During the CMJ and when landing during the DJ, subjects were instructed to flex their knees 30-60° and then rebound upward in a maximal vertical jump. During the squat jump, with knees at 60° of flexion, the subjects were instructed to execute a maximal vertical jump and were not allowed to use any downward movement prior to the maximal vertical jump. Force data were recorded with a Zenith 386-Sx microcomputer interfaced to the AMTI amplifier by a data translation DT2801-A, 12-bit analog-to-digital converter. For each trial the data were sampled at a rate of 1,000 Hz for 4.0 sec. The force curves were inspected to verify that the SJ were executed without any downward movements prior to the vertical jump.

Training. The 12-week training program, designed to improve vertical jumping ability, involved 2 training sessions a week. During the first 2 weeks the subjects performed 2 sets of 8 reps to familiarize themselves with the training. For the remaining 10 weeks, both training groups completed 4 sets of 8 reps. The CMJ group rested 5 sec between each repetition. The DJ group rested 5 sec between each repetition upon returning to the 40cm step. Additionally, 1 min of rest between each set was provided. A height of 40 cm was chosen for DJ because of the reported high levels of Achilles tendon tension when jumping from greater heights.

Data Analysis

From each vertical ground reaction force curve, the average of the 2 best trials, based on jumping height, was analyzed. Vertical jump height was determined using projectile equations and time in the air as established from vertical ground reaction force data. Jump height, positive energy, and elastic energy were calculated using the methods of Komi and Bosco (11). The positive energy (Epos) obtained in the squat jump trials represents contractile performance on a pure concentric contraction. DJ and CMJ subjects executed a stretch-shorten cycle (eccentric to concentric). For both groups, the increase in positive energy over that in the squat jump reflects the utilization of stored elastic energy. In the CMJ and DJ, the change in positive kinetic energy (ΔEpos) was calculated by subtracting the positive kinetic energy obtained in the SJ from either the CMJ or DJ group.

A two-factor repeated measures ANOVA was used to test for differences in training group and time, pretest and posttest. The dependent variables were jumping height, positive kinetic energy, and elastic energy. Alpha level was set at $p < 0.05$ for all comparisons. A Scheffe procedure was used for all post hoc comparisons.

Results

The results of the present study indicated that a 12-week training program significantly improved vertical jump height and positive energy production for both training groups. However, there was no significant change in elastic energy utilization during either the CMJ or DJ jumping conditions following the 12-week training program.

When comparing pre- to posttest data, the DJ training group increased their mean vertical jump ability by 113.61, 108.04, and 110.95% during the SJ, CMJ, and DJ, respectively. The CMJ training group improved their mean vertical jumping ability by 106.83, 105.40, and 108.74% during the SJ, CMJ, and DJ, respectively. Both training groups significantly improved their vertical jump ability after 12 weeks of training. As expected, the control group showed inconsistent changes over the

Table 1
Pre- and Posttest Jump Height (cm) by Training Group (±*SD*)

	Pretest		Posttest		Change (Ht)	
	M	±*SD*	*M*	±*SD*	*M*	±*SD*
Control group ($n = 10$)						
SJ	24.66	9.84	25.28	8.58	0.62	2.87
CMJ	27.81	9.69	26.95	8.70	–0.86	2.89
DJ	25.91	8.54	26.09	7.39	0.18	2.60
CMJ training group ($n = 7$)						
SJ*	27.50	7.47	29.38	6.42	1.88	1.09
CMJ*	30.50	7.20	32.15	7.59	1.65	0.97
DJ	27.45	4.75	29.85	7.93	2.40	3.44
DJ training group ($n = 11$)						
SJ*	24.02	5.87	27.29	5.77	3.27	2.99
CMJ*	26.50	9.11	28.63	5.23	2.13	1.86
DJ*	25.47	5.59	28.26	4.90	2.79	2.07

SJ = squat jumps; CMJ = countermovement jumps, DJ = depth jumps. *Significant ($p < 0.05$) pre- to posttest comparisons.

Table 2
Pre- and Posttest Positive Energy (J) by Training Group (±*SD*)

	Pretest		Posttest		
	M	±*SD*	*M*	±*SD*	Change (J)
Control group ($n = 10$)					
SJ	145.93	68.74	149.37	63.02	3.44
CMJ	162.98	66.29	159.23	64.33	–3.75
DJ	153.11	62.84	153.54	55.82	0.43
CMJ training group ($n = 7$)					
SJ*	153.63	63.04	163.35	59.65	9.72
CMJ*	170.68	68.67	179.28	70.04	8.60
DJ	151.35	48.19	166.83	68.90	15.48
DJ training group ($n = 11$)					
SJ*	154.36	56.21	175.87	62.98	21.51
CMJ*	169.57	54.57	183.68	59.21	14.11
DJ*	163.45	54.75	181.84	58.31	18.39

SJ = squat jumps; CMJ = countermovement jumps, DJ = depth jumps. *Significant ($p < 0.05$) pre- to posttest comparisons.

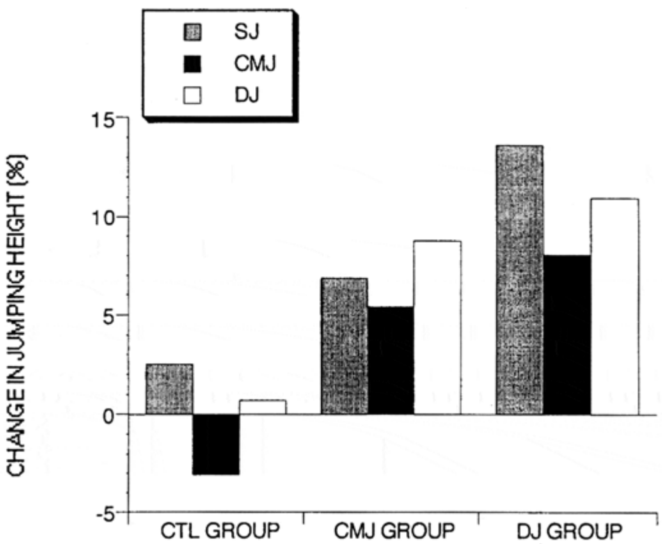

Figure 1. Mean change (pre to post) in jump height % by training group.

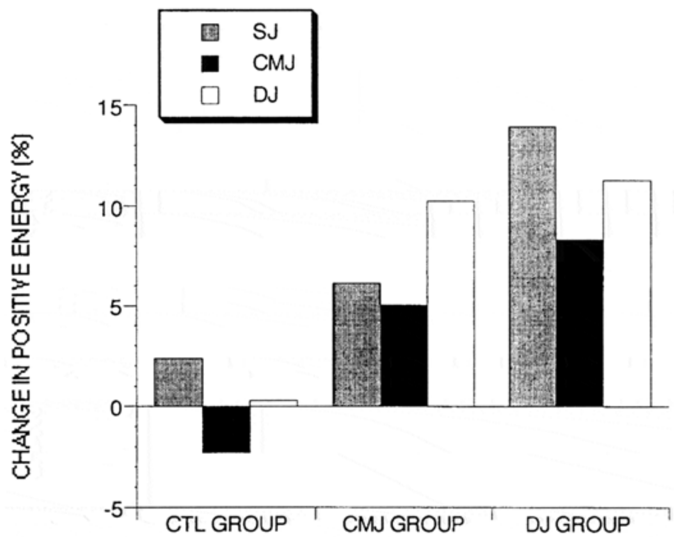

Figure 2. Mean change (pre to post) in positive energy by training group.

training period. Their vertical jump ability improved by 0.62 and 0.18 cm during the SJ and DJ and decreased by 0.86 cm during the CMJ; these pre- to posttest differences were not significant.

Table 1 compares the effects of training techniques of vertical jumping height. The % change in jumping height is shown in Figure 1. With regard to group data, both training groups were significantly different from the control group in vertical jump ability following the training program. There were no significant differences in jumping height between the training groups after training under the 3 test conditions.

Table 2 compares pretest/ posttest positive energy production in vertical jumping. The % change in positive energy production is shown in Figure 2. The training program led to significant improvement in positive energy production for the CMJ training group in both the SJ and CMJ conditions (improvements of 9.72 and 8.60 J, respectively), but not in the DJ. The DJ training group significantly improved their positive energy production in all 3 jumping conditions: 21.51, 14.11, and 18.39 J for SJ, CMJ, and DJ, respectively. There were no significant pre/ post differences for the control group.

The training resulted in no significant improvement in elastic energy utilization for either training group when comparing pre- and posttest means (Table 3 and Figure 3). There were no significant differences between training groups in utilization of elastic energy.

Table 3
Pre- and Posttest Elastic Energy by Training Group (±*SD*)

	Pretest		Posttest		
	M	±*SD*	*M*	±*SD*	Change
Control group ($n = 10$)					
CMJ	49.10	41.96	22.08	27.65	–22.07
DJ	3.11	11.60	2.07	6.01	–1.04
CMJ training group ($n = 7$)					
CMJ	59.88	47.11	24.88	9.81	–35.00
DJ	–0.25	7.13	1.03	4.34	0.78
DJ training group ($n = 11$)					
CMJ	51.71	54.43	28.76	33.35	–22.95
DJ	3.61	8.33	2.46	5.19	–1.15

CMJ = countermovement jumps, DJ = depth jumps.

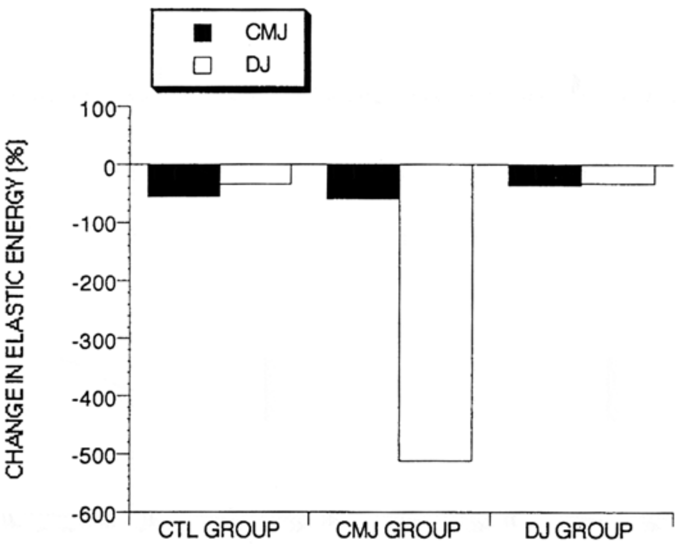

Figure 3. Mean change (pre to post) in elastic energy % by training group.

Discussion

Depth jumps are a popular training mode for improving strength, power, and speed. The results of this study demonstrated that both training groups significantly improved vertical jump height compared to the control group. The improvement can be attributed to an increase in positive energy production. The DJ training group improved their positive energy production by 13.93, 8.32, and 11.25% during the SJ, CMJ, and DJ, respectively The CMJ training group improved their positive energy production by 6.13, 5.04, and 10.23% during the SJ, CMJ, and DJ, respectively, although the improvement in DJ was not statistically significant.

Our results suggest that CMJ and DJ training are equally effective in improving vertical jump ability. Bartholomew (4) also found that plyometric training is no more effective than CMJ training in improving vertical jump ability. Clutch et al. (9) conducted two studies on different DJ training programs. Their results led them to conclude that while any kind of jumping can improve vertical jump ability, maximum CMJ training is as effective as DJ training in this regard.

The results of this study indicate that the mechanism for improved jumping ability following CMJ or DJ training is improved contractile component rather than elastic component performance, since both training groups had significantly greater positive energy production following training. The DJ training may enhance neuromuscular factors that affect the specificity of training. As shown in Tables 1 and 2, the CMJ training group only improved vertical jump height and positive energy production in the squat jump and CMJ, whereas the DJ training group improved jump height and positive energy production in all 3 jumping conditions. These differences between training modes may have important implications for athletes in sports such as basketball and volleyball, which involve dynamic stretch-shorten cycles.

Our results support the hypothesis that DJ training is superior to CMJ training for improving both jump height and muscular contractile performance in depth jumps. It can be argued that depth jumps more closely approximate sport-specific jumping and may have more application to sport than squat or simple countermovement jumps.

The majority of training studies conducted did not assess other variables that may have been influenced by the training program. Adams (1) in a 7-week training study measured vertical jump ability via the Sergeant jump and did not assess changes in positive energy or the effects on elastic energy. Brown et al. (8) evaluated the subjects of their 12-week training study on a special platform but presented only vertical jump height means and did not discuss changes in positive energy or the effects of elastic energy.

Clutch et al. (9), in their two-part training study, measured vertical jump ability on a timing platform and on a special apparatus attached to a basketball backboard. Again, they took no measurements of the effects of the training program on positive energy production or elastic energy utilization. In an 8-week training study, Blattner and Noble (5) used a jump and reach test for all subjects before and after the training period. Bartholomew (4), in an 8-week training study, also employed the jump and reach test and did not collect data on the change in positive energy production or on the utilization of elastic energy.

Other researchers have evaluated the utilization of elastic energy following DJ, CMJ, and SJ, but not after a training program. In their classic experiment, Asmussen and Bonde-Petersen (3) found that when rebound or countermovement is possible, the efficiency is considerably higher than when no rebound occurs; they coneluded that the role of muscle elasticity in the economy of muscular exercise is significant.

Bosco and Komi (6) found that increases in vertical jump ability following a CMJ or DJ could be attributed to a combination of the utilization of elastic energy and the stretch reflex potentiation of the muscle activation. In a follow-up study, Bosco et al. (7) found that a CMJ enhanced the average concentric force and mechanical power by 66 and 81%, respectively, when compared to SJ. They concluded that the elastic phenomenon is probably of primary importance in this increase. In an earlier study, Komi and Bosco (11) found that women were able to utilize 91.6% of the elastic energy absorbed in the stretching phase of the CMJ condition while men were able to utilize only 49 and 50% of the available elastic energy.

Our results indicated that the 12-week training program had no effect on elastic energy utilization during either the CMJ or DJ evaluations when comparing the pretest to posttest results. However, we did find an increase in positive energy production for both training groups following the 12-week training program.

Practical Applications

The results of this study indicated that a 12-week training program using either DJ or CMJ training significantly improved vertical jump ability. The improvements in jumping ability were attributed to enhanced concentric contractile performance, not the use of stored elastic energy. In activities involving explosive or dynamic stretch-shorten cycles, DJ training proved superior to CMJ training due to neuromuscular specificity. From a training standpoint, DJ should be combined with other sport-specific jumps as part of the athlete's over all training program. Because of the small improvement noted during this study, we suggest that plyometric DJ be used only as one component of a comprehensive strength and conditioning program designed to improve jumping ability.

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