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EFFECTS OF HIGH VOLUME UPPER EXTREMITY PLYOMETRIC TRAINING ON THROWING VELOCITY AND FUNCTIONAL STRENGTH RATIOS OF THE SHOULDER ROTATORS IN COLLEGIATE BASEBALL PLAYERS

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ABSTRACT. Carter, A.B., T.W. Kaminski, A.T. Douex Jr, C.A. Knight, and J.G. Richards. Effects of high volume upper extremity plyometric training on throwing velocity and functional strength ratios of the shoulder rotators in collegiate baseball players. *J. Strength Cond. Res. 21(1):208–215. 2007.*—To achieve maximal force output, clinicians and coaches have been experimenting with upper extremity plyometric exercises for years, without sufficient scientific validation of this training method. The goal of this study was to examine the effects of an 8-week course of high volume upper extremity plyometric training on the isokinetic strength and throwing velocity of a group of intercollegiate baseball players. Twenty-four Division I collegiate baseball players (age: 19.7 ± 1.3 years; height: 183.9 ± 5.9 cm; mass: 90.7 ± 10.5 kg) were recruited to participate in this study. Throwing velocity, isokinetic peak torque, isokinetic functional strength ratios, and time to peak torque were measured pre- and posttraining. Subjects were rank-ordered according to concentric internal rotation (IR) strength and were assigned randomly to either the plyometric training group (PLY) or the control group (CON). Training consisted of 6 upper extremity plyometric exercises ("Ballistic Six") performed twice per week for 8 weeks. Subjects assigned to CON performed regular off-season strength and conditioning activities, but did not perform plyometric activities. PLY demonstrated significant increases ($p < 0.05$) in throwing velocity following 8 weeks of training when compared with CON (83.15 mph [pre] vs. 85.15 mph [post]). There were no statistically significant differences in any of the isokinetic strength measurements between PLY and CON groups pre- to posttraining. Statistically significant differences were seen within PLY for concentric IR and eccentric external rotation (ER) isokinetic strength at $180°\cdot s^{-1}$ and $300°\cdot s^{-1}$; and within CON for eccentric ER isokinetic strength at $300°\cdot s^{-1}$ and concentric IR isokinetic strength at $180°\cdot s^{-1}$. The Ballistic Six training protocol can be a beneficial supplement to a baseball athlete's off-season conditioning by improving functional performance and strengthening the rotator cuff musculature.

KEY WORDS. muscle balance, power, rotator cuff, isokinetic, overhead-throwing

INTRODUCTION

The sport of baseball is dependent on the physical qualities of power, speed, strength, and local muscular endurance, specifically in the upper extremity. It is the goal of clinicians and coaches to maximize these attributes in order to increase performance characteristics while concomitantly decreasing the likelihood of injury. Dynamic neuromuscular stabilization of the shoulder is imperative in the prevention of shoulder injury in the overhead-throwing athlete. The glenohumeral joint itself is inherently unstable, losing stability at the expense of mobility. The ligamentous restraints about the shoulder complex are moderately sufficient in providing static stabilization; however, dynamic stabilization is required to prevent glenohumeral translation during the overhead-throwing motion. Dynamic shoulder stability is achieved primarily by the muscles of the rotator cuff. Additionally, the rotator cuff acts concentrically and eccentrically to produce internal and external rotational torques during the overhead-throwing motion (3, 4, 12, 23). It has been reported that during the overhead-throwing motion, strong eccentric force production by the shoulder external rotators plays a vital role in the prevention of shoulder injuries caused by excessive glenohumeral translation (12, 23). The majority of upper extremity training programs (i.e., plyometrics) questionably emphasize concentric internal rotator strength as a primary outcome measure. The shoulder external rotator musculature is functionally responsible for eccentric deceleration of the rapidly moving throwing arm (8, 12, 23) and, if not strong enough to do so, the athlete may be predisposed to a shoulder injury.

In the realm of strength and conditioning, many coaches implement functional exercises into their training programs. Prior to being used in traditional strength and conditioning programs, many of these exercises were employed by rehabilitation specialists in the clinical environment. Although many movement patterns are difficult to reproduce (i.e., the overhead-throwing motion), rehabilitation techniques have been founded in the practice of making the imposed demands during training closely replicate those incurred during athletic competition. In the overhead-throwing motion, the stress is centered on a muscle's capacity to exert its maximal force output in a minimal amount of time. Historically, clinicians and coaches alike have employed weight training regimens and, more recently, plyometric routines to maximize power. Wilson et al. (24) examined the differences between conventional weight training and plyometric exercise on both concentric and eccentric muscular force production in both the upper and lower extremities and found that upper extremity plyometric training, when compared with conventional weight training, is neither superior nor inferior for increasing power output.

Much of the previous research on plyometrics has been confined to assessing power output in the lower extremity and suggests that due to the principles of neurophysiological adaptation, stretch-shortening cycle activation is similar between the upper and lower extremities. Hence, both will yield similar responses to plyometric training (7, 18, 23). Heiderscheit et al. (7) compared the effects of a low volume plyometric training program and isokinetic training with emphasis on the shoulder internal rotators in untrained subjects, reportedly unfamiliar with the overhead-throwing motion. After 8 weeks of plyometric training, the subjects showed no significant improvements in concentric or eccentric isokinetic strength of their shoulder internal rotators, nor did they show an improvement in softball throwing distance when compared with the isokinetically-trained control group. In a follow-up study, Fortun et al. (5) utilized trained athletes proficient in the overhead-throwing motion with a protocol similar to that of Heiderscheit et al. (7). Results of this investigation demonstrated significant increases in passive external rotation, isokinetic concentric internal rotation strength at 180°·s^{-1} and 300°·s^{-1}, and softball throwing distance. Swanik et al. (20) sought to determine the effects of upper extremity plyometric training on shoulder proprioception, kinesthesia, isokinetic strength, and power of the shoulder internal rotators in female collegiate swimmers. The results of their study established that the plyometric training group significantly improved measures of proprioception and kinesthesia. Significant improvements also were seen in time to peak torque at 60°·s^{-1} and 240°·s^{-1}, as well as peak torque-to-body weight ratio at 60°·s^{-1}. Additionally, significant improvements in torque decrement (slower decline) at 240°·s^{-1} were observed, demonstrating neuromuscular adaptations for endurance. Based on the current body of literature, it appears that plyometrics can be beneficial for athletes using overhead movements.

It was the goal of the present study to examine the effects of an 8-week course of high volume upper extremity plyometric training ("Ballistic Six") on a functional eccentric external rotation-to-concentric internal rotation strength ratio and throwing velocity in a group of National Collegiate Athletic Association (NCAA) Division I baseball athletes. We hypothesized that following training, (a) the plyometric training group would demonstrate greater increases in throwing velocity than the control group; (b) the plyometric training group would demonstrate greater increases in eccentric isokinetic peak torque for shoulder external rotation (ER) than the control group; (c) the plyometric training group would demonstrate greater increases in concentric isokinetic peak torque for shoulder internal rotation (IR) than the control group; (d) the plyometric training group would demonstrate lower functional strength ratios (closer to 1.0) than the control group; and (e) the plyometric training group would demonstrate a shorter time to peak torque than the control group.

METHODS

Experimental Approach to the Problem

This study included 1 independent variable with 2 levels and 6 dependent variables. The independent variable in this study was the treatment effect of the Ballistic Six upper extremity plyometric training protocol. The dependent variables were throwing velocity, eccentric isokinetic peak torque, concentric isokinetic peak torque, functional peak torque ratios of the shoulder involving eccentric ER-to-concentric IR force, eccentric isokinetic time to peak torque, and concentric isokinetic time to peak torque. Each isokinetic variable was measured at angular velocities of 180°·s^{-1} and 300°·s^{-1}. A pretest-posttest randomized groups design was employed with this study.

Subjects

A total of 24 NCAA Division I collegiate baseball players (age: 19.7 ± 1.3 years; height: 183.9 ± 5.9 cm; mass: 90.7 ± 10.5 kg) participated in this study. All players had just completed their shortened fall baseball season and were involved in the off-season strength and conditioning phase of their training. All subjects were familiar with generalized strength training routines, and all had been involved in some form of conditioning since high school. Eighteen of the subjects reported their right arm as being their dominant throwing arm; the remaining 6 subjects reported being left-arm dominant. Thirteen subjects were assigned to the plyometric training group (by position: 7 pitchers, 2 catchers, 2 infielders, and 2 outfielders) and 11 were assigned to the control group (by position: 5 pitchers, 1 catcher, 3 infielders, and 2 outfielders). The two groups started with equal numbers (13 in each), however, 2 of the subjects originally assigned to the control group dropped out of the study after leaving the team during the off-season. Participants were excluded from the study if they (a) had undergone shoulder or elbow surgery within the past year; (b) had experienced a shoulder injury in the past year; or (c) had experienced an elbow injury in the past year. Prior to participating in this study, all subjects were required to fill out an upper extremity injury history questionnaire and to sign an informed consent agreement approved by our university's Human Subjects Review Board.

Pretesting Procedures

After being cleared to participate in the study, all subjects underwent isokinetic testing using the Biodex Multi-Joint System 3 (Biodex Medical Systems Inc., Shirley, NY) isokinetic dynamometer and throwing velocity assessment using the JUGS MPH Cordless Radar Gun (JKP Sports Inc., Tualatin, OR).

Isokinetic Assessment. Before isokinetic assessment, subjects were instructed to perform a 5-minute warm-up on the Cybex UBE (Upper Body Ergometer; Cybex Co., Ronkonkoma, NY). Isokinetic strength assessment included concentric shoulder IR and eccentric shoulder ER movements at speeds of 180°·s^{-1} and 300°·s^{-1}. Assessment was performed using only the dominant (throwing) arm. Isokinetic torque was expressed in newton-meters (N·m). Test-retest reliability for measurements derived from isokinetic testing involving the Biodex dynamometer and shoulder strength was established previously. (6, 7, 10, 21)

The setup of the Biodex Multi-Joint System 3 isokinetic dynamometer (Biodex Medical Systems), as previously described by Noffal (14), included the subjects positioned supine, shoulder abducted to 90°, and elbow flexed to 90° (Figure 1). Range of motion was set between 90° of ER and 60° of IR, for a total of 150° of motion (14). Data obtained from the isokinetic assessment included mean peak torque (strength), eccentric ER-to-concentric IR strength ratios (functional ratio), and time to peak torque (power). Eccentric-to-concentric strength ratios were derived using mean peak torque values; eccentric shoulder ER torque was divided by concentric shoulder IR torque, resulting in a functional ratio. Time to peak torque data were obtained from analysis of the isokinetic torque curves, taking the time index of the peak torque value and subtracting it from the zero point or onset of movement. Gravity correction was not needed in this test position, because both the internal and external rotator muscles moved with and against gravity as the subjects applied force (14). The subjects completed 3–5 warm-up repetitions to become familiar with the range limits and the accommodating resistance of the dynamometer. Following a 1-minute rest period, each subject completed 5

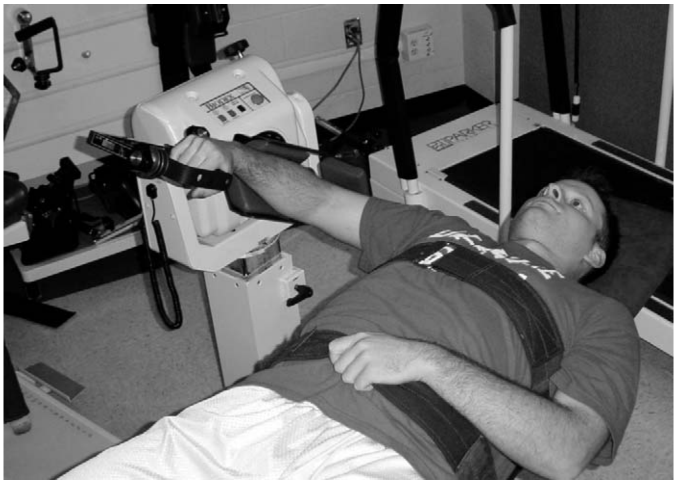

FIGURE 1. Subject positioned for isokinetic strength assessment.

TABLE 1. Control group rotator cuff strengthening exercises.*

Day 1	Day 2
IR tubing exercises 3 × 12	Dumbbell IR 2 × 12
ER tubing exercises 3 × 12	Dumbbell ER 2 × 12
Shoulder EXT tubing exercises 3 × 12	Rear DELT raise 2 × 12
	Empty cans 2 × 12

* IR = internal rotation; ER = external rotation; EXT = extension; DELT = deltoid.

maximal test repetitions at both velocities. Concentric and eccentric muscle actions were assessed with each maximal test repetition.

Throwing Velocity. Forty-eight hours after completion of the isokinetic strength testing, each subject's throwing velocity was tested using a calibrated JUGS MPH Cordless Radar Gun. Subjects were instructed to complete 10–15 minutes of baseball throwing as a warm-up, including baseball-specific stretching of the shoulder musculature. Maximum throwing velocity was assessed over a distance of 18.44 m (60 ft 6 in.), the standard distance from home plate to the center of the pitcher's mound for intercollegiate baseball games. Subjects threw on flat ground to a target located immediately behind home plate. Each subject was given 5 test throws with 1 minute of rest between each throw. Test repetitions were disregarded if the ball was out of the range of the target. The highest speed, measured in miles per hour (mph), was deemed maximal throwing velocity.

Plyometric Training Protocol. At the completion of pretesting, all subjects were rank-ordered according to their concentric isokinetic IR peak torque at $180°\cdot s^{-1}$ and were assigned randomly to either the plyometric training group (PLY) or the control group (CON). By randomly assigning subjects based on this ranking system, we ensured fairness in strength levels between the groups. Subjects in PLY continued to participate in their off-season strength and conditioning activities, as well as in the Ballistic Six exercises. Subjects in the CON performed off-season strength and conditioning activities that included routine cardiovascular conditioning and general overall strength training exercises incorporating some isotonic strengthening of the rotator cuff (Table 1). The thrice-weekly off-season strength and conditioning that all subjects participated in is outlined in Table 2. The strength

TABLE 2. Off-season general upper extremity workout routine performed thrice weekly by all players.*

	Phase I†	Phase II‡	Phase III§
Day 1	Push-up PLUS 2 × 20 Ceiling punches 2 × 15	Manual rear DELT raise 1 × 15 Push-up ROTATOR 3 × 10	Push-up PLUS 3 × 20 Mass movement patterns 3 × 10
Day 2	Scapular squeeze 2 × 20 Hand walk for 1 min	Sabers 3 × 12 Push-up PLUS 2 × 20 Mass movement patterns 3 × 10	Push-up ROTATOR 3 × 10
Day 3	Seated row 3 × 10 LAT pull-downs w/scaption 3 × 12	Push-up w/row 3 × 10 Wall SCAP push-ups	Scapular squeeze 3 × 15 Shoulder shrugs 3 × 12 2-way bent row 2 × 8

* PLUS = scapular protraction; DELT = deltoid; ROTATOR = torso twist; LAT = latissimus dorsi; SCAP = scapular.
† Phase I (weeks 1–2): no throwing.
‡ Phase II (weeks 3–5): flat ground throwing twice weekly.
§ Phase III (weeks 6–8): long-toss twice weekly.

and conditioning coach closely monitored and supervised all training sessions.

The Ballistic Six plyometric training protocol (Figure 2) used in this study was previously described by Pretz (16) and comprises 6 upper extremity plyometric exercises commonly used in the latter stages of rehabilitation (16, 22). Subjects assigned to the PLY performed the Ballistic Six twice weekly for 8 weeks, whereas their counterparts in the CON did the same with their own rotator cuff strengthening exercises. Subjects were instructed to use maximal effort and to perform exercises in a ballistic manner in order to decrease the amortization phase and to maximize the training effects of the stretch-shortening cycle (SSC). Exercises were performed using 3 sets of 10–20 repetitions, with 30 seconds of rest between each set. The progression of the training protocol is shown in Table 3. The equipment utilized in the Ballistic Six exercises included Thera-Band (The Hygenic Corp., Akron, OH) latex tubing (red) and medicine balls (2-lb for the single-arm exercises and 6-lb for the 2-handed exercises).

Posttesting Procedures. Following 8 weeks of training, the PLY and CON groups completed both the isokinetic testing and throwing velocity assessment, identical to that described in the pretesting protocol.

Statistical Analyses

All statistical analyses were conducted using SPSS (version 12.01; SPSS, Inc., Chicago, IL). A 2-factor repeated measures analysis of variance (ANOVA) with 1 between-subjects factor (group) and 1 within-subjects factor (test) was used for all comparisons. In the presence of a significant group × day interaction, the estimated marginal means statement was used to test simple main effects (of n levels of test) within each level of group.

RESULTS

Throwing Velocity

The 2-factor repeated measures ANOVA revealed a statistically significant difference between groups pre- to posttraining ($F[1,22] = 4.44$, $p < 0.05$) (Figure 3). The PLY group experienced a 2.00 mph increase in velocity

FIGURE 2. The Ballistic Six. (a–b) Latex tubing external rotation. (c–d) Latex tubing 90/90 external rotation. (e–f) Overhead soccer throw using a 6-lb medicine ball. (g–i) 90/90 external rotation side-throw using a 2-lb medicine ball. (j–l) Deceleration baseball throw using a 2–lb medicine ball. (m–o) Baseball throw using a 2-lb medicine ball..

TABLE 3. The "Ballistic Six" training progression.

Week	Training routine
1–2	3 sets of 10 repetitions
3–5	3 sets of 15 repetitions
6–8	3 sets of 20 repetitions

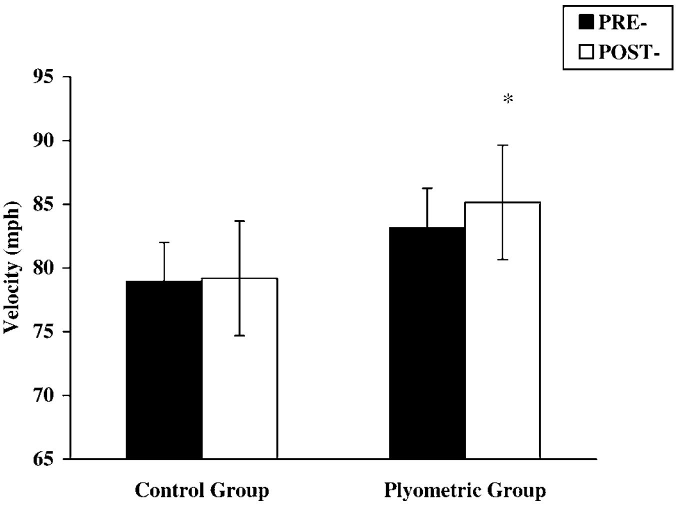

FIGURE 3. Pre- to posttest mean throwing velocity (mph) between the 2 groups. * $p < 0.05$.

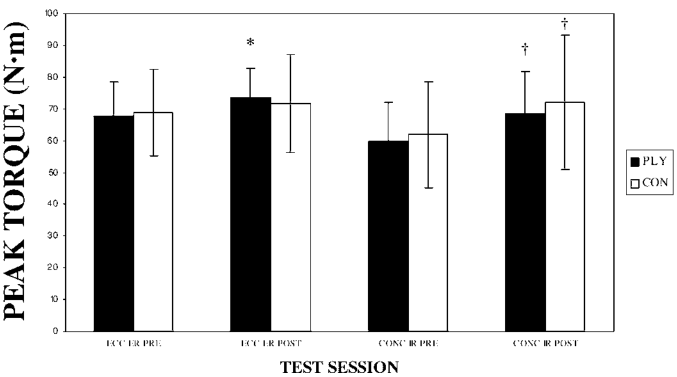

FIGURE 4. Mean peak torque values (N·m) for external rotation (ER) and internal rotation (IR) of the dominant shoulder at 180°·s⁻¹. ECC = eccentric; CONC = concentric. * Significantly different ($p < 0.05$) from ECC ER pretest value. † Significantly different ($p < 0.05$) from CONC IR pretest value.

pre- to posttesting, whereas CON had a slight increase of 0.27 mph over that same time period. Of note is the fact that there was a statistically significant difference ($F[1,22] = 11.56$, $p < 0.05$) in velocity between groups prior to training: PLY (83.15 mph) > CON (78.91 mph).

Isokinetic Strength

Peak Torque Values at 180°·s⁻¹. Mean concentric and eccentric isokinetic peak torque values for ER and IR of the dominant shoulder at 180°·s⁻¹ are presented in Figure 4. The ANOVA revealed no statistically significant differences between groups for either eccentric ER ($F[1,22] = 0.007$, $p = 0.934$) or concentric IR ($F[1,22] = 0.217$, $p = 0.646$). There was a significant difference pre- to posttraining in peak torque values for eccentric ER in PLY that was not seen in CON ($p = 0.001$). There was also a statistically significant difference in concentric IR pre- to

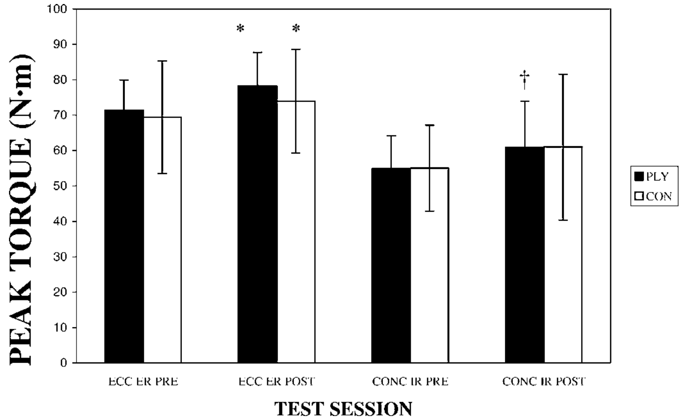

FIGURE 5. Mean peak torque values (N·m) for external rotation (ER) and internal rotation (IR) of the dominant shoulder at 300°·s⁻¹. ECC = eccentric; CONC = concentric. * Significantly different ($p < 0.05$) from ECC ER pretest value. † Significantly different ($p < 0.05$) from CONC IR pretest value.

TABLE 4. External rotation/internal rotation (ER/IR) strength ratios (± *SD*) at 180°·s⁻¹ and 300°·s⁻¹ in N.m.*

	Pre ER/IR ratio 180°·s⁻¹	Post ER/IR ratio 180°·s⁻¹	Pre ER/IR ratio 300°·s⁻¹	Post ER/IR ratio 300°·s⁻¹
PLY	1.15 ± 0.17	1.09 ± 0.14	1.33 ± 0.23	1.33 ± 0.30
CON	1.13 ± 0.11	1.02 ± 0.15	1.27 ± 0.17	1.26 ± 0.23

* Pre = pretest; Post = posttest; PLY = plyometric training group; CON = control group.

TABLE 5. Time to peak torque (± *SD*) at 180°·s⁻¹ in seconds.*

	Pre ECC ER	Post ECC ER	Pre CONC IR	Post CONC IR
PLY	0.21 ± 0.08	0.23 ± 0.11	0.37 ± 0.19	0.38 ± 0.20
CON	0.22 ± 0.13	0.21 ± 0.07	0.37 ± 0.21	0.37 ± 0.20

* Pre = pretest; Post = posttest; ECC = eccentric; CONC = concentric; ER = external rotation; IR = internal rotation; PLY = plyometric training group; CON = control group.

posttraining in both PLY ($p = 0.006$) and CON ($p = 0.004$).

Peak Torque Values at 300°·s⁻¹. Mean concentric and eccentric isokinetic peak torque values for ER and IR of the dominant shoulder at 300°·s⁻¹ are presented in Figure 5. The ANOVA revealed no statistically significant difference between groups for either eccentric ER ($F[1,22] = 0.440$, $p = 0.514$) or concentric IR ($F[1,22] = 0.0001$, $p = 0.985$). There was a statistically significant difference in eccentric ER at 300°·s⁻¹ pre- to posttraining in both PLY ($p = 0.002$) and CON ($p = 0.045$). There was also a significant difference in concentric IR pre- to posttraining in PLY ($p = 0.047$) that was not observed in CON.

Eccentric-to-Concentric Strength Ratios. Pre- and posttraining eccentric ER strength-to-concentric IR functional strength ratios at both 180°·s⁻¹ and 300°·s⁻¹ are presented in Table 4. The ANOVA revealed no statistically significant difference between groups for either ER/IR ratio at 180°·s⁻¹ ($F[1,22] = 0.812$, $p = 0.377$) or 300°·s⁻¹ ($F[1,22] = 0.506$, $p = 0.484$).

Time to Peak Torque. Mean time to peak torque values for eccentric ER and concentric IR at 180°·s⁻¹ and 300°·s⁻¹ are presented in Table 5 and Table 6, respectively. The ANOVA revealed no statistically significant differences between groups at 180°·s⁻¹ in either concentric IR (F[1,22]

TABLE 6. Time to peak torque (± *SD*) at $300°\cdot s^{-1}$ in seconds.*

	Pre ECC ER	Post ECC ER	Pre CONC IR	Post CONC IR
PLY	0.13 ± 0.03	0.13 ± 0.03	0.21 ± 0.05	0.22 ± 0.08
CON	0.14 ± 0.08	0.12 ± 0.03	0.18 ± 0.05	0.22 ± 0.06

* Pre = pretest; Post = posttest; ECC = eccentric; CONC = concentric; ER = external rotation; IR = internal rotation; PLY = plyometric training group; CON = control group.

= 0.011, p = 0.919) or eccentric ER (F[1,22] = 0.0001, p = 0.989). There were also no statistically significant differences between groups at $300°s^{-1}$ in either concentric IR (F[1,22] = 0.322, p = 0.576) or eccentric ER (F[1,22] = 0.023, p = 0.882).

DISCUSSION

Results from this study reveal that following an 8-week course of high volume upper extremity plyometric training, subjects assigned to PLY showed a significant improvement in baseball throwing velocity. These results conflict with the findings of Heiderscheit et al. (5), who examined the effects of a low volume plyometric training program concentrating on the shoulder internal rotators in untrained subjects who were unfamiliar with the overhead-throwing motion. The authors reported no significant improvement in either isokinetic strength or softball throwing distance. Additionally, our results counter those reported by Newton and McEvoy (13), who observed no significant changes in throwing velocity in a group of baseball players following 8 weeks of upper body medicine ball training. We suggest that differences in the plyometric exercises we employed are the reason for such differences in results between the studies. Interestingly, in a more recent study by McEvoy and Newton (11), baseball players who participated in a 10-week plyometric training program utilizing bench throws with a light load recorded significant improvements in throwing speed when compared with the control group subjects. The ballistic nature of the bench throws is similar to that of the Ballistic Six exercises performed in the present study. Lachowetz et al. (9) also reported significant improvements in throwing velocity after 8 weeks of a generalized strength training routine in a group of collegiate baseball players. Although their protocol did not focus on plyometrics, nonetheless, it implied that throwing velocity could be improved via a structured strength training program. Fortun et al. (5), in a follow-up to the Heiderscheit study (7), utilized trained athletes (proficient in the overhead-throwing motion) and demonstrated significant increases in softball throwing distance posttraining. Although we did not measure throwing distance, we speculate that trained athletes may be more conducive to increases in throwing velocity than are persons who are unfamiliar with the overhead-throwing motion. The subjects in the present study were all highly conditioned athletes, which may have contributed to the significant increases in throwing velocity seen in the PLY.

Furthermore, the Ballistic Six upper extremity plyometric training protocol involves a series of functional exercises performed at high volumes to simulate the movements, positions, and forces involved with the overhead-throwing motion. In order to take advantage of the stretch reflex, plyometric training was conducted in a ballistic, high-velocity manner to decrease the amortization phase of the SSC. Although subjects in the CON group did not perform upper extremity plyometric exercises, they did participate in a program with emphasis on isotonic rotator cuff strengthening (Table 1). We speculate that because these exercises were performed in a slow and deliberate (nonballistic) manner, subjects in CON did not demonstrate any improvement in throwing velocity.

There was also a statistically significant increase within the groups for measures of eccentric peak torque in the PLY at both speeds, whereas there was only a significant increase in the CON at the faster speed. The data, however, did not yield any significant differences in mean peak torque between the groups. At the slower speed ($180°\cdot s^{-1}$), mean peak torque of the eccentric shoulder external rotators in the PLY revealed an 8% improvement, compared with a 4% improvement in the CON, resulting in a statistically significant difference. At the faster speed ($300°\cdot s^{-1}$), the PLY improved eccentric ER by 9%, compared with an improvement of 6% in the CON, both of which were statistically significant increases within the respective groups.

Thirdly, we examined the training effects on concentric isokinetic strength between groups. When peak torque was measured at $180°\cdot s^{-1}$, the PLY showed a mean improvement of approximately 13% posttraining, compared with an improvement of 14% in the CON; both of these results were found to be statistically significant within the respective groups. At the higher speed ($300°\cdot s^{-1}$), both the CON and PLY demonstrated improvements of approximately 10%. Although both groups revealed very similar results and increased the same amount, only the PLY showed statistical significance pre- to posttraining. It can be noted that there was a large variability in peak torque values within the CON, as evidenced by much larger standard deviations seen in this group (Figures 4 and 5). Such a large variance could possibly be attributed to the vast range of body masses (70.7–117.1 kg) within the CON. All data were presented in raw values and were not standardized by body mass; the authors have acknowledged this as a delimitation to the present study. However, very few researchers have normalized peak torque values for body mass, which usually confounds clinical interpretation, thus we decided not to normalize for body mass in our study. The improvement in mean concentric peak torque in the PLY, as seen at the faster isokinetic speed ($300°\cdot s^{-1}$), could have been due to the velocity at which the plyometric training was conducted. As was previously noted in the "Methods" section, our subjects were closely monitored to ensure that they performed the plyometric exercises in a quick, ballistic manner.

Results from the present study suggest no significant differences between the groups in isokinetic force production following a plyometric training program. Few published studies have been able to identify the significant differences between groups that Fortun et al. (5) reported. Heiderscheit et al. (7) and Swanik et al. (20) both reported significant isokinetic force gains within groups following training, however, like we have reported, these investigators were unable to demonstrate differences between training and control groups in their respective studies. Swanik et al. (20), along with reports by Wilk et al. (23), and Perrin et al. (15), have suggested that highly trained individuals may not be influenced by plyometric training as much as an untrained population. It is unlikely that the trained individual will undergo the magnitude of muscle hypertrophy that a nontrained individual might experience, especially over a brief 8-week period. The athletes used in the present study were highly trained collegiate baseball players who would have had to develop monumental strength gains to significantly change their isokinetic strength profile pre- to posttraining. Additionally, the present study did not utilize a true control group; if a control group that did not undergo the rigors of a functional off-season strength and conditioning program had been employed, one may argue that there may have been different results, perhaps yielding statistically significant differences between groups. Baseball, like most other intercollegiate sports experiences, has become a year-round training endeavor, so finding baseball athletes to serve as control subjects and to go without training for 8–10 weeks is nearly an impossible task. Several previously reported studies (9, 11, 13) employed control groups that continued with routine baseball activities during the course of the project.

Our data clearly show that both groups improved in isokinetic strength (both eccentric and concentric) regardless of training program. However, we cannot say that one form of training is superior to the other. Baker (2) has advocated specialty training for development beyond strength, whereby a strength program is enhanced with additional training exercises to improve upon other functional performance assets (e.g., power, speed, balance). The Ballistic Six plyometric strength training program could be thought of as a sport-specific strength training program. It was developed specifically to mimic baseball throwing activities that utilize ballistic movements. Additional studies examining the effects of such a sport-specific program of greater duration are needed to determine any potential benefits above and beyond that of traditional strength training programs.

Another delimitation of the present study is that isokinetic strength assessment may not be the ideal method of evaluating the effectiveness of plyometric training. The subjects in the present investigation performed high-intensity ballistic isotonic movements, but strength assessment was conducted using controlled isokinetic movements. The Heiderscheit (7) and Pretz (17) investigations both yielded results that suggest both training and assessment should be performed in a parallel fashion. This, however, places certain limits on the applicability of experimental results to functional outcomes. It can be assumed that the differences in modes of training and testing could have yielded these results.

A unique aspect of this investigation was the examination of functional ratios between eccentric ER strength and concentric IR strength at both $180°\cdot s^{-1}$ and $300°\cdot s^{-1}$. Our results did not reveal a significant change in functional ratios between the PLY and the CON pre- to posttraining. The eccentric-to-concentric strength ratio is a novel means of quantifying a functional ratio in the overhead-throwing athlete. These ratios specifically illustrate the relationship between antagonist and agonist muscle groups. Scoville et al. (19) suggested that eccentric ER torque values would be greater than concentric IR torque, implying as others (4, 14) had that the greater eccentric strength of the shoulder external rotators may be necessary to decelerate the arm during overhead-throwing activities. Noffal (14) examined the functional ratio at $300°\cdot s^{-1}$ in an attempt to find normative values for shoulder strength in both throwers and nonthrowers. Noffal suggested that overhead-throwing athletes had a lower ratio than nonthrowing athletes had and concluded that eccentric shoulder ER strength might improve as a consequence of repeated bouts of stretch-shortening activation, leading to a lower functional ratio (14). After 8 weeks of high volume upper extremity plyometric training in the present study, the functional ratio derived from the PLY decreased at the slower testing speed ($180°\cdot s^{-1}$), but the decrease was not statistically significant between groups. At the higher speed ($300°\cdot s^{-1}$), neither the PLY nor the CON altered their functional ratios from pre- to posttraining. The ratios in the present study may have differed from the findings of Noffal (14), because the present population consisted of both position players and pitchers, whereas the Noffal study only utilized position players. The inclusion of pitchers may contribute to the differences between the studies, because, by virtue of repetition alone, the baseball pitcher places more consistent strain on the dominant shoulder than a position player does, which may induce a training effect and thus increase eccentric shoulder external rotator muscular strength. The increase in eccentric strength values will lead to a subsequently higher functional ratio. Future studies are needed to address whether or not differences exist between position players and pitchers.

Ratios (range at $180°\cdot s^{-1}$ = 1.02–1.15 N·m; range at $300°\cdot s^{-1}$ = 1.27–1.33 N·m) from this study were higher than the values reported by Noffal (14), Scoville et al. (19), and Bak and Magnusson (1). Our study replicated the methods used by Noffal (14) and produced greater functional ratios at the higher speed ($300°\cdot s^{-1}$). Noffal (14) reported higher functional ratios (1.17 N·m) than both the Scoville et al. (19) and the Bak and Magnusson (1) studies, stating that higher functional ratios may be attributed partially to higher test speeds: $300°\cdot s^{-1}$ vs. $80°\cdot s^{-1}$ and $30°\cdot s^{-1}$, respectively. Relative to the force-velocity relationship of muscle, as the speed of isokinetic assessment increases, concentric muscular force production decreases and eccentric muscular force production increases or plateaus, which technically should lead to a higher functional ratio (14). The functional ratios in the present study were all above 1.0, related to the fact that the eccentric strength of the shoulder external rotator muscles was greater than the concentric strength of the shoulder internal rotator muscles. The greater eccentric strength is necessary in deceleration of the fast moving arm in the overhead throw.

Finally, we hypothesized that a significant increase in power (decreased time to peak torque) in the PLY would result following training. The basic principles of plyometrics state that the SSC, when applied properly, will facilitate maximum power output in a minimal amount of time (23). The results of the present study, however, did not reveal a significant decrease in time to peak torque. It is reasonable to mention that the Biodex Multi-Joint System 3 isokinetic dynamometer (Biodex Medical Systems) does have a built-in safety feature referred to as an acceleration limiter, which by its nature may limit accurate measurement of time to peak torque. Conversely, Swanik et al. (20) used a similar isokinetic dynamometer and reported that, following a 6-week plyometric training program, there were significant within-group differences for time to peak torque at the slower speed ($60°\cdot s^{-1}$), but not at the higher speeds ($200°\cdot s^{-1}$ and $450°\cdot s^{-1}$). The higher speeds are relatively similar to those in the present study ($180°\cdot s^{-1}$ and $300°\cdot s^{-1}$) and show agreement between this investigation and the Swanik et al. study. In the same report (20), the authors found there was a statistically significant difference for the effect of plyometric training between the control and the experimental groups at $60°\cdot s^{-1}$ and $200°\cdot s^{-1}$, but not statistically significant at $450°\cdot s^{-1}$, a more representative velocity of the overhead-throwing motion. Swanik et al. (20) stated that the improved time to peak torque is likely the result of adaptations in the elastic properties of the muscle, which contributes to the muscles' ability to utilize stored energy more efficiently. The authors also suggest that perhaps their subjects underwent neural component adaptations, thus contributing to increasing motor unit recruitment and increased power.

Power indices in this study were measured in collegiate baseball athletes, whereas Swanik et al. (20) utilized female collegiate swimmers, athletes who place a much different stress on the shoulder musculature. Although both the overhead throw and the swimming motion require high angular velocities at the shoulder complex, the freestyle swim stroke requires little eccentric muscle action. Conversely, the overhead-throwing motion requires a significant amount of eccentric muscle action to decelerate the upper limb. The differences in dynamics of swimming and baseball alone could be a plausible explanation for the differing results between the studies.

The results from this study illustrated that both the Ballistic Six training protocol and a standardized strength and conditioning program yield similar results in improvement of the shoulder isokinetic strength profile of intercollegiate baseball players, yet neither is superior to the other. These results support the rationale that in highly trained individuals, plyometric training may not be the optimal method of enhancing isokinetic strength (20). The plyometric training group failed to demonstrate significantly greater increases in measures of peak torque and would have needed near-unattainable improvements (>25 N·m of torque) to increase significantly when compared with the control group. Swanik et al. (20) suggested plyometric exercises alone were not sufficient to increase isokinetic strength and should be used in conjunction with other strengthening exercises. This study was unique in that it examined the effects of a high volume upper extremity plyometric training program on isokinetic measurements, specifically the novel functional ratio, and throwing velocity. Results of the present study revealed that upper extremity plyometric training had a positive effect on shoulder strength and throwing velocity that may be valuable for future investigations. Future research is warranted to examine the effectiveness of the functional ratio and to consider different methods to impact this ratio.

PRACTICAL APPLICATIONS

Based on the results of the present study, high volume upper extremity plyometric training can significantly increase throwing velocity and some measures of isokinetic strength. Because the exercises of the Ballistic Six upper extremity plyometric training program are performed in a ballistic fashion, the muscle contraction and joint velocities appear to have greater functional applicability to the overhead-throwing motion. Upper extremity plyometric exercises have gained popularity, and their use by strength and conditioning specialists is increasing. Previous research has supported their use, citing the within-group increases in both throwing velocity and peak torque (strength; 9, 13, 17). Some studies have suggested that plyometric training protocols have resulted in increases in rate of torque development (power) and proprioceptive factors (1, 20). As certain isokinetic measures demonstrated no significant evidence for improvement following the Ballistic Six training program, it should be noted that isokinetic testing might not be the best way assess functional outcomes. However, clinicians and coaches in solidifying a scientific basis for the utilization of upper extremity plyometric training in overhead-throwing athletes can use this program.

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