The Effects of Plyometric Training on the Shoulder Internal Rotators

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Plyometric training has become an important part of upper extremity rehabilitation protocols. The purpose of this study was to determine the effects of plyometric training on the shoulder internal rotators (IR). Male subjects (N=34) were randomly divided into two groups: control or plyometric training. Pre- /interim/posttesting measurements included: 1) kinesthetic measurements of shoulder IR at 100, and external rotation (ER) at 10° and 75°, 2) passive and active rotation measurements of shoulder ER; 3) softball distance test; and 4) concentric isokinetic power measurements of the shoulder IRs at 60°/sec, 180°/sec, and 30°Psec. The plyometric group trained 2x/wk for two 4-week sessions. A dependent *t* test was performed on interim tests one and two. A repeated measure analysis of variance (RM ANOVA) was performed on the pre/post test data A dependent t test was performed on the significant vasiabies as revealed by the RM ANOVA. There were significant ($p<. 05$) increases in passive ER, concentric isokinetic power at 180°/sec and 300°/sec, and softball throwing distance for the plyometric group. Plyometric training of the shoulder IRs improves isokinetic power, passive ROM, and functional performance as measured by a softball throw for distance.

Key Words: shoulder, plyometric, throwing

Today's sports and recreation activities have become more and more competitive, with this increased competitive nature comes an increase in the desire to improve performance. Many techniques have been used over the years in an attempt to enhance performance, and thus improve success. One of the most important aspects of performance enhancement, other than skill, is the ability to produce power (38).

Many athletic events rely on the ability of the athlete to produce power. In order to assist the athlete in training for these events, the concept of plyometrics was introduced in Russia in 1969 (36,37). This technique was originally known as the shock method of training. Presently, plyometrics are also being used for lower and upper extremity rehabilitation Many research studies have documented the effectiveness of plyometric training on increasing power in the lower extremities (1,4,7,8,9,11,33,35,36). No research studies have documented the effectiveness of plyometric training on the upper extremities. With an increased role of the third party payer in today's medical environment it is imperative that sound research document the use of various therapeutic techniques.

Therefore, the purpose of this research study was to determine the effects of plyometric training on the upper extremity on various performance parameters.

A plyometric activity is divided into three phases: 1) the eccentric preload phase, 2) the amoritization phase, and 3) the concentric contraction (24,32,34). The eccentric preload is the phase in which elastic energy is stored in the series elastic components (SEC) of the muscle (10,13,14,15). The amortization phase is described as the time between the eccentric preload phase and the concentric contraction. The shorter the amortization phase, the greater the work output in the concentric phase due to optimal utilization of the stored elastic energy (13,14,15).

In order to fully understand the plyometric activity, it is important to know the role ofa few key structures. These structures are the SECs of the muscle and the muscle proprioceptors, i.e muscle spindles and golgi tendon organs (GTO) (17). The SECs are the portions of the muscle that do not contract. This includes tendons, sarcolemmal ends of muscle fibers and the hinged arms of cross-bridges (22). The SECs are responsible for storing the potential elastic energy involved in the plyometric activity.

The muscle spindles function as stretch receptors by monitoring the rate and magnitude of change in length of the muscle, thus preventing the muscle from being over stretched (40). The muscle spindles form the stretch or myotatic stretch reflex. This reflex responds to stretch by causing contraction of the extrafusal agonist muscle fibers. During the eccentric preload phase, the muscle is stretched thus activating the myotatic stretch reflex, which enhances the concentric contraction of the agonist muscle. The intensity of the concentric contraction is directly dependent on the speed that the muscle is stretched during the eccentric preload phase. Thus, the faster the muscle is stretched during the eccentric preload phase, the greater the resulting concentric contraction (10,14,39).

The other proprioceptor involved in a plyometric activity is the GTO. GTOs are located in muscle tendons. GTOs are responsible for transmitting information about tension or the rate of change of tension produced by a muscle; thus they assist in preventing over contraction by inhibiting the muscle (24,39).

It has been theorized that plyometric training desensitizes the GTOs by elevating the level at which inhibition occurs, thus allowing greater accumulation of force (40). The GTOs in combination with the muscle spindles are also involved in joint proprioception. Joint proprioception involves determining a joint's angle and detecting its rate of movement in space. This is also a very important factor in determining athletic performance. Therefore, the theorized raising of the GTO firing threshold may result in a change in joint proprioception or kinesthetic sense.

As previously mentioned there have been numerous research studies that have documented the effectiveness of plyometric training for increasing power in the lower extremities (1,4,7,8,9,11,33,35,36). Adams et al. reported that plyometric training improved vertical jump performance in a group of "non-athletes" (1). Anderst et al. reported that both plyometric training and explosive resistance training improved takeoff velocity, takeoff power, and jump height (4). Blattner and Noble compared the effects of isokinetic training versus plyometric training on the lower extremities. They reported that both techniques improved vertical jump performance, but neither technique was superior (8). Parcells et al.compared the effects of plyometric training versus isotonic training on the lower extremities. They reported that plyometric training produced significant increases in vertical jump performance over isotonic training (33). Verkhoshanski et al. reported that plyometric training improved vertical jump performance in high school basketball players (36).

As stated earlier there have been no research studies that have documented the effectiveness of plyometric training on the upper extremities. Only one research study has attempted to document the effectiveness of plyometric training on the upper extremities. Heiderscheit et al. compared the effects of isokinetic versus plyometric training on the shoulder internal rotators. They randomly divided 78 college-aged females into three groups: control, isokinetic training, or plyometric training. All subjects underwent pre/post testing which included: isokinetic power testing, kinesthetic awareness testing, and a softball distance-throwing test. Both training groups trained two times per week for eight weeks. The plyometric group showed no significant change in any of the variables tested. The isokinetic group showed a significant increase in internal rotator power at 60°/sec eccentric, 120°/sec concentric and eccentric, and 240°/sec concentric and eccentric. The isokinetic group showed no significant change in any of the other variables tested (26).

One limitation with this study was that they used female subjects who were unskilled in the throwing motion versus the use of skilled subjects. This was a problem because many of the subjects threw utilizing an elbow extension pattern. Consequently, the major muscle used to throw the softball was their triceps rather than the glenohumeral internal rotators. Therefore, by training their internal rotators you would expect to see no carry over to improved functional performance in the softball-throwing test.

The second limitation of this study was that they tested and trained the subjects with their arm positioned in 45° of shoulder abduction and 5°-10° of horizontal flexion versus the 90°/90° position (90° of shoulder abduction and 90° of elbow flexion). The 90°/90° position as described by Wilk et al. most functionally simulates the throwing motion(40). By testing and training the subjects in the former position you not only decrease the neural adaptation to the throwing motion, but you also put the subjects in a position that encourages the use of accessory muscles.

With the need for research on upper extremity plyometrics clearly stated the purpose of this project was to document the effects of plyometric training on: 1) glenohumeral internal and external rotation kinesthetic sense, 2) glenohumeral active and passive external rotation, 3) softball throwing distance, and 4) glenohumeral internal rotation concentric isokinetic power.

METHODOLOGY

Subject Selection

College-aged (18-28) males (N=34) with at least one year of experience in a competitive overhead sport (baseball, volleyball, tennis, etc.) were recruited as subjects. Exclusion criteria included: 1) active participation in an intercollegiate sport, 2) shoulder pathology in the dominant arm within the last year, and 3) current involvement in a non-maintenance upper body strength training program. All subjects signed an informed consent form, which was approved by the University of Wisconsin-La Crosse's Institutional Review Board.

Pretest

The following tests were performed one week prior to the initiation of the training program.

Kinesthetic Awareness - Kinesthetic awareness was evaluated using the Cybex EDI-320 electronic inclinometer (Lumex, Inc., Ronkonkoma, NY), to measure joint angle replication (Figure 1). The Cybex EDI 320 electronic inclinometer has shown acceptable reliability in measuring low back range of motion(16). Measurements were taken for internal rotation at 10° and external rotation at 10° and 75°. The IR and ER angles at 10° were chosen based on a study by Lephart et al. In this study they reported a significant difference in kinesthetic sense for patients with anterior instability at these angles (30). 75° of ER was chosen based on a study by Allegrucci et al. In this study they reported that kinesthetic feedback is enhance when the joint capsule was taut (2).

The subjects were positioned supine with their dominant arm (determined by which arm the subject used to throw the softball) in the 90°/90° position. The inclinometer was placed on the dorsal aspect of the forearm for internal rotation and on the ventral aspect of the forearm for external rotation. Prior to test trials the subject performed one practice trial at 35° of internal rotation. With the inclinometer on the dorsal/ventral aspect of the subjects forearm the Cybex EDI- 320 electronic inclinometer was zeroed at the neutral (O°) rotation position. With the subject's eyes closed, the dominant arm was passively rotated to the specified angle. The subject was then instructed to actively hold this position for 10 seconds. The subject's arm and the inclinometer was then passively rotated back to the original zero position (O°). The subject was then instructed to actively reproduce the previous angle. The difference between the original angle and the reproduced angle was then recorded. The subject was randomly tested at each of the specified angles three times. The three results at each angle were then averaged to obtain one measurement per angle. The same examiner performed all testing.

Range of Motion

The same examiner using a standard goniometer evaluated range of motion. Testing was performed according to the guidelines described for external rotation in Measurement of Joint Motion (32). The subjects were positioned supine with their dominant arm in the 90°/90° position. Active and passive external rotation was measured.

Softball Distance Throw

The Underkofler softball distance throw was used as a functional measure of internal rotator strength. This test was performed using a modified version of the Underkofler Softball Skills Test (19). The subjects performed a submaximal three-minute (1.5 minutes forward, 1.5 minutes retro) warm-up on a Cybex Fitron (Lumex, Inc.,Ronkonkoma, NY) adapted for upper body exercise. Subjects then performed a 30-second stretch of the shoulder internal and external rotators (27), followed by a three-minute session of soft toss. The subjects were then placed in the tall kneeling position. This position was used to further isolate the upper extremities in the throwing motion. The subjects performed four submaximal to maximal warm-ups (25%-100%). Subjects then performed three maximum throws. Distance was determined to the nearest half inch using a tape measure placed at the position of the subject and at the point of the ball-ground contact. These three maximal throws were recorded and the mean calculated.

Isokinetic Power Test

Testing was performed using the Cybex 340 System (Lumex, Inc., Ronkonkoma, NY). The reliability and validity of the Cybex dynamometers have been demonstrated in many studies (6,29,31). The system was set up according to the guidelines described in the user's manual for measurement of shoulder internal/external rotation at 90° of abduction (20) (Figure 2).

Testing was performed on the subject's dominant arm. Internal rotator concentric strength was measured. Eccentric internal rotator strength was not measured due to the limitations of the Cybex 340 System. Range of motion was set at 70° internal rotation and 70° external rotation. The testing protocol consisted of testing at 60°/sec, 180°/sec, and 300°/sec. The subjects performed four submaximal to maximal warm-ups (25%-100%), followed by five maximal tests at each speed (21). Subjects were instructed to give 100% effort on the maximum tests, and were also provided with positive verbal feedback during the testing (34). Subjects also were advised to use stretching, ice, and ibuprofen to help relieve any soreness that may develop.

Training Program

Subjects were randomly assigned to two groups: control (N=17) and plyometric (N=17). The plyometric group trained two times per week (3,17,33) for a total of eight weeks (12). This frequency allowed the needed rest period associated with plyometric training (17). The plyometric group trained for two four-week sessions with one week off in between. The week off between the two four week sessions allowed the researchers to determine if there was a detraining effect after the first four week training session.

The plyometric group performed a three-minute (1.5 minute forward, 1.5 minute retro) submaximal warm-up on a Cybex Fitron (Lumex, Inc., Ronkonkoma, NY) adapted for upper body exercise. The subjects then performed a 30-second stretch of the internal and external rotators (27).

The plyometric group trained on the Plyoback System (Functionally Integrated Technologies, Watsonville, CA) (Figure 3). The subjects stood 228.6 cm from the front of the plyoback system, and threw the weighted ball at the center of the trampoline using a one handed overhead throwing motion. The subjects were required to maintain their shoulder in the 90°/90° position described by Chu and Panariello and Wilk et al(19,40). The subjects were observed by trained research assistants who provided positive verbal feedback throughout the training (34).

The plyometric training protocol (Table 1) consisted of using a .91-kg ball for the first four-week session. Weeks one and two the subjects completed three sets of ten repetitions. In weeks three and four the subjects completed four sets of ten repetitions. In the second four-week training session, the subjects used a 1.36- kg ball. In weeks five and six, the subjects completed three sets of ten repetitions. In weeks seven and eight, the subjects completed five sets of ten repetitions. This increase in sets was due to the ability of the subjects to maintain a 90°/90° position during training. Subjects were provided with a 90-second rest period between each set in order to allow for the rebuilding of the muscles ATP-CP stores (23,28).

Interim Test 1/Interim Test Z/Posttest

As previously mentioned, the training protocol consisted of two four week session with one week off in between. In order to judge the effects of each training session individually and the entire training session as a whole it was necessary to implement a pre and posttest after each session (posttest for session one = interim test one, pre test for session two = interim test two). These interim tests also allowed us to evaluate a possible detraining effect associated with a week off between sessions one and two.

Interim and post testing consisted of the four tests (kinesthetic awareness testing, range of motion testing, softball distance throwing test, and isokinetic power testing) outlined in the pretest protocol.

Statistical Analysis

A dependent *t* test was performed on the plyometric group's interim test one and interim test two data, in order to determine if there was a detraining effect associated with the week off between session one and two. No significant change was noted between interim tests one and two for the plyometric group. For this reason the researchers will now focus on the pre/posttest data

A repeated measure analysis of variance (RM ANOVA) was performed on the control and plyometric group's pre/posttest data, in order to determine if there was a significant group by time interaction. A dependent t test was then performed on the significant variables (as determined by the RM ANOVA) to determine which group demonstrated a significant change. The level of significance for all statistical analysis was set at $p < .05$.

RESULTS

A 100% compliance rate was achieved by all subjects, with all thirty-four subjects completing the study. Demographics of the subjects are summarized in Table 2. The groups were not statistically different in terms of age, height, or weight. The control group showed no significant improvement in any of the variables tested (Tables 3-6).

Kinesthetic Awareness

The plyometric group demonstrated no significant change in kinesthetic score at any of the positions tested. These results indicate that plyometric training does not effect glenohumeral rotational kinesthetic sense at any of the positions tested within the limitations of this study.

Range of Motion Testing

The plyometric group demonstrated a non-significant increase in active external rotation ($p < .203$). The plyometric group did show a significant increase in passive external rotation ($p < .037$) (Table 4).

Isokinetic Power Test

The plyometric group showed no significant increase in concentric isokinetic power at 60°/sec. The plyometric group did show a significant increase in concentric isokinetic power at 180°/sec ($p < .004$) and 300°/sec ($p < .029$) (Table 5).

Softball Distance Throw

A significant increase in softball throwing distance was also demonstrated by the plyometric group ($p < .001$) (Table 5).

DISCUSSION

The control group did not demonstrate a significant learning effect as no significant improvement was observed in any of the pre/posttest variables.

The plyometric group showed no significant change between interim test one and interim test two. This demonstrates that there was no detraining effect associated with the one week off between sessions one and two. This fact will now allow the researchers to focus their attention on the pre/posttest data.

The plyometric group failed to show any significant change in kinesthetic sense of the shoulder. Lephart et al. reported that athletically active individuals with chronic, traumatic shoulder instability had significant kinesthetic deficits. They also reported that surgical stabilization of such a shoulder normalized kinesthetic sense (30). This lack of kinesthetic sense may result in abnormal neuromuscular coordination, which could lead to further injury. Lephart et al. also suggest further research on the effects of upper extremity exercise on shoulder proprioception(30). Allegrucci et al. has also reported a decrease in kinesthetic awareness for overhand athletes dominant arm as compared to their non-dominant arm. They also suggest that this decrease in proprioception may be a mechanism for shoulder instability (2).

Based on these studies there is a clear need for upper extremity proprioceptive rehabilitation. Halbach and Tank also state the need for kinesthetic rehabilitation of the shoulder (25). The results of this study show plyometric training to be ineffective in changing the rotational proprioception of the non-pathological glenohumeral joint. A study by Heiderscheit et al. also failed to show any change in upper extremity kinesthetic sense with plyometric or isokinetic training (26).

Possible limitations with this study include the method of measuring kinesthetic sense. The method used may not be sensitive enough to detect the changes if they occur. Another possible limitation may be the duration and intensity of the training. A longer duration and more intense training protocol may be necessary to cause a noticeable change in kinesthetic sense. The lack of research and conclusive results on this topic present a need for further research on upper extremity proprioception.

The plyometric group showed a significant improvement in passive external rotation. Since the plyometric movement is predicated on the stretch-shortening cycle, it is logical to create a stretch response to the involved tissue (39). The rapid speed at which plyometrics occur causes a quick pre-stretching to the passive non-contractile tissue, which causes an increase in the passive range of motion of the involved structures. In this case the involved structures include the anterior non-contractile tissue and the internal rotator muscle groups. Although there was an increase in active external rotation, the increase was not significant. This can be expected because in order to improve active external rotation, strengthening of the external rotators must also occur in conjunction with the stretching of the anterior structures.

The plyometric group also showed significant improvement in concentric internal rotator power at 180º/sec and 300º/sec. The plyometric group showed no significant change at 60º/sec. These results are easily explained. Plyometric training implements the stretch-shortening cycle, which occurs at rapid angular velocities(39). Therefore, the plyometric training group utilized the specificity of physiological training response to improve significantly at the higher angular velocities.

In today's medical environment function has become the all-important word. In this study the softball distance throwing test was used as a functional measure of internal rotator strength. In this study the plyometric group showed a significant increase in softball throwing distance. These results show that plyometric training does provide functional improvement for the upper extremities. This improvement is due to a couple of factors. First, the plyometric group has demonstrated a significant increase in the ability to produce power at fast speeds. Second, the plyometric exercise was performed in the 90°/90° position which most functionally represents the throwing motion (19,40). Third, the plyometric group showed significant improvement in passive range of motion. Together these three factors help to explain the improvement in softball throwing distance for the plyometric group.

Although this study has demonstrated the effectiveness of plyometric training on improving certain variables there are still a number of questions to be answered. The results of this study do provide some information on the appropriate number of repetitions, sets, and rest period, although they do not provide information on the optimal amount for each parameter.

In reviewing both this article and the study by Heiderschiet et al. a few basic concepts can be developed for the use of upper extremity plyometric training (26). First, there is a need to select appropriate subjects (patients) when designing a plyometric upper extremity exercise program. Second, there is a need for the population to have experience with certain movement patterns that require neuromuscular coordination to perform. Third, it is important to use the concept of specificity of training to create the appropriate training response.

CONCLUSION

Plyometric training of the shoulder internal rotators for eight weeks produced no significant change in kinesthetic awareness, active external rotation, or isokinetic concentric power at 60°/sec. The plyometric training did produce a significant increase in concentric isokinetic power at 180°/sec and 300°/sec. The plyometric training group also showed significant improvement in passive external rotation and softball throwing distance. This study demonstrated that plyometric training ofthe shoulder internal rotators does improve passive range of motion, isokinetic power at fast speeds, and functional performance as demonstrated by the softball throwing test within the limitations ofthis study.

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Tables (I-VI)

I. Progressive protocol used for the plyometric training group.

Training Week	Ball Size	Repetitions
Weeks 1-2	.91 kg	3x10
Weeks 3-4	.91 kg	4 x 10
Weeks 5	OFF	OFF
Weeks 6-7	1.36 kg	3 x 10
Weeks 8-9	1.36 kg	5 x 10

II. Subject demographics ofcontrol and plyometric groups (mean + SD).

	N	Age (years)	Height(cm)	Weight (kg)
Control group	17	21.2 ± 2.5	180.5 ± 9.5	76.5 ± 8.0
Plyometric group	17	21.2 ± 2.2	180.6 ± 5.7	78.6 ± 13.3

III. Kinesthetic changes as a result of training (mean ± SD).

	Pretest (degrees)	Posttest (degrees)	Difference (degrees)	Significance
Control group				
IR 10°	2.5 ± 2.3	2.5 ± 2.0	-.08 ± 2.7	NS
ER 0°	3.6 ± 2.9	2.9 ± 3.5	-.67 ± 2.5	NS
ER 75°	2.4 ± 2.0	3.3 ± 1.9	.88 ± 1.8	NS
Plyometric group				
IR 10°	1.9 ± 1.7	2.2 ± 1.6	.37 ± 2.2	NS
ER 10°	2.6 ± 2.2	2.9 ± 2.4	.25 ± 2.5	NS
ER 75°	3 5 ± 2 4	2 1 ± 1 8	-1.4 ± 3.0	NS

IR = Internal rotation.
ER = External rotation.
NS = Nonsignificant ($p < .05$).

IV. Range of motion changes as a result of training (mean ± SD).

	Pretest (degrees)	Posttest (degrees)	Difference (degrees)	Significance
Control group				
AER	112.6 ± 12.1	106.5 ± 11.2	-6.1 ± 5.6	$p<.0001$
PER	127.8 ± 14.0	124.2 ± 13.4	-3.6 ± 10.3	NS
Plyometric group				
AER	103.2 ± 11.6	107.2 ± 9.7	4.0 ± 12.4	NS
PER	120.4 ± 11.1	126.6 ± 11.6	6.2 ± 11.2	$p< .037$

AER = Active external rotation.
PER = Passive external rotation.
NS = Nonsignificant ($p < .05$).

V. Softball throw distance changes as a result of training (mean ± SD).

	Pretest	Posttest	Difference	Significance
Control group	41.0 ± 3.8	41.0 ± 3.3	.01 ± 2.7	NS
Plyometrie group	39.8 ± 4.4	2.8 ± 4.6	3.0 ± 2.9	$p< .001$

NS = Nonsignificant ($p < .05$).

VI. Power changes as a result of training (mean ± SD).

	Pretest (Watts)	Posttest (Watts)	Difference (Watts)	Significance
Control group				
Concentric				
60°/sec	45.1 ± 6.4	43.2 ± 5.9	-1.9 ± 6.2	NS
180°/sec	110.2 ± 20.3	104.7 f 17.1	-5.5 ± 15.8	NS
300°/sec	143.7 ± 35.2	134.4 ± 30.5	-9.3 ± 27.8	NS
Plyometric group				
Concentric				
60°/sec	48.2 ± 8.6	47.6 ± 7.7	-.65 ± 5.1	NS
180°/sec	110.4 ±21.1	119.3 ± 19.3	8.9 ± 10.9	$p< .004$
300°/sec	138.8 ± 31 8	153.4 ± 30.4	14.5 ± 24.9	$p< .029$

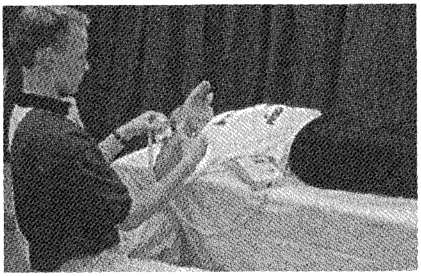


Fig. I Position for kinesthetic awareness testing.

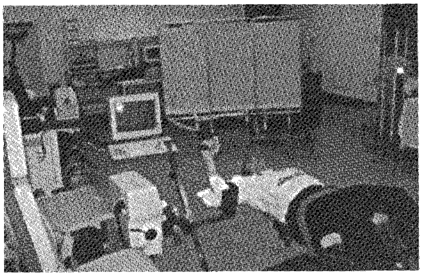


Fig. II Isokinetic testing position on the Cybex 340 System.

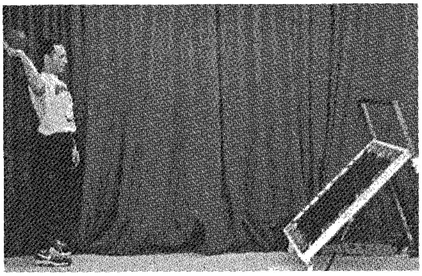


Fig. III Plyoback System used for plyometric training.

Fig. IV Difference in pre- to posttest kinesthetic values of the control and plyometric groups.
IR = Internal Rotation,
ER = External Rotation

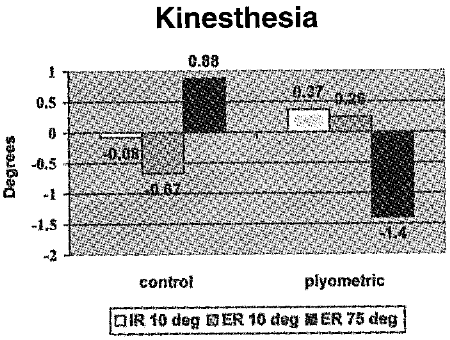
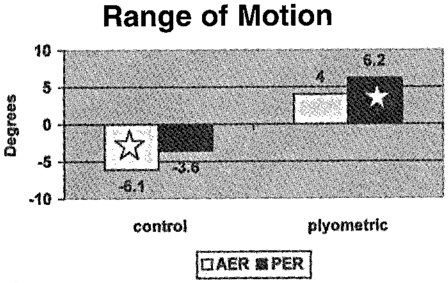


Fig. V Difference in pre- to posttest external range of motion values for the control and plyometric groups.
AER = Active External Rotation
PER = Passive External Rotation



☆ indicates significance (p< .05)

Fig. VI Difference in pre- to posttest softball values of the control and plyometric groups.

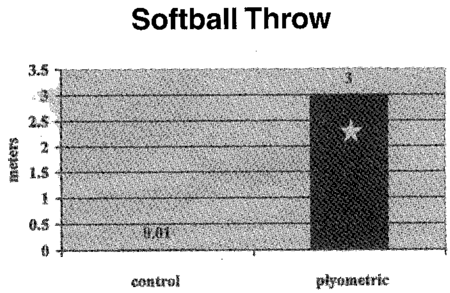
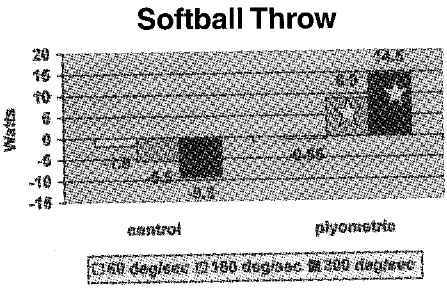


Fig. VII Difference in pre- to posttest average power values of the control and plyometric groups.



☆ indicates significance (p< .05)