

The effects of shoulder plyometric training on proprioception and selected muscle performance characteristics

Kathleen A. Swanik, PhD, ATC,^a Scott M. Lephart, PhD, ATC,^b C. Buz Swanik, PhD, ATC,^c Susan P. Lephart, PhD, ATC,^d David A. Stone, MD,^b and Freddie H. Fu, MD,^b Philadelphia and Pittsburgh, Pa

The purpose of this study was to determine the effect of plyometric training of the shoulder internal rotators on proprioception, kinesthesia, and selected muscle performance characteristics in female swimmers. Twenty-four female division I swimmers were evaluated before and after a 6-week plyometric training program. Proprioception and kinesthesia were assessed for internal and external rotation at 0°, 75°, and 90% of the subject's maximum external rotation. The Biodex II was used to assess strength characteristics at 60°/s, 240°/s, and 450°/s. Plyometric training sessions (2 times/week) involved 3 sets of 15 repetitions with a trampoline, weighted balls, and elastic tubing. A 2-way analysis of variance revealed significant improvement ($P < .05$) in proprioception at 0° moving into external rotation, as well as 75° and 90% moving into both internal and external rotation. Kinesthesia demonstrated significant improvement for all test conditions after plyometric training. Significant gains in selected muscle performance characteristics included time to peak torque (60°/s and 240°/s), amortization time (450°/s), and torque decrement (240°/s). This study suggests that plyometric activities may facilitate neural adaptations that enhance proprioception, kinesthesia, and muscle performance characteristics. Significant neuromuscular benefits may be attained if they are implemented earlier into shoulder rehabilitation programs. (J Shoulder Elbow Surg 2002;11:579-86.)

From the Undergraduate Athletic Training Program^a and Graduate Athletic Training Program,^c Temple University, Philadelphia, and Neuromuscular Research Laboratory, University of Pittsburgh, Department of Orthopaedic Surgery, University of Pittsburgh Medical Center^b, and Aircast Foundation,^d Pittsburgh, Pa.

Kathleen A. Swanik, PhD, ATC, Director, Undergraduate Athletic Training Program, Temple University, 1800 N Broad St, 129 Pearson Hall (048-00), Philadelphia, PA 19122 (E-mail: kswanik@unix.temple.edu).

Copyright © 2002 by Journal of Shoulder and Elbow Surgery Board of Trustees.

1058-2746/2002/\$35.00 + 0 **32/1/127303**
doi:10.1067/mse.2002.127303

Upper extremity rehabilitation programs have begun to incorporate plyometric activities to promote the restoration of comprehensive neuromuscular control and functional joint stability. Plyometric activities have received attention in the lower extremity for enhancing muscle performance characteristics. In addition, these tasks have also been thought to improve proprioception and kinesthesia, which are beneficial to functional stability. In the upper extremity there are limited data available exploring the specific neuromuscular adaptations sought by clinicians.^{27,39,41}

Restoring stability in the shoulder encompasses both strengthening of the dynamic stabilizers and reestablishing the neuromuscular control necessary for functional activities. Historically, rehabilitation programs have attempted to regain shoulder stability by strengthening the scapular and humeral musculature. However, traditional strength exercises are initiated only through voluntary muscle activation. Contemporary theories on dynamic restraint and muscle performance focus on both preprogrammed and reflexive muscle recruitment patterns in an attempt to maximize stored elastic energy and force production capabilities, while also maintaining the force couple relationship necessary for dynamic restraint.^{13,14,36,38,41}

Plyometric activities are composed of 3 parts: eccentric loading, amortization time, and concentric contraction. Through theoretical models, these tasks are believed to evoke both peripheral and chronic neural adaptations. Plyometric exercises require voluntary muscle activation to pretension muscles during eccentric loading, which is coupled with reflexive activity induced by the muscle spindles, and can increase muscle force production (concentric contraction) by 10% to 15% to enhance dynamic restraint.^{4,8-10,12,31} In addition, chronic adaptations to plyometric training may also enhance joint proprioception and kinesthesia, characteristics that are also essential for the restoration of functional stability.⁷ In response to chronic exercise, the Golgi tendon organs (GTOs) may desensitize, and in the absence of their inhibitory influence, muscle spindle sensitivity is increased.^{21,23,24,35} By modifying the sensitivity of the muscle spindle, proprioceptive and kinesthetic awareness may be enhanced.^{5,19,35} The purpose of this

study was to determine the effect of plyometric training on shoulder proprioception, kinesthesia, and selected muscle performance characteristics in female athletes.

MATERIALS AND METHODS

This study had a pretest/posttest design and assessed measures of isokinetic performance, proprioception, and kinesthesia. Twenty-four female division I swimmers (age, 20 ± 1.10 years; weight, 62.48 ± 5.85 kg; height, 168.38 ± 6.38 cm) participated. Those in the experimental group were selected by a random numbers list and participated in a 6-week plyometric training program that focused on the internal rotators of the shoulder. Both the control ($n = 12$) and experimental ($n = 12$) groups continued to participate in all aspects of varsity practice, which included swimming (6 days/week), traditional weight training (3 times/week), and functional training (2 days/week). Functional training involved exercises that were performed at sport-specific angles with elastic tubing. In addition to this training, the experimental group performed plyometric exercises on the same days as the functional training and was supervised by one of the investigators. Subjects were excluded from participating in this study if they had a positive Neer and/or Hawkins' impingement sign or pain during manual muscle testing of the shoulder. Subjects were also excluded if they had had surgery on either shoulder or had been limited in practice because of shoulder pain within 3 months prior to testing. Written consent was given before participation, in accordance with the University of Pittsburgh's Biomedical Institutional Review Board. All testing procedures were performed on the dominant limb (20 right and 4 left) by the same investigator.

Proprioception and kinesthesia testing

Proprioception and kinesthesia were assessed with a Biodex II Isokinetic Dynamometer (Biodex Medical Inc, Shirley, NY) and Proprioception Testing Device (PTD, School of Engineering, University of Pittsburgh, Pittsburgh, Pa), respectively. Testing included both internal and external rotation from 3 different starting (reference) positions. These positions were 0° , 75° , and 90° of the subject's maximum external rotation. The starting position was counterbalanced and the direction randomized.

Shoulder proprioception was assessed by measuring active reproduction of passive positioning on the Biodex II. Subjects were tested in an upright, seated position and were secured with pelvic and torso straps. The glenohumeral joint was positioned at 90° of abduction, and the elbow was flexed. The forearm was secured to the resistance arm, limiting shoulder motion to internal and external rotation. Subjects were also fitted with a blindfold and given an on/off switch. After 3 practice attempts, the shoulder was passively rotated from 1 of 3 reference positions to both internal and external rotation angles. The velocity was varied to nullify the use of time. Subjects were allotted 10 seconds to concentrate on the presented angle. The arm was then passively rotated back to the reference position, and the subject was instructed to depress an on/off switch when she actively reproduced the presented angle.²⁹ One

test trial from each reference position was performed moving into both internal and external rotation.

Kinesthesia was assessed by measuring threshold to detect passive motion on the PTD. With the patient lying in the supine position, the arm was positioned in a pneumatic sleeve at 90° of shoulder abduction and 90° of elbow flexion (Figure 1). A headset and blindfold were fitted to eliminate visual and auditory cues.²⁸ After 3 practice attempts, the subject signaled when she was ready to begin testing, and within the next 10 seconds, the PTD passively rotated her arm at a velocity of $0.5^\circ/s$. When motion was detected, the subject disengaged the device by pressing a handheld switch. Three trials were performed, moving into both external and internal rotation.²⁸

Isokinetic assessments

Isokinetic muscle performance of the internal rotators was assessed at 3 speeds ($60^\circ/s$, $240^\circ/s$, and $450^\circ/s$) with the Biodex II. These measurements were assessed during reciprocal concentric contractions and included time to peak torque (milliseconds), peak torque-to-body weight ratio (percent), torque decrement (percent), and amortization time (milliseconds). In addition, agonist/antagonist peak torque ratios (percent) were established for internal and external rotation at $60^\circ/s$. The order of isokinetic testing was counterbalanced for the 3 speeds.

Arms were placed in 90° of shoulder abduction and elbow flexion. All subjects completed a warm-up period that consisted of 3 submaximum (50%-75%) repetitions, followed by 3 maximum repetitions.²⁹ The test began when the subject indicated she was prepared to start. The slow speed ($60^\circ/s$) involved 5 maximum concentric contractions of internal and external rotation, with a predetermined range of motion from 0° to 90° of external rotation. The intermediate speed assessed concentric contraction for internal rotation at $240^\circ/s$ for 25 maximum repetitions. Strength decrement was calculated by dividing the mean of the peak torque for the last 3 contractions by the mean of the peak torque for the first 3 contractions.⁶ Concentric contractions for internal rotation, again through the subject's functional range of motion, were also performed at $450^\circ/s$ for 10 maximum repetitions.

Plyometric training

The experimental group performed the plyometric exercises with elastic tubing and the Pitchback System (Functionally Integrate Technologies, Watsonville, Calif). Three sets of 15 repetitions were performed 2 days a week for 6 consecutive weeks. Both exercises focused on strengthening the internal rotators of the shoulder. Subjects were instructed to maintain the arm at 90° shoulder abduction and elbow flexion while performing the plyometric exercises.

Because of the intensity level of this type of exercise, plyometric training was initiated with elastic tubing for the initial 2 weeks and then progressed to the Pitchback System. Subjects were instructed to perform concentric internal rotation using elastic tubing to their endpoint (forearm horizontal to the ground), hold this position for 2 seconds, and then release the isometric contraction, allowing the tubing to pull the arm into external rotation. As soon as full external rotation was



Figure 1 Threshold to detect passive motion test on the PTD.

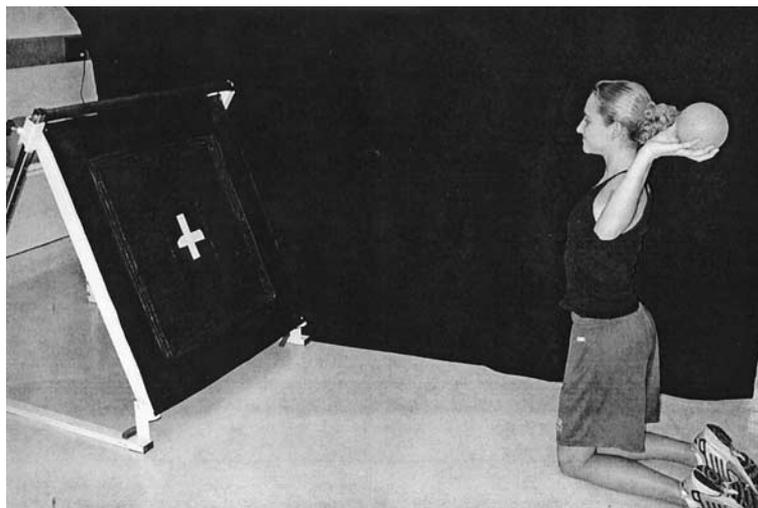


Figure 2 Internal rotation exercise with a weighted ball and the Pitchback trampoline.

achieved, the subjects were to perform concentric internal rotation immediately.⁴¹ After 2 weeks of training with elastic tubing, the subjects progressed to plyometric exercises on the Pitchback System. The same arm position was used, but these exercises were performed while kneeling to eliminate compensatory motion in the lower extremity (Figure 2).⁴¹ Subjects

were instructed to throw and catch a weighted ball ranging from 2 to 8 pounds at the rate of 1 cycle/2 seconds. The primary investigator determined the appropriate starting weight, and the rate was maintained with the aid of a metronome. Because of the nature of swimming, all exercises were performed with both shoulders.

Table I Active reproduction of passive positioning

Position	Control		Experimental	
	Pretest	Posttest	Pretest	Posttest
Neutral				
Internal	3.25 ± 2.09	3.08 ± 2.31	3.25 ± 2.22	2.08 ± 2.10
External	3.92 ± 2.71	4.92 ± 2.67	4.75 ± 1.81	3.00 ± 1.81*
75° of external rotation				
Internal	3.58 ± 2.15	3.83 ± 2.24	4.25 ± 2.37	2.25 ± 1.48*
External	3.33 ± 1.61	3.41 ± 1.73	3.41 ± 1.88	1.17 ± 0.94*
90% of maximum external rotation				
Internal	1.92 ± 1.31	2.75 ± 1.48	3.50 ± 1.73	1.25 ± 1.05*
External	2.67 ± 1.43	2.67 ± 1.28	3.16 ± 1.70	1.25 ± 1.28*

Values depict degrees of error.

*Significant between-group differences ($P < .05$).

RESULTS

Proprioception/kinesthesia

Active reproduction of passive positioning. Results revealed significant within-group differences in measurements for active reproduction of passive positioning at the reference position of 75° moving into both internal rotation ($F[1,22] = 5.30, P = .031$) and external rotation ($F[1,22] = 6.25, P = .020$), as well as 90% of external rotation moving into external rotation ($F[1,22] = 5.22, P = .032$). No significant differences were revealed at 0° of rotation moving into either internal rotation ($F[1,22] = 1.73, P = .210$) or external rotation ($F[1,22] = 0.52, P = .478$) for all subjects. No significant within-group differences were identified at 90% of maximum external rotation moving into internal rotation ($F[1,22] = 2.45, P = .131$).

After 6 weeks of plyometric training, significant differences were found between the control and experimental groups at the reference positions of 0° moving into external rotation ($F[1,22] = 7.02, P = .015$), 75° of external rotation moving into both internal rotation ($F[1,22] = 8.76, P = .007$) and external rotation ($F[1,22] = 7.25, P = .013$), and 90% of maximum external rotation moving into both internal rotation ($F[1,22] = 11.63, P = .003$) and external rotation ($F[1,22] = 5.22, P = .032$). No significant differences were found between the control and experimental groups for 0° moving into internal rotation ($F[1,22] = 0.98, P = .334$) (Table I).

Threshold to detect passive motion. Results revealed significant within-group differences for threshold to detect passive motion from the reference position of 0° moving into internal rotation ($F[1,22] = 10.83, P = .003$) and external rotation ($F[1,22] = 14.62, P = .001$). Detection of passive motion from the reference position of 75° of external rotation moving into both internal rotation ($F[1,22] = 8.71, P = .007$) and external rotation ($F[1,22] = 7.63, P = .011$) revealed significant within-group differences.

Significant within-group differences were also found at the reference position of 90% of maximum external rotation moving into internal rotation ($F[1,22] = 8.94, P = .007$). No significant within-group differences were revealed at the reference position of 90% of maximum external rotation moving into external rotation ($F[1,22] = 1.00, P = .329$).

There were significant between-group differences for detection of passive motion for 0° moving into both internal rotation ($F[1,22] = 6.62, P = .016$) and external rotation ($F[1,22] = 11.49, P = .003$). Significant differences were also revealed at the reference position of 75° of external rotation moving into internal rotation ($F[1,22] = 5.55, P = .028$) and external rotation ($F[1,22] = 26.19, P < .001$). Finally, significant differences were revealed for 90% of maximum external rotation for internal rotation ($F[1,22] = 13.92, P = .001$) and external rotation ($F[1,22] = 11.13, P = .003$) (Table II).

Isokinetic measures

Time to peak torque. Results revealed significant within-group differences for time to peak torque (milliseconds) for the speed of 60°/s ($F[1,22] = 8.70, P = .007$). No significant differences were found within subjects at 240°/s ($F[1,22] = 0.55, P = .466$) or 450°/s ($F[1,22] = 1.28, P = .269$). Significant differences were found for the effect of plyometric training between the control and experimental groups at 60°/s ($F[1,22] = 6.26, P = .020$) and 240°/s ($F[1,22] = 15.41, P = .001$). No significant differences were found between the control and experimental groups at 450°/s ($F[1,22] = 0.90, P = .353$) (Table III).

Peak torque-to-body weight ratio for internal rotation. Results revealed significant within-group differences for peak torque-to-body weight ratio (percent) for the isokinetic speeds of 60°/s ($F[1,22] = 11.68, P = .002$), 240°/s ($F[1,22] = 6.12, P = .022$), and 450°/s ($F[1,22] = 6.36, P = .019$). No significant

Table II Threshold to detect passive motion

Position	Control		Experimental	
	Pretest	Posttest	Pretest	Posttest
Neutral				
Internal	1.31 ± 0.63	1.20 ± 0.78	1.83 ± 1.17	0.91 ± 0.73*
External	1.11 ± 0.48	1.05 ± 0.47	1.69 ± 0.63	0.89 ± 0.70*
75° of external rotation				
Internal	1.19 ± 0.57	1.09 ± 0.70	1.80 ± 0.91	0.91 ± 0.75*
External	1.17 ± 0.53	1.43 ± 0.68	1.71 ± 0.68	0.86 ± 0.56*
90% of maximum active external rotation				
Internal	1.44 ± 0.58	1.47 ± 0.86	1.68 ± 0.71	0.59 ± 0.27*
External	0.92 ± 0.33	1.26 ± 0.85	1.67 ± 0.72	1.07 ± 0.74*

Values depict degrees of rotation before motion is detected.
*Significant between-group differences ($P < .05$).

Table III Time to peak torque (in milliseconds)

Speed	Control		Experimental	
	Pretest	Posttest	Pretest	Posttest
60°/s	611.67 ± 233.90	596.67 ± 227.32	600.83 ± 207.90	418.33 ± 157.12*
240°/s	442.50 ± 70.47	490.83 ± 66.67	487.5 ± 66.76	416.67 ± 88.45*
450°/s	349.17 ± 34.56	347.50 ± 35.19	363.92 ± 39.75	345.00 ± 54.02

*Significant between-group differences ($P < .05$).

Table IV Amortization time for shoulder external to internal rotation (in milliseconds)

Speed	Control		Experimental	
	Pretest	Posttest	Pretest	Posttest
240°/s	533 ± 158	468 ± 138	580 ± 158	424 ± 201
450°/s	543 ± 133	490 ± 141	635 ± 340	389 ± 184*

*Significant between-group differences ($P < .05$).

differences were found between groups for the effect of plyometric training at 60°/s ($F[1,22] = 0.00, P = .963$), 240°/s ($F[1,22] = 0.01, P = .921$), or 450°/s ($F[1,22] = 1.80, P = .193$).

Torque decrement. Results revealed no within-group differences for torque decrement ($F[1,22] = 2.44, P = .133$). However, the plyometric group demonstrated significant improvement in endurance (mean, 94.50% ± 3.18%) compared with the control group (mean, 82.25% ± 10.35%) at 240°/s ($F[1,22] = 11.81, P = .002$).

Amortization time. Results revealed significant within-group differences for amortization time for the isokinetic speeds of 240°/s ($F[1,22] = 7.30, P = .013$) and 450°/s ($F[1,22] = 20.66, P < .001$). Significant differences were also found between the control and experimental groups at 450°/s ($F[1,22] = 8.56, P = .008$). No significant differences were found between the control and experimental groups at 240°/s ($F[1,22] = 1.27, P = .273$) (Table IV).

Agonist/antagonist torque ratio. Agonist/antagonist torque ratio was examined at 60°/s. Results revealed significant within-group differences for internal and external rotation ($F[1,22] = 10.63, P = .004$). No significant differences were found between the control and experimental groups ($F[1,22] = 0.23, P = .633$).

DISCUSSION

Plyometric training resulted in significant improvements in both proprioception and kinesthesia. The plyometric group improved significantly more than the control group in 5 of 6 proprioceptive tests (active reproduction of passive positioning) and in all 6 kinesthetic tests (threshold to detect passive motion). These differences suggest that peripheral and central neural adaptations were induced by plyometric training, resulting in improved joint position sense and detection of joint motion.

Peripheral adaptations that may have occurred because of plyometric training likely resulted from the repetitive stimulation of the articular mechanoreceptors near the end range of motion in the shoulder during these exercises.^{15,18,41} Previous research has suggested that articular mechanoreceptors are maximally stimulated when the shoulder is rotated to these end ranges.^{29,30} In addition, rapid length/tension changes placed on the tenomuscular structures during eccentric loading may have facilitated adaptations to muscle spindles and GTOs. Several authors agree that desensitizing the GTO heightens the stretch sensitivity of the muscle spindles to length change.^{13,16,25,27,29,31,37,41} Heightening the sensitivity of the muscle spindle system may increase their afferent contributions to the central nervous system with regard to joint position. These adaptations may also be responsible for the enhanced proprioception demonstrated by these athletes.

Central adaptations resulting from plyometric training may also improve proprioception. The novelty of this task required preparatory muscle activation in anticipation of catching the ball and involuntary muscle activity for concentric force production while throwing the ball. Joint position sense is significantly improved when muscles are stimulated; therefore, this activity may have reinforced or enhanced conscious awareness of joint position.³ Currently, only one upper extremity proprioception study has examined the effect of plyometric training. Heiderscheit et al²⁰ conducted an 8-week plyometric training program for the internal rotators on sedentary, healthy female subjects and found no significant differences between pretest and posttest conditions. However, several authors have suggested that joint position sense can be enhanced with training or rehabilitation.^{7,22,27,35,40} The results of this study confirm these hypotheses. Incorporating these exercises into upper extremity rehabilitation can assist in reestablishing proprioception and neuromuscular control through peripheral and/or central adaptations.

Kinesthesia is another component of sensory information believed to be enhanced through the use of plyometric activities.^{26,41}

Improvements in kinesthesia may also be related to desensitization of the GTOs and heightened sensitivity of the muscle spindles.^{26,41} Although this mechanism is theoretical, the results of this study suggest that adaptations do occur. Several authors have investigated kinesthetic deficits as a result of capsular laxity and injury, but this is the first study to evaluate the effects of upper extremity training on kinesthesia.^{3,16,30,41} Allegrucci et al³ compared shoulder kinesthesia in unilateral overhead athletes and found significant deficits in the dominant arm when compared with the nondominant arm. This was attributed to an increase in external rotation and capsular laxity.

The findings of this study support the use of plyometric training for improving kinesthetic awareness. Consequently, the incorporation of plyometric activities into upper extremity rehabilitation can address the kinesthetic deficits that occur after injury and capsular laxity.

This study revealed significant overall gains in the rate of contractile strength of the subjects when measured as time to peak torque at 60°/s. This effect could be attributed to the strength and functional training programs that all subjects were required to undergo. Group differences were also revealed, demonstrating the significant effect plyometric training had on time to peak torque at speeds of 60°/s and 240°/s. Improved contraction time is likely the result of adaptations in both the elastic properties and neural components of muscle. After the 6-week plyometric training period, the athletes became adept at performing the exercise, thus enabling muscles to use the stored elastic energy efficiently, while also increasing motor unit recruitment. The findings of our study support the theoretical basis for plyometric training^{34,41} and validate its important contribution to the rehabilitation process, as the speed of muscle contraction plays a critical role in both performance and protection to the shoulder.

A significant overall improvement in peak torque-to-body weight ratio was revealed at the speed of 60°/s. This strength gain can be attributed to the functional and traditional weight-training programs performed by all subjects. The plyometric group did not demonstrate greater gains in peak torque-to-body weight ratio and would have needed drastic improvements in strength to differ significantly from the control group. This is unlikely to occur in highly trained individuals without time for morphologic changes such as muscle hypertrophy.^{26,37,38,41}

The results of this study support the rationale that plyometric training may not be the most effective activity to enhance torque development, particularly in highly trained athletes.³³ Plyometric activities should not be integrated into rehabilitation programs for pure strength gains and should be implemented gradually until strength has been reestablished. In addition, because plyometric activities can be performed at varying levels of intensity, it is appropriate the use them in conjunction with strengthening exercises.

The plyometric group's improvement in torque decrement demonstrates important neuromuscular adaptations for endurance. The relatively high repetitions performed during training could have promoted neurologic adaptations that increased muscle coordination and efficiency, resulting in the maintenance of torque production during prolonged bouts of exercise. Beach et al⁶ and Falkel and Murphy¹⁷ have demonstrated that poor endurance is directly related

to shoulder pain in swimmers. This study revealed that plyometric exercises promote endurance adaptations in the shoulder rotator cuff musculature, which is critical for reestablishing functional stability.

Amortization time for shoulder external to internal rotation

Amortization time is defined as the period between eccentric loading (prestretch) and concentric contraction. This was measured by calculating the transition period between maximum external rotation and the beginning of internal rotation where no measurable change in position or velocity was detected with the Biodex II. Similar to the isokinetic variables, amortization time improved overall for both groups, suggesting that the components of varsity training resulted in enhanced muscle performance. However, the plyometric group revealed greater improvement compared with the control group at 450°/s.

This is the first study to reveal adaptive changes in amortization time after plyometric training for the upper extremity. The times recorded in our study were much slower in contrast to those for the lower extremity.¹¹ However, it is difficult to make comparisons between upper and lower extremity amortization time because of the differences in overall strength, fiber type, and muscle mass. Since the initial work by Cavagna et al¹² and Bosco and Komi,⁸ several studies have examined the impact of amortization time on concentric contractile forces and muscle performance in the lower extremity.^{4,8,10-12} These investigations were able to establish a relationship between decreased amortization times and increased muscle performance. These improvements were believed to occur as a result of an increase in motor unit recruitment and efficient utilization of the elastic energy, thus producing a stronger concentric contraction.¹¹

Upper extremity sports require that a maximum amount of muscle force be produced in a minimal amount of time. These specific demands can effectively be reproduced by performing shoulder plyometric activities, and if a decrease in amortization time does enhance involuntary muscle activity, it will allow for greater muscle recruitment and utilization of stored elastic energy. Increased neuromuscular efficiency and coordinated muscle firing may decrease the onset of fatigue and assist with dynamic restraint and functional stability.

External to internal rotation torque ratio

A significant change in the external to internal rotation torque ratio was revealed as a result of improvements in the internal rotation mean peak torque values. The slight improvement in internal rotation torque can be attributed to sport-specific adaptations induced by the swim training all subjects com-

pleted. This placed significant demands on the shoulder internal rotator and adductor muscles; however, the lack of group differences suggests that plyometric training does not affect torque ratio.

Normal strength ratios for the external and internal rotators of the shoulder have been reported to be 2:3.^{1,2,6,17,20,32,41} Maintaining a balance of strength between the external and internal rotators of the shoulder is critical for normal muscular force couple activity and, therefore, necessary for glenohumeral stability. A disruption of these strength ratios will ultimately affect containment of the humeral head within the glenoid cavity. The findings in this study revealed that external to internal strength ratio decreased after 6 weeks of functional training. For this reason, we suggest that emphasis be placed on strengthening the external rotators in these athletes, particularly during the competitive season.

This study demonstrates that plyometric activities are an important component of rehabilitation, based on our findings, which support the theoretical concepts for using these types of activities for the upper extremity. Most of the literature suggests that this type of exercise be performed in the latter stages of rehabilitation or for shoulder strength training; however, because of the various levels of intensity associated with plyometrics, as well as the significant effects these exercises have on proprioception and muscle performance, it is reasonable that plyometrics could also be beneficial if implemented in the earlier stages of shoulder rehabilitation.

We would like express our gratitude toward the University of Pittsburgh's Women's Swimming Team for their participation in this study, and we acknowledge Dr Elaine Rubinstein for her time and expertise with the statistical analyses.

REFERENCES

1. Alderink GJ, Kuck DJ. Isokinetic shoulder strength of high school and college-aged pitchers. *J Orthop Sports Phys Ther* 1986;7:163-72.
2. Allegrucci M, Whitney SL, Irrgang JJ. Clinical implications of secondary impingement of the shoulder in freestyle swimmers. *J Orthop Sports Phys Ther* 1994;20:307-18.
3. Allegrucci M, Whitney SL, Lephart SM, Irrgang JJ, Fu FH. Shoulder kinesthesia in healthy unilateral athletes participating in upper extremity sports. *J Orthop Sports Phys Ther* 1995;21:220-6.
4. Assmussen E, Bonde-Peterson F. Storage of elastic energy in skeletal muscle in man. *Acta Physiol Scand* 1974;91:385-92.
5. Barker D. The morphology of muscle receptors. In: Hunt CC, editor. *Handbook of sensory physiology*. Germany: Springer-Verlag; 1974. p. 191-234.
6. Beach ML, Whitney SL, Dickoff-Hoffman SA. Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *J Orthop Sports Phys Ther* 1992;16:362-8.
7. Borsa PA, Lephart SM, Kocher MS, Lephart SP. Functional assessment and rehabilitation of shoulder proprioception for glenohumeral instability. *J Sport Rehabil* 1994;3:84-104.
8. Bosco C, Komi P. Potentiation of the mechanical behavior of the

- human skeletal muscle through prestretching. *Acta Physiol Scand* 1979;106:467-72.
9. Bosco C, Komi P. Muscle elasticity in athletes. In: *Exercise and sports biology*. Champaign (IL): Human Kinetics Publishers; 1982.
 10. Bosco C, Tarkka C, Komi P. Effect of elastic energy and myoelectric potentiation of triceps surae during stretch-shortening cycle exercise. *Int J Sports Med* 1982;2:137-140.
 11. Bosco C, Tihanyi J, Komi P, Fekete G, Apor P. Store and recoil of elastic energy in slow and fast types of human skeletal muscles. *Acta Physiol Scand* 1982;116:343-9.
 12. Cavagna GA, Dismar B, Margarai R. Positive work done by a previously stretched muscle. *J Appl Physiol* 1968;24:21-32.
 13. Chu D. Plyometric exercise. *Nat Strength Condition Assoc J* 1984;6:56-62.
 14. Chu D. The language of plyometrics. *Nat Strength Condition Assoc J* 1984;6:30-1.
 15. Clark FJ, Burgess PR. Slowly adapting receptors in cat knee joint: can they signal joint angle? *J Neurophysiol* 1975;38:1448-63.
 16. Davies GJ, Dickoff-Hoffman S. Neuromuscular testing and rehabilitation of the shoulder complex. *J Orthop Sports Phys Ther* 1993;18:449-58.
 17. Falkel JE, Murphy TC. Case principles: swimmer's shoulder. In: Malone TE, editor. *Shoulder injuries, sports injury management*. 1(2). Baltimore: Lippincott Williams & Wilkins; 1988. p. 109-25.
 18. Grigg P. Peripheral neural mechanisms in proprioception. *J Sport Rehabil* 1994;9:1-17.
 19. Guyton AC. *Textbook of medical physiology*. 6th ed. Philadelphia: Saunders; 1981, p. 122-37, 534-6, 562-4, 588-95, 629-9.
 20. Heiderscheit BC, Mclean KP, Davies GJ. The effects of isokinetic vs plyometric training on the shoulder internal rotators. *J Orthop Sports Phys Ther* 1996;23:125-33.
 21. Hutton RS, Atwater SV. Acute and chronic adaptations of muscle proprioceptors in response to increased use. *Sports Med* 1992;14:406-21.
 22. Jobe FW, Tibone JE, Perry J, Moynes D. An EMG analysis of the shoulder in pitching and throwing: a preliminary report. *Am J Sports Med* 1983;11:3-5.
 23. Johansson H, Sjolandeer P, Sojka P. Actions on the gamma-motoneurons elicited by electrical stimulation of joint afferent fibres in the hind limb of the cat. *J Physiol* 1986;375:137-52.
 24. Johansson H, Sjolandeer P, Sojka P. Receptors in the knee joint ligaments and their role in the biomechanics of the joint. *Crit Rev Bio Med Eng* 1991;18:341-368.
 25. Komi P, Bosco C. Utilization of stored elastic energy in leg extensor muscles by men and women. *Med Sci Sports Exerc* 1978;10:261-5.
 26. Lees A, Graham-Smith P. Plyometric training: a review of principles and practice. *Sports Exerc Inj* 1996;2:24-30.
 27. Lephart SM, Henry TJ. The physiological basis for open and closed kinetic chain rehabilitation for the upper extremity. *J Sport Rehabil* 1996;5:71-87.
 28. Lephart SM, Kocher MS. The role of exercises in the prevention of shoulder disorders. In: Fu FH, Hawkins RJ, editors. *The shoulder: a balance of mobility and stability*. Rosemont (IL): American Academy of Orthopaedic Surgeons; 1993. p. 597-620.
 29. Lephart SM, Pincivero DM, Giraldo JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. *Am J Sports Med* 1997;25:130-7.
 30. Lephart SM, Warner JJ, Borsa PA, Fu FH. Proprioception of the shoulder joint in healthy, unstable, and surgically repaired shoulders. *J Shoulder Elbow Surg* 1994;3:371-80.
 31. Lundin PE. A review of plyometric training. *Nat Strength Condition Assoc J* 1985;7:65-70.
 32. McMaster WC, Long SC, Caiozzo VJ. Shoulder torque changes in the swimming athlete. *J Orthop Sports Phys Ther* 1992;20:323-7.
 33. Perrin DH. *Isokinetic exercises and assessment*. Champaign (IL): Human Kinetics Publishers; 1993. p. 13-20, 25-33.
 34. Pezzullo DJ, Karas S, Irrgang JJ. Functional plyometric exercises for the throwing athlete. *J Athl Training* 1995;30:22-6.
 35. Swanic CB, Lephart SM, Giannantonio FP, Fu FH. Reestablishing neuromuscular control in the ACL injured athlete. *J Sport Rehabil* 1997;6:182-206.
 36. Verkhoshanski Y. Perspectives in the improvement of speed-strength preparation of jumpers. *Yessis Rev Sov Phys Educ Sports* 1969;4:28-9.
 37. Voight ML. Stretch-strengthening: an introduction to plyometrics. *Orthop Phys Ther Clin North Am*:1992;1:243-52.
 38. Voight ML, Draovitch P. Plyometrics. In: Albert M, editor. *Eccentric muscle training in sports and orthopedics*. New York: Churchill Livingstone; 1991. p. 45-73.
 39. Warner JJ, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Scapulothoracic motion in normal shoulders and shoulders with glenohumeral instability and impingement syndrome. *Clin Orthop Rel Topics* 1992;285:191-9.
 40. Wilk KE, Arrigo CA, Andrews JR. Current concepts: the stabilizing structures of the glenohumeral joint. *J Orthop Sports Phys Ther* 1997;25:364-79.
 41. Wilk KE, Voight ML, Keirns MA, Gambetta V, Andrews JR, Dillman CJ. Stretch-shortening drill for the upper extremities: theory and clinical application. *J Orthop Sports Phys Ther* 1993;17:225-39.