Journal of Strength and Conditioning Research, 1999, 13(3), 275–279

Muscle Power and Fiber Characteristics Following 8 Weeks of Plyometric Training

JEFFREY A. POTTEIGER, ROBERT H. LOCKWOOD, MARK D. HAUB, BRETT A. DOLEZAL, KHALID S. ALMUZAINI, JAN M. SCHROEDER, AND CAROLE J. ZEBAS

Department of Health, Sport, and Exercise Sciences, University of Kansas, Lawrence, Kansas 66045.

ABSTRACT

We examined changes in muscle power output and fiber characteristics following a 3 d·wk^{-1}, 8-week plyometric and aerobic exercise program. Male subjects (n = 19) were randomly assigned to either group 1 (plyometric training) or group 2 (plyometric training and aerobic exercise). The plyometric training consisted of vertical jumping, bounding, and depth jumping. Aerobic exercise (at 70% maximum heart rate) was performed for 20 minutes immediately following the plyometric workouts. Muscle biopsy specimens were collected from the musculus vastus lateralis before and after training. Type I and type II fibers were identified and cross-sectional areas calculated. Peak muscle power output, measured using a countermovement vertical jump, significantly increased from pretraining to posttraining for group 1 (2.8%) and group 2 (2.5%). Each group demonstrated a significant increase in fiber area from pretraining to posttraining for type I (group 1, 4.4%; group 2, 6.1%) and type II (group 1, 7.8%; group 2, 6.8%) fibers, but there were no differences between the groups. Following plyometric training, there is an increased power output that may in part be related to muscle fiber size.

Key Words: power training, fiber hypertrophy

Reference Data: Potteiger, J.A., R.H. Lockwood, M.D. Haub, B.A. Dolezal, K.S. Almuzaini, J.M. Schroeder, and C.J. Zebas. Muscle power and fiber characteristics following 8 weeks of plyometric training. *J. Strength Cond. Res. 13(3):275–279. 1999.*

Introduction

Explosive leg power is a critical component for successful performance in many athletic events. Vertical jumping ability may best exemplify this, as evidenced by the strong association between increased lower-body power and vertical jump height. An increase in lower-body strength, however, is not the only means by which to enhance vertical jump performance. Increasing the degree of coordination and skill in performing the movement and maximizing the ability to use the stretch-shortening cycle in the muscle are other integral factors in vertical jump performance (1, 6, 24).

Plyometric exercises parallel the movement patterns used by athletes in activities that involve sprinting and jumping. Lower-body plyometric exercise typically includes bounding, hopping, and various jumps with 1 or 2 legs. These exercises use the stretch-shortening cycle that occurs when a muscle undergoes a rapid eccentric elongation just before a rapid concentric contraction. The muscle is essentially stretched while active, resulting in greater force production during the subsequent concentric contraction than could be generated during a concentric contraction from a static position (18). The ability of the muscle to adapt to this stretch-shortening cycle should enable the individual to generate greater power. In fact, many studies have established the effectiveness of plyometric training for improving power output (4, 8) and vertical jump performance (1, 7, 8, 11, 13, 17, 24).

To our knowledge, no studies have addressed the influence of plyometric training on both vertical jump power production and muscle fiber characteristics. The purpose of this study was to examine the effect of plyometric training on leg muscle power output and muscle fiber size of the musculus vastus lateralis.

Methods

Nineteen physically active men (mean ± SD; age = 21.3 ± 1.8 years, height = 185 ± 10.1 cm) voluntarily participated in the investigation. None of the subjects had participated in any structured plyometric training program, although all subjects had regularly performed resistance training and aerobic exercise for at least 3 months before beginning the study. All subjects were given a verbal explanation of the procedures involved in the study and provided written informed consent in accordance with university guidelines for human experimentation. All subjects completed a medical history questionnaire and were judged as healthy according to guidelines established by the American College of Sports Medicine.

Study Design

Each subject participated in pretest and posttest measurements and an 8-week plyometric training program. On day 1 of testing, body composition and vertical jump power were measured. On day 2, each subject performed a graded exercise test to determine maximal aerobic power ($\dot{V}O_{2max}$). After a day of rest, a muscle biopsy sample was collected on day 4. After completion of testing, subjects were randomly assigned to a training group.

Pretest and Posttest Measurements

Body composition was determined via hydrostatic weighing with a direct measurement of residual lung volume (23). Subjects reported to the laboratory in a 3-hour postprandial state. Subjects were given 5 trials, with the average of the final 3 measurements used to calculate body density (12). Percent body fat (%FAT) was then determined using the Siri equation (20). Test-retest reliability measures (r) for hydrostatic weighing in our laboratory have ranged from 0.94–0.98.

Vertical jump height was measured using a standard jump-and-reach technique and an adjustable measuring device (Vertech, Inc.). Subjects were given a controlled warm-up of jogging and stretching and 3 practice jumps at submaximal effort. Three test jumps were allowed for each subject, with 3 minutes of recovery between jumps. A countermovement with the arms and legs was allowed during each jump. The best score was used to calculate vertical jump peak power and vertical jump average power (16). The test-retest reliability for vertical jump was 0.93.

The graded exercise test was performed on a Quinton Treadmill ergometer. The test began with a 3-minute warm-up at 162 $m \cdot min^{-1}$ and 0% grade. The speed was then increased to 189 $m \cdot min^{-1}$ for 3 minutes with 0% grade. Thereafter, the grade was increased by 2% every 2 minutes until the subject reached exhaustion. During testing, subjects breathed through a 2-way nonrebreathing valve. Expired gases were collected in a 5-L mixing chamber and then directed through a Parkinson-Cowan CD-4 dry gas meter. Expired gas temperature was measured by a Yellow Springs Instrument Model 409 thermistor attached to the inlet side of the dry gas meter. A small sample of dry gas was analyzed for concentrations of oxygen and carbon dioxide using Applied Electro Chemistry Model N-22 and Beckman LB-2 analyzers, respectively. A computer, interfaced with the dry gas meter, gas analyzers, and thermistor, was used to determine metabolic and ventilatory values. During testing, heart rate was monitored using a telemetry unit. The subject's rating of perceived exertion was determined 30 seconds before the end of each stage using Borg's 15-point scale (9). The criteria for achieving $\dot{V}O_{2max}$ required the subjects to achieve any 3 of the following: a heart rate within ± 10 $beats \cdot min^{-1}$ of age predicted maximum; a leveling of $\dot{V}O_2$ with an increase in workload; a respiratory exchange ratio of ≥ 1.10; and an end exercise perceived exertion of >18. Previous reliability measures for $\dot{V}O_{2max}$ have ranged from 0.91–0.94.

A muscle sample from the musculus vastus lateralis was obtained from the subjects at rest according to the percutaneous needle biopsy procedure of Bergström (5). The sample was immediately frozen in isopentane, which was cooled by liquid nitrogen. Once the sample was properly mounted, it was frozen at $-70°$ C until analysis. The samples were sectioned serially (10 μm) and stained histochemically for type I and type II fibers by the myofibrillar adenosinetriphosphatase reaction using acid and alkaline preincubation (10). The fiber area was determined using the lesser diameter technique (22) by an investigator who was blinded to the subject's group assignment. At least 75 fibers of both type I and type II were randomly selected and measured for fiber area determination.

After completion of all pretest measurements, subjects were assigned using stratified random sampling to 1 of 2 groups using the subject's pretest $\dot{V}O_{2max}$ value. Group 1 ($n = 8$) performed plyometric training, and group 2 ($n = 11$) performed plyometric training and aerobic exercise. The aerobic exercise training consisted of continuous running at an intensity equal to 70% of measured heart rate maximum.

Plyometric Training Program

All subjects participated in an 8-week plyometrics training program. The length of the study (8 weeks) was selected because this is the length of many summer or preseason conditioning programs. Jump training exercises were performed 3 $d \cdot wk^{-1}$. The intensity of each exercise was maximal, with daily changes in the number of sets and repetitions. The plyometric training included 2-ft vertical jumps, tuck jumps, 2-legged broad jumps, 1- and 2-legged bounding, and depth jumps completed from a height of 40 cm. During all jumping exercise, subjects were instructed to achieve maximum height, whereas during bounding and depth jumping subjects were instructed to minimize ground contact. The length of recovery between repetitions and sets was 15–30 seconds. A summary of the training program is shown in Table 1. The aerobic exercise performed by group 2 was completed immediately after the plyometric training session. Exercise heart rate was monitored by radial palpation every 5 minutes. An investigator continuously monitored subjects as they performed all plyometric and aerobic exercise.

During the 8 weeks of plyometric training, the subjects did not participate in any physical training other than what they would encounter during normal daily

Table 1. Summary of exercises used in the plyometric training program.

	Weeks							
Movement	1	2	3	4	5	6	7	8
Vertical jumping*	5 (10)	9 (10)	11 (10)	13 (10)	13 (10)	17 (10)	17 (10)	17 (10)
Bounding†	3 (30 m)	4 (30 m)	4 (30 m)	3 (30 m)	1 (30 m)			
Broad jumping†	1 (15 m)	2 (30 m)	4 (30 m)	4 (30 m)	4 (30 m)	4 (30 m)	4 (30 m)	4 (30 m)
Depth jumping*			1 (4)	3 (10)	5 (10)	5 (10)	6 (10)	8 (10)

* Number of sets followed by repetitions.
† Number of sets followed by distance.

Table 2. Vertical jump power prior to and following 8 weeks of plyometric and aerobic exercise training (mean ± *SEM*).*

	Peak power (W)		Average power (W)	
Groups	Pretest	Posttest	Pretest	Posttest
Group 1†	8,335 ± 179	8,578 ± 174	1,670 ± 69	1,767 ± 62
Group 2‡	8,629 ± 146	8,855 ± 136	1,795 ± 77	1,886 ± 72

* No significant ($p > 0.05$) differences were noted between groups on posttest scores for peak or average power . A significant difference was found between posttest and pretest scores ($p \leq 0.05$) within groups.
† In group 1 ($n = 8$), no aerobic exercises were performed.
‡ In group 2 ($n = 11$), 20 minutes of aerobic exercises were performed.

activities. Subjects were also instructed to maintain their normal dietary practices throughout the investigation. At the end of the 8-week training program, subjects were posttested on all measurements using the same procedures and schedule as during pretesting.

Statistical Analysis

An analysis of covariance was used to determine significant differences between the groups, with the pretest measure serving as the covariate. Post hoc comparisons were made using dependent and independent *t*-tests. A Pearson correlation analysis was performed to determine the relationship between the change in fiber area and improvements in vertical jump power production. Significance was set at $p \leq 0.05$. All values are reported as mean ± *SEM*.

Results

No significant differences were observed in body mass between or within the groups following training. The pretest values for body mass were as follows: group 1, 78.0 ± 2.5 kg, and group 2, 80.3 ± 3.6 kg. The body mass values for the posttest were as follows: group 1, 79.3 ± 2.3 kg, and group 2, 81.6 ± 3.6 kg. The plyometric training program did not significantly alter body composition. The pretest values for %FAT were as follows: group 1, 15.6 ± 2.1%, and group 2, 12.7 ± 1.0%. The %FAT values for the posttest were as follows: group 1, 16.8 ± 2.3%, and group 2, 12.7 ± 0.9%.

Vertical jump height improved in each group from pretraining to posttraining. Group 1 increased by 2.7 cm and group 2 increased by 3.1 cm. This represents an increase of 4.6% and 5.0% for groups 1 and 2, respectively. No significant difference was observed between the groups. The peak power and average power from the vertical jump measurements are shown in Table 2. No significant differences were observed between the groups following training for either peak or average power. Both groups displayed significant increases from pretesting to posttesting for both peak and average power. Group 1 increased by 2.8% and 5.5% for peak and average power, respectively. Group 2 increased 2.5% in peak power and 4.8% in average power.

No significant differences were observed in $\dot{V}O_{2max}$ between the groups following the 8-week training program. Each group significantly improved in aerobic power from pretraining to posttraining. Group 1 improved by 12% (44.9 ± 3.9–51.1 ± 5.4 $ml \cdot kg^{-1} \cdot min^{-1}$), and group 2 improved by 14% (43.5 ± 5.3–50.6 ± 4.7 $ml \cdot kg^{-1} \cdot min^{-1}$).

Table 3 illustrates the fiber-type percentages and fiber area before and after the 8 weeks of training. No significant changes in fiber-type percentage were observed. No significant differences in fiber area were found between the groups following training for either type I or type II fibers. Both groups did show significant increases in fiber area after the 8-week training program. For the type I fibers, group 1 increased by

Table 3. Fiber characteristics (by area) prior to and following 8 weeks of plyometric and aerobic exercise training (mean ± *SEM*).

Groups	% Type I Pretest	Type I (μm⁻²) Pretest	Type I (μm⁻²) Posttest	Type II (μm²) Pretest	Type II (μm²) Posttest
Group 1†	42.6 ± 1.9	4,183 ± 62	4,377 ± 53	4,781 ± 153	5,184 ± 165
Group 2‡	42.4 ± 0.7	4,589 ± 81	4,887 ± 113	4,810 ± 108	5,159 ± 195

* No significant differences were noted between groups on posttest scores for Type I or Type II fiber area ($p > 0.05$). A significant difference was found between posttest and pretest scores ($p \leq 0.05$) within groups.

† In group 1 ($n = 8$), no aerobic exercises were performed.

‡ In group 2 ($n = 11$), 20 minutes of aerobic exercises were performed.

Table 4. Correlation coefficients for changes in power output and changes in muscle fiber size following 8 weeks of concurrent plyometric and aerobic exercise training ($n = 19$).

	Peak power	Average power
Type I	0.4768 ($p \leq 0.004$)	0.4709 ($p \leq 0.005$)
Type II	0.5793 ($p \leq 0.001$)	0.6185 ($p \leq 0.001$)

4.4% and group 2 increased by 6.1%. Type II fiber area increased by 7.8% for group 1 and 6.8% for group 2.

Since there were no significant differences in power production or fiber area among the groups, the data were collapsed together for correlation analysis. Significant correlations were observed for the change in vertical jump power production and changes in muscle fiber size for each group. The correlation coefficients for the comparisons are presented in Table 4.

Discussion

In the present study, performing plyometric training resulted in an improvement in leg power production and an increase in muscle fiber size. Additionally, participating in the training program improved $\dot{V}O_{2max}$ but did not significantly alter body composition.

Plyometric training has been proposed as a training mode designed to enhance movement patterns that are used in motor activities such as sprinting and jumping (2). In plyometric training, the amortization phase between eccentric and concentric movements is shortened, allowing greater power production (21). By taking advantage of stored elastic energy and the stretch reflex (18), the muscle is capable of performing more work in the concentric phase. This would allow for improvements in sport performance. In the present study, improvements in vertical jump height and peak and average power production were observed following plyometric training. These results are supported by others who have demonstrated improvement in vertical jump performance (1, 7, 11, 13, 17, 24) and leg power production (4, 8) after plyometric training.

The improvement in muscle performance following plyometric training is most likely due to a combination of enhanced motor unit recruitment patterns and increased muscle fiber cross-sectional area. Although not measured in the present investigation, part of the improved muscle performance could come from neuromuscular adaptations such as an increased inhibition of antagonist muscles, a better co-contraction of synergistic muscle, an increased activation of synergistic muscles, an inhibition of neural protective mechanisms, and/or an increased motor neuron excitability (18, 19). The improvement in power output by the leg muscles could also be due to an increase in muscle fiber size. Improvements in force production have been attributed to increases in muscle fiber size (14, 22). The fiber hypertrophy that occurred in both the type I and type II fibers in the present investigation likely helped to contribute to the increase in jump height and peak and average power output. This concept is supported by the significant correlations observed between the changes in muscle performance and fiber size. Although correlation analyses do not indicate cause and effect, we believe they do provide support for interpretation of the present results.

The increase in $\dot{V}O_{2max}$ for each group was likely the result of the high-intensity work and the short-duration rest intervals used in the plyometric training program. This scenario is similar to interval training, which has been shown to significantly improve $\dot{V}O_{2max}$ (15). The lack of changes in body mass and composition was likely due to the short duration of the study (8 weeks) and the absence of modifications to daily energy intake.

Practical Applications

Maximizing power production is critical for strength/power athletes. Increases in power output are likely to contribute to improvements in athletic performance. The data from the present study indicate that significant increases in leg power output and muscle fiber hypertrophy occur during participation in a plyometric training program. This fiber hypertrophy appears to occur in both slow twitch and fast twitch fibers. The data from the present investigation support the use of plyometric training as a means to improve vertical jump and lower-body power production.

References

1. Adams, K., J. O'Shea, K. O'Shea, and M. Climstein. The effect of six weeks of squat, plyometric and squat plyometric training on power production. *J. Appl. Sport Sci. Res.* 6:36–41. 1992.
2. Asmussen, E., and F. Bonde-Peterson. Storage of elastic energy in skeletal muscle in man. *Acta Physiol. Scand.* 91:385–392. 1974.
3. Baker, D. Improving vertical jump performance through general, special, and specific strength training: A brief review. *J. Strength Cond. Res.* 10:131–136. 1996.
4. Bedi, J., A. Cresswell, T. Engel, and S. Nicoi. Increase in jumping height associated with maximal effort vertical depth jumps. *Res. Q. Exerc. Sport* 58:11–15. 1987.
5. Bergström, J. Muscle electrolytes in man. *Scand. J. Clin. Lab. Invest.* 68:1–110. 1962.
6. Blakey, J., and D. Southard. The combined effects of weight training and plyometrics on dynamic leg strength and leg power. *J. Appl. Sport Sci. Res.* 1:14–16. 1987.
7. Blattner, S., and L. Noble. Relative effects of isokinetic and plyometric training on vertical jumping performance. *Res. Q. Exerc. Sport* 50:583–588. 1979.
8. Bobbert, M. Drop jumping as a training method for jumping ability. *Sports Med.* 9:7–22. 1990.
9. Borg, G. Perceived exertion as an indicator of somatic stress. *Scand. J. Rehabil. Med.* 2:92–98. 1970.
10. Brooke, M.H., and K.K. Kaiser. Three ''myosin adenosine triphosphatase'' systems: The nature of their pH lability and sulfhydryl dependence. *J. Histochem. Cytochem.* 18:670–672. 1970.
11. Brown, M., J. Mayhew, and L. Boleach. Effect of plyometric training on vertical jump performance in high school basketball players. *J. Sports Med. Phys. Fitness* 26:1–4. 1986.
12. Brozek, J., and A. Keys. Densitometric analysis of body composition: Revision of some qualitative assumptions. *Ann. N. Y. Acad. Sci.* 110:113–140. 1963
13. Clutch, D., M. Wilton, C. McGown, and G. Bryce. The effect of depth jumps and weight training on leg strength and vertical jump. *Res. Q. Exerc. Sport 54:5–10. 1983.*
14. Gollnick, P., B. Timson, R. Moore, and M. Riedy. Muscular enlargement and number of fibers in skeletal muscles of rats. *J. Appl. Physiol.* 50:936–943. 1981.
15. Gorostiaga, E., C. Walter, C. Foster, and R. Hickson. Uniqueness of interval and continuous training at the same maintained exercise intensity. *Eur. J. Appl. Physiol.* 63:101–107. 1991.
16. Harman, E., M. Rosenstein, P. Frykman, R. Rosenstein, and W. Kraemer. Estimation of human muscle power output from vertical jump. *J. Appl. Sport Sci. Res.* 3:116–120. 1990.
17. Holcomb, W., J. Lander, R. Rutland, and G. Wilson. The effectiveness of a modified plyometric program on power and the vertical jump. *J. Strength Cond. Res.* 10:89–92. 1996.
18. Komi, P. Physiological and biomechanical correlates of muscle function: Effects of muscle structure and stretch shortening cycle on force and speed. In: *Exercise Sport Science Review.* R.L. Terjung, ed. Lexington, MA: Callamore-Health, 1988. pp. 81–122.
19. Lyttle, A.D., G.J. Wilson, and K.J. Ostrowski. Enhancing performance: Maximal power versus combined weights and plyometrics training. *J. Strength Cond. Res.* 10:173–179. 1996.
20. Siri, W. Body composition from fluid spaces and density. In: *Techniques for Measuring Body Composition.* J. Brozek and A. Henschel, eds. Washington, DC: National Academy of Science, 1961. pp. 223–244.
21. Steben, R., and A. Steben. The validity of the stretch shortening cycle in selected jumping events. *J. Sports Med.* 21:28–37. 1981.
22. Thorstensson, A., B. Hulten, W. von Döbelin, and J. Karlsson. Effect of strength training on enzyme activities and fibre characteristics in human skeletal muscle. *Acta Physiol. Scand.* 96: 392–398. 1976.
23. Wilmore, J. A simplified method for determination of residual lung volume. *J. Appl. Physiol.* 27:96–100. 1980.
24. Wilson, G., R. Newton, A. Murphy, and B. Humphries. The optimal training load for the development of dynamic athletic performance. *Med. Sci. Sports Exerc.* 25:1279–1286. 1993.

Acknowledgments

The authors would like to thank Dr. Steve Myrick for performing the biopsy. This study was supported in part by a University of Kansas General Research Fund Grant and Power Bar Inc.