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The Combined Effects of Weight Training and Plyometrics on Dynamic Leg Strength and Leg Power

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Abstract

The purpose of this study was to determine the effects of plyometric exercise (depth drops), combined with weight training, on dynamic leg strength and leg power. Plyometrics are exercises that force a rapid lengthening of muscle prior to contraction, to result in increased force output during contraction. Thirty-one volunteer university students were randomly assigned to three groups according to height of drop (1.1m=high, 0.4m=low and no height). Subjects in each group were classified in two conditions according to leg strength-body weight ratio (low=less than 2, and high=greater than 2). All groups were administered a dynamic leg strength test and Magaria anaerobic power test prior to and following an eight-week plyometric and weight training program. A two-way ANOVA (groups (3) x conditions (2)) revealed no significant differences between groups, conditions, and no significant interactions for leg strength and Magaria power scores. Independent T-tests for mean differences between pre- and post-test scores demonstrated significant gains in both strength and power for each group. It was concluded that participating in a combined 8-week program of plyometrics and weight training will improve leg strength and power. Furthermore, coaches and athletes should be apprised that neither the level of strength nor height of drop variables altered the resultant training effects of the combination program used in this study. The possibility of reducing the time between forced stretch at impact and initiation of contraction to improve plyometric training effects was discussed.

Key Words: **Strength, weight training, plyometrics, stretch-shortening cycle.**

Introduction

Training techniques for athletes often consist of a variety of exercises, all aimed at peak performance during competition. Plyometrics is one such exercise. It is becoming increasingly popular for the improvement of leg strength and power. Theoretically, plyometrics are exercises which use the rapid lengthening of a muscle, just prior to contraction, resulting in an increased force output during contraction (3). Any exercise which forces a rapid lengthening of the muscle prior to its contraction may be considered plyometric. One of the most popular plyometric exercises is the depth jump. Depth jumps require a person to drop from a controlled height and, upon landing, immediately perform a maximum vertical jump. Verhoshanski (11), in a discussion of plyometric exercise, has divided depth jumps into three phases. The first phase is called amortization and occurs as a result of yielding work forcing a rapid stretch of the lower body extensor muscles. In the second phase, muscles perform a reactive switch from yielding work to overcoming work to initiate a positive vertical velocity. The third phase is the phase of active take-off. The extensor muscles contract to perform the jump. The first phase stretches the extensor muscle groups, the second is a reactive recovery, and the third uses the benefit of a reciprocal increase of force during contraction.

Plyometrics were first popularized by Russian athletes and coaches. The Soviets proclaim depth jumps will "stimulate maximum contraction capabilities, those above the athlete's conscious will" and "will improve the viscoelasticity of the contractile properties of soft tissues" (7). While there is no evidence to directly support or refute the Russian propositions, a number of investigators offer evidence to support the plyometric theory. Cavagna (3) has shown that stored elastic energy within a stretched muscle affects the production of contractile force following muscle stretch. Other factors which may contribute to this elastic energy storage and the increase in the contractile force of muscle are: time between muscle stretch and contraction (8), amplitude of movement (10), and stiffness of muscle (1).

A few studies have compared the plyometric principle to other training techniques. Smith (9) found myotatic (prestretched) strength training superior to isometric training relative to gains in static leg strength. Blattner and Noble (2) compared an isokinetic weight training group and a depth jump group in vertical jump performance. Each group showed significant gains in vertical jump following the eight-week training period; however, there were no significant differences between groups. Subjects in the Blattner and Noble study jumped from a box of the same height three times a week but no leg strength data was collected. Clutch, et al. (4) explored the effect of varying heights of drop, in combination with weight training, on squat strength (1 repetition maximum), isometric knee extension strength and vertical jump. All groups increased in the three tests but no significant differences occurred between groups. Asmussen and Bonde-Peterson (1) found that as heights of drop increased to 0.4m the force output of extensor muscles increased following the resultant stretch. Whether this increased force output results in concomitant strength gains was not determined. No studies were found where investigators' measures of strength reflected gains in applied dynamic strength independent of stretch. In addition, dependent measures have either been incongruent (i.e. isometric strength dependent variable for a dynamic task) or confounded by past experience by scoring data from performance on tasks such as squatting, where output can vary due to a learning effect.

The purpose of this study was to determine the effects of plyometric exercise (depth jumps), in combination with weight training, on dynamic leg strength and leg power.

Methods

Thirty-one subjects were randomly assigned to three groups according to height of drop (1.1m=high, 0.4m=low, and no height) for plyometric exercise. Subjects were male volunteers enrolled in beginning weight training classes at Texas Christian University, ranging from 18 to 21 years old. Informed consent was obtained.

Training. All groups participated in a combined weight training and depth jumping program for eight weeks. Because subjects were enrolled in university weight training classes, the program consisted of both upper body exercises (bench press, arm curls, military press, lat pull, and dips) and the leg press exercise on a Universal weight machine. Subject training three times a week (Monday, Wednesday, and Friday), attempting 3 sets of 8 repetitions on each exercise. Initial weights were set so that subject could perform at least the first of the 3 sets. Resistance was increased individually when the subjects could perform the required 8 repetitions for each set of an exercise.

The quantity of sets and repetitions in depth jump training was graduated to insure a progressive intensity. The subjects performed 2 sets of 10 repetitions the first two weeks, 3 sets of 10 repetitions the following three weeks and 4 sets of 10 repetitions the last three weeks. Depth jump training preceded weight training exercises on Mondays and Fridays. Subjects in the no-height group performed maximum vertical jumps from a stationary position, pausing between jumps to prevent a stretch prior to contraction. Subjects dropping from a height (1.1m or 0.4m) stepped off a box, and landed on a 1-inch thick gymnastics mat. Upon landing, they were instructed to immediately perform a maximum vertical jump. When the instructions were given, the researcher did not place extra emphasis on either the time they took to reduce velocity to zero or the height of the rebound jump. Both were treated equally.

Design and Analysis. Muscle stretch is directly related to the force required to reduce vertical velocity to zero, following impact with the mat. Therefore, degree of muscle stretch prior to contraction for vertical jump is related to mass of the subject, velocity at landing and the distance required to reduce velocity to zero. As velocity at landing increases, so also should muscle stretch for a given mass and distance required to reduce velocity to zero. The amount of stretch is inversely related to the distance required to reduce vertical velocity to zero. The following work-energy equation demonstrates the relationship.

$$F \times d = \text{kinetic energy} + \text{potential energy}$$

$$F \times d = 1/2mv^2 + wh$$

(at landing the equation becomes)

$$F \times d = 1/2mv^2$$

(hence)

$$F = \frac{1/2mv^2}{d}$$

Where F equals force required to reduce vertical velocity to zero, m equals mass of the subject, v equals vertical velocity at impact, w equals weight of the subject, h equals height of a reference point (bottom of the feet), and d equals the distance over which F is applied to reduce v to zero. Because v=0 for the no height group, they do not receive the benefit of an added force to muscle stretch, preceded by an active contraction, as do the depth jump groups.

Those subjects with a greater leg strength/body weight ratio (leg strength in pounds divided by body weight in pounds) may obtain a more advantageous muscle stretch by reducing d at landing, resulting in a more forceful contraction at takeoff, for a given mass and velocity. Consequently, subjects were assigned to groups according to conditions of low (less than 2) and high (greater than 2) leg strength/body weight ratios. A between-groups design was used with Group I (n=11) performing depth jumps from a 1.1m height. Group 2 (n=10) performed depth jumps from a 0.4m height. Group 3 performed maximum vertical jumps from ground level. A two-way ANOVA groups (3) X conditions (2) was used to determine differences between groups for dynamic leg strength and Magaria power scores. Independent T-tests were utilized to determine within group differences for dependent measures.

Collection of Data. Before the training period, all subjects were administered the Magaria anaerobic power test and dynamic leg strength test. The Magaria anaerobic power test required running a flight of 12 steps (every other step) as fast as possible. The elapsed time between foot placement on the fourth step and foot placement on the twelfth step was recorded to the nearest .05 seconds with a stop watch. The calculation of work per unit time provided a power value in watts. The procedure and calculations are consistent with those recommended by deVries(5).

Dynamic leg strength was determined by a maximum repetition (RM) on the leg press station of a Universal weight machine. As a muscle warm-up, all subjects initially performed 20 deep knee bends, 1 set of 10 repetitions (50% 1 RM) and 1 set of 6 repetitions (70% 1 RM). The seat was adjusted so the angle between the thigh and lower leg was 110° (±5°). Each subject executed four attempts at a maximum lift. The greatest successful attempt was recorded as the dynamic leg strength score. A successful attempt was defined as complete extension of the leg. The rest periods between attempts were controlled according to the subjects perceived readiness.

Subjects were retested for dynamic leg strength and Magaria anaerobic power at the end of the training period. The same procedures as those utilized in the pre-test were used for the post-test.

Results

The ANOVA for differences between pre- and post-test dynamic leg strength scores and pre- and post-test Magaria power scores revealed no significant main effects or interactions: for groups, $F(2, 30)=.056$ leg strength/1.050 Magaria power ($p=.242$); for conditions, $F(1, 30)=.115$ leg strength/.460 Magaria power ($p=.691$). The T-tests for mean differences between pre- and post-test dynamic leg strength and Magaria power scores were significant for each group. Differences between pre- and post-test scores may be found in **Table 1**.

Discussion

It was assumed in this study that because a subject had a greater leg strength/body weight ratio, the distance required to reduce vertical velocity to zero, following impact from a depth drop, would be reduced, resulting in a more forceful stretch prior to vertical jump. The findings of this study concerning comparisons of leg strength/body weight ratios and heights of drop leads to the following two caveats and issues of discussions. First, the subjects may have been more concerned with the height of jump after landing than jumping immediately upon landing and thus, varied distance (d) volitionally so as to facilitate a maximum vertical jump height. That is, upon landing the primary concern of subjects may have been to increase distance, so the angle between the thigh and leg would subserve a maximum jump rather than the greatest stretch or minimum time between stretch and contraction. This possibility was

Table 1. Pre and Post Differences for Mean of Strength and Power

Leg Press Strength scores in kgs

Grp	N	X	SD	X	SD	Diff	T	Df	Prob.
1	11	153.81	13.88	164.92	14.33	11.11	4.08	10	.002
2	10	154.35	27.08	165.78	25.08	11.43	4.60	9	.001
3	10	151.72	15.10	163.96	18.82	12.24	7.22	9	.000

Magaria Power scores in watts

Grp	N	X	SD	X	SD	Diff	T	Df	Prob.
1	11	860.78	119.87	978.89	122.58	118.11	3.82	10	.003
2	10	771.02	123.26	939.30	101.02	168.28	5.69	9	.000
3	10	792.85	105.22	886.42	67.39	93.57	3.35	9	.003

further examined in a cinemagraphic analysis of the distance over which forces were applied to reduce vertical velocity to zero. Photographic data (Photosonics 16N fast action camera, 48 fps) of randomly selected subjects from each of the three groups (n=20) performing depth jumps from both heights were analyzed.

A tape mark on the anterior superior illiac crest was used as the reference point. Using a motion analyzer, d was measured as the distance the reference point moved downward from impact to initiation of the vertical jump. This distance was then correlated with the subjects' leg strength/body weight ratio. The low correlations (r=.258 from 1.1m and r=.147 from 0.4m) support the contention that d was regulated by each subject in order to increase the height of vertical jump following stretch. Such a circumstance may explain a lack of significance between groups for this study as well as others utilizing plyometrics. If force of muscle stretch is paramount to a training effect, the subject may actually dissipate such forces by increasing d at landing, thereby nullifying the plyometric stretch effect. With an increase in d, the stretch reflex training effect is lost since time between stretch and muscular contraction increases with d.

A second point of discussion is the possibility that the amount of force exerted to reduce the velocity to zero and the corresponding reciprocal force exerted to jump are not primary training factors for depth jumps. It may be that time between a forceful stretch and contraction is of primary importance to a training effect. The key to increased force output after muscle stretch is utilization of the mechanical energy, stored as elastic energy in muscle. This elastic energy is a supplement to the active contraction and can be dissipated as heat or reutilized during contraction (3). Cavagna (3) contrasted studies by Thys, et al. (10) and Magaria, et al. (8) to suggest the time interval between stretch and contraction and amplitude of movement are related factors that affect elastic energy usage. Cavagna (3) states "the effect of utilization of elastic energy is greater the smaller amplitude of movement. It is likely that the recoil of the elastic elements affects mainly the first part of the movement, whereas in the case where movement is continued, the active shortening of the contractile component becomes relatively more important." In summary of the distance and time issues, benefit from depth jump training may arise from a decrease in distance to reduce vertical velocity to zero or a decrease in time from stretch to initiation of vertical jump. Distance and time are related, but independent, factors, since subjects may decrease distance and yet pause long enough to dissipate the stored elastic energy. Conversely, subjects may decrease the time between stretch and contraction. However, if in doing so they increase distance, a loss of elastic energy will result.

The athlete and coach should note the findings of this study and consider them when implementing a combination program of weight training and depth jumps. To insure initial muscle stretch is maximized, and that time between stretch and contraction is minimized, athletes should be instructed to keep distance to a minimum, or at least to execute the vertical jump as rapidly as possible following impact with the mat.

While the combination program produced gains in leg strength and power, this study did not enable separation of contributions from weight training, or from depth jumping. Further research should be conducted to examine the effects of depth jumping alone. A recommended design would contain conditions of high and low leg strength/body weight ratios and four groups: (1) depth jumping only (1.1m and 0.4m), (2) weight training only, and (3) a non-active control. Using dynamic leg strength and Magaria power scores as dependent measures, this design would better facilitate separation of benefits for each training method.

Practical Applications

Results from this study show that a combined 8-week program of plyometrics and weight training will increase dynamic leg strength and power. In addition, coaches and athletes should be apprised that neither level of strength nor height of drop altered the resultant training effects of depth jumps. Indeed, results show that these factors are of little importance to a combined weight training/plyometric program. Results suggest that using a low height of drop (0.4m) will produce the same training effect as the higher height (1.1m). This finding, put into practice, would mean athletes may receive benefits of a combined program without contending with possible injury from increased velocity associated with greater heights.

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