Closed–Kinetic Chain Upper-Body Training Improves Throwing Performance of NCAA Division I Softball Players

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ABSTRACT

Prokopy, MP, Ingersoll, CD, Nordenschild, E, Katch, FI, Gaesser, GA, and Weltman, A. Closed–kinetic chain upper-body training improves throwing performance of NCAA Division I softball players. J Strength Cond Res 22(6): 1790–1798, 2008—Closed–kinetic chain resistance training (CKCRT) of the lower body is superior to open–kinetic chain resistance training (OKCRT) to improve performance parameters (e.g., vertical jump), but the effects of upper-body CKCRT on throwing performance remain unknown. This study compared shoulder strength, power, and throwing velocity changes in athletes training the upper body exclusively with either CKCRT (using a system of ropes and slings) or OKCRT. Fourteen female National Collegiate Athletic Association Division I softball players were blocked and randomly placed into two groups: CKCRT and OKCRT. Blocking ensured the same number of veteran players and rookies in each training group. Training occurred three times weekly for 12 weeks during the team’s supervised off-season program. Olympic, lower-body, core training, and upper-body intensity and volume in OKCRT and CKCRT were equalized between groups. Criterion variables pre- and posttraining included throwing velocity, bench press one-repetition maximum (1RM), dynamic single-leg balance, and isokinetic peak torque and power (PWR) (at 180° s⁻¹) for shoulder flexion, extension, internal rotation, and external rotation (ER). The CKCRT group significantly improved throwing velocity by 2.0 mph (3.4%, p < 0.05), and the OKCRT group improved 0.3 mph (0.5%, NS). A significant interaction was observed (p < 0.05). The CKCRT group improved its 1RM bench press to the same degree (1.9 kg) as the OKCRT group (p < 0.05 within each group). The CKCRT group improved all measures of shoulder strength and power, whereas OKCRT conferred little change in shoulder torque and power scores. Although throwing is an open-chain movement, adaptations from OKCRT may confer benefits to subsequent performance. Strength coaches can incorporate upper-body CKCRT without sacrificing gains in shoulder strength and power scores. This study compared shoulder strength, power, and throwing velocity changes in athletes training the upper body exclusively with either CKCRT (using a system of ropes and slings) or OKCRT. Fourteen female National Collegiate Athletic Association Division I softball players were blocked and randomly placed into two groups: CKCRT and OKCRT. Blocking ensured the same number of veteran players and rookies in each training group. Training occurred three times weekly for 12 weeks during the team’s supervised off-season program. Olympic, lower-body, core training, and upper-body intensity and volume in OKCRT and CKCRT were equalized between groups. Criterion variables pre- and posttraining included throwing velocity, bench press one-repetition maximum (1RM), dynamic single-leg balance, and isokinetic peak torque and power (PWR) (at 180° s⁻¹) for shoulder flexion, extension, internal rotation, and external rotation (ER). The CKCRT group significantly improved throwing velocity by 2.0 mph (3.4%, p < 0.05), and the OKCRT group improved 0.3 mph (0.5%, NS). A significant interaction was observed (p < 0.05). The CKCRT group improved its 1RM bench press to the same degree (1.9 kg) as the OKCRT group (p < 0.05 within each group). The CKCRT group improved all measures of shoulder strength and power, whereas OKCRT conferred little change in shoulder torque and power scores. Although throwing is an open-chain movement, adaptations from OKCRT may confer benefits to subsequent performance. Strength coaches can incorporate upper-body CKCRT without sacrificing gains in maximal strength or performance criteria associated with an athletic open-chain movement such as throwing.

Key Words: resistance training, open–kinetic chain, shoulder peak torque, shoulder power

INTRODUCTION

Modern strength training programs for athletes combine closed– and open–kinetic chain exercises to improve core upper- and lower-body strength, sport-specific strength, performance, and for injury prevention. Closed–kinetic chain exercises (CKCEs) require fixing the terminal segment or providing it with considerable resistance (15), such as the hands pushing against the ground during the push-up. Open–kinetic chain exercises (OKCEs) either do not fix the terminal segment or allow the terminal segment to move freely without external resistance (15), such as the hands moving a weighted barbell against gravity during the bench press. Collegiate strength training programs often incorporate both types of exercises into periodized training regimens. The literature notes several strengths and weaknesses (summarized below) of CKCE and OKCE and supports the rationale for comparing their effects on throwing performance.

Closed–kinetic chain exercises often involve multijoint movements to develop the main biarticulate muscle groups of the body. A CKCE such as the back squat mimics the biomechanical and neuromuscular demands of sport-specific movements as in jumping. The OKCE analog to the back squat (leg press) engenders similar demands on the global muscles, yet the CKCE version is often used because of coaches’ preference, equipment limitations, or performance
effects. Indeed, lower-body CKCE training is advantageous to OKCE training to improve vertical jump performance (1). Lower-body CKCE test performance correlates highly ($r = 0.722$ and 0.650, respectively) with vertical jump height and broad jump length in female athletes, whereas lower-body OKCE correlates poorly ($r = 0.097$ and 0.070, respectively) with performance (2).

Several studies note a significant amount of muscular cocontraction about dynamic joints during CKCE performance (3,10,12,16), possibly in neuromuscular response to the articular compressive forces of CKCE (4). Ligaments aid in static joint stability, yet muscular cocontraction about a joint is crucial to dynamic joint stability as in limiting glenohumeral translation during overhead throwing (11,13). Knee-dominant CKCEs are commonly selected for athletes, possibly because they result in significantly less anterior tibiofibormal shear force than knee-dominant OKCEs (9). A reduction in this shear force places less tension on the anterior cruciate ligament (9). In the upper extremity, healthy subjects significantly improved glenohumeral joint stability by executing CKCE (18). For the above reasons, closed–kinetic chain resistance training (CKCRT) improves performance, dynamic joint stability, and proprioception and is commonly encountered in the lower-body training regimens of athletes.

Open–kinetic chain exercises generally involve single (biceps curl) or double (bench press) joint movements that more frequently isolate specific muscle groups. Proximal to distal segment kinetics involved in OKCE confer maximal distal segment acceleration. This kinetic chain succeeds in modeling overhead sport-specific throwing movements and is favored by many strength coaches for upper-body training (7). Whereas OKCEs and CKCEs have been noted to improve glenohumeral proprioception to a similar degree (14), OKCEs do not elicit the same muscular cocontractions about a dynamic joint as CKCEs (10,12,19). There is possibly a trade-off between kinetic modeling of sport-specific movements and the development of dynamic joint stability in open–kinetic chain resistance training (OKCRT).

Upper-body CKCEs are typically limited by body weight as the source of resistance. Thus, low-repetition/high-intensity cycles can be difficult to execute in upper-body CKCRT. Varying training intensity and volume is a widely accepted method for strength development because it reduces the likelihood of a plateau. Perhaps a trade-off exists between developing dynamic joint stability and executing periodized programs in upper-body CKCRT. Indeed, upper-body OKCEs are more commonly employed in the training of throwing athletes in the collegiate environment (7). Because of the strengths and weaknesses of CKCE and OKCE as training paradigms, comparing the effects of the two methods on throwing performance is warranted. Yet, evaluations of the efficacy of OKCE and CKCE upper-body training are lacking in the literature.

This study evaluated changes in concentric isokinetic shoulder strength (flexion, extension, internal rotation, external rotation), throwing velocity, bench press one-repetition maximum (1RM), and dynamic single-leg balance by using either CKCRT or OKCRT for a 12-week periodized, off-season, thrice-weekly training regimen for National Collegiate Athletic Association (NCAA) Division I softball players. We hypothesized that after training, (a) both CKCRT and OKCRT would increase shoulder strength (peak torque) and 1RM bench press to a similar degree, (b) shoulder power (time to peak torque/peak torque) and throwing velocity would improve more in the CKCRT group because of increased neural adaptations in the glenohumeral joint, and (c) the dynamic single-leg balance of athletes would improve more in the CKCRT group because of the extra demands upper-body CKCE places on core stability.

**Methods**

**Experimental Approach to the Problem**

This study included one independent variable with two levels (pre- and posttraining) and 12 dependent variables. The independent variable was the type of upper-body training in which the subject engaged (CKCRT or OKCRT). Dependent variables included throwing velocity; bench press 1RM; isokinetic peak torque and power for dominant shoulder flexion, extension, internal rotation, and external rotation; and dynamic single-leg balance of each leg. Isokinetic variables were measured at $180^\circ \cdot \text{s}^{-1}$. Pitchers and position players were split evenly among both groups. First-year players and veteran players were split evenly among both groups because first-year players could be expected to make greater strength gains.

**Subjects**

The study was approved by the university’s institutional review board. Fourteen female NCAA Division I softball players (mean age = 20.6 years, mean weight = 64.8 kg, mean height = 165.0 cm) who compete in the Atlantic Coast Conference volunteered for this study and provided written informed consent. Subject training ages ranged from 0 to 5 years. Before the start of this study, the subjects had just returned from summer activities or were new to the team. All subjects had 1 week (three sessions) to learn basic weight training techniques and safety guidelines. Twelve subjects were right-arm dominant, and two were left-arm dominant. Subjects were excluded if they had undergone shoulder or elbow surgery within the past year or if otherwise contraindicated by the university’s sports medicine staff. Two subjects (one in each group) were unable to complete the posttraining throwing test (but did complete all other assessments).

**Procedures**

**Performance Testing.** Pre- and posttraining testing consisted of isokinetic concentric phase peak torque for shoulder flexion, extension, internal rotation, and external rotation; dynamic single-leg balance; throwing velocity; 1RM bench press; and isokinetic concentric phase peak power for shoulder flexion, extension, internal rotation, and external rotation. A 5-minute
shoulder warm-up was performed before isokinetic, 1RM bench press, and dynamic single-leg balance tests. The team’s typical throwing warm-up preceded testing of throwing velocity.

Isokinetic strength testing was performed using a Biodex System 3 multijoint dynamometer (Shirley, NY). Data were acquired via analog signals connected to an MP150 BIOPAC interface module equipped with Acqknowledge version 3.7.3 analysis software. All subjects performed three trials of five repetitions of each exercise, with 90 seconds between trials. Verbal encouragement was given for each repetition. Concentric shoulder flexion and extension tests were conducted simultaneously at 180°·s⁻¹, with the seatback angle set at 55° and the height adjusted such that the rotor center was in line with the acromion of the subject’s dominant arm. Seat and rotor orientation were set at 0°, as prescribed by the manufacturer. The lever handle was adjusted for subject comfort while maintaining acromion-rotor alignment and elbow extension. Concentric internal rotation and external rotation tests were conducted at 180°·s⁻¹, with the seatback angle set at 75°. The dynamometer was tilted 50° upwards in the subject’s frontal plane, and 25° laterally from the subject’s dominant arm in the transverse plane. Dynamometer and seat height were adjusted such that the humerus was in line with the rotor and the humerus was in 50° of abduction, as recommended by the manufacturer.

Dynamic single-leg balance testing was performed with an Accusway PLUS (AMTI, Watertown, Mass.) force plate with accompanied software (SWAYWIN 95). Subjects removed their shoes and performed three single-leg squats on each leg to a depth sufficient to elicit a minimum of 80° of knee flexion for each repetition. Arms remained extended with the nonbalance leg elevated to promote depth during the trials. Verbal encouragement was given for each repetition. Three trials were performed for each leg; the test leg was alternated to provide sufficient rest time.

Throwing velocity took place at least 48 hours after isokinetic strength testing. A JUGS cordless radar gun (JKP Sports, Tualatin, Ore) evaluated throwing velocity in a controlled environment. The gun was placed behind a protective screen 18.29 m (60 ft) away from subjects as they threw official softballs (Rawlings Sports, St. Louis, Mo) in a step-and-throw manner off a flat surface. Verbal encouragement was given for each repetition. Five throws were recorded per subject.

The 1RM bench press assessment took place after throwing velocity tests and at least 48 hours after isokinetic strength testing. Subjects warmed up by performing repetitions of the bench press on 45-lb bars and free weights (York Barbell, York, Pa), such that they would build to their previous 1RM load by the fifth set. A successful repetition was scored if the bar was lowered to the chest and raised to full arm extension without the subject losing foot, hip, back, or shoulder contact with the floor or bench, and no help was provided by the spotter. Loads above a subject’s previous 1RM were increased by 5 lb per attempt. Three failed repetitions at a given weight or voluntary termination ended the test.

Training Interventions. Periodized strength training sessions took place three times weekly for 12 weeks during the team’s fall off-season strength and conditioning program. The intensity and density of fall training is highest in the team’s yearly cycle, because spring in-season training is reduced and on-site summer training is not mandatory. All exercise sessions were supervised by coaches certified in the field of strength and conditioning. All subjects completed the same warm-up; Olympic (power clean, power snatch, dumbbell clean, etc.), lower-body (squat variations, lunge variations, deadlift variations) and core exercises (stability, rotational, and sit-up variations); and team conditioning drills, all of which were selected by the university’s director of strength and conditioning such that only upper-body exercises were different among treatment groups. The duration, relative intensity, and volume of each session were the same for both treatment groups. All subjects engaged in throwing, batting, and position-specific drills during the training cycle. The OKC and CKC groups did not differ in time or frequency of sport-specific practice during the training intervention.

The OKC group performed its training with free weights and dumbbells (York Barbell, York, Pa). Exercise intensity and volume were adjusted relative to a subject’s 1RM for major press and pull lifts. Intensity for assistance exercises was determined by subject familiarity and proper form.

The CKC group completed upper-body training with RedCord (Kilsund, Norway) mini-trainers, which are ropes with handles that can be height adjusted, hung from PowerLift (Jefferson, Iowa) power racks. Exercise intensity was controlled by adjusting handle height relative to the floor, foot height, and hand position relative to the rope fulcrum. Although there was some trial and error inevitable in the determination of relative intensity of major press and pull lifts, all subjects realized their capabilities within the first full week of training. By keeping the handles elevated, subjects could complete assistance exercises with intensity and volume comparable with those in the OKC group.

Examples of commonly selected OKCE and their CKCE analogs, in italics, are shown below:

1. Barbell/dumbbell flat or incline bench press/bilateral or unilateral push-ups.
2. Barbell/dumbbell seated or bent-over row/bilateral or unilateral inverted row.
3. Cable column pulldown (aka lat pulldown) with various grips/chin-ups or pull-ups.
4. Straight arm cable-column pulldown/shoulder extension (from the knees or standing).
8. Barbell/dumbbell/cable column triceps extension/triceps extension.

Figure 1 provides visual examples of OKC/CKC exercise pairs.

**Statistical Analyses**

Isokinetic strength data were collected and analyzed using Acqknowledge version 3.73. Peak torque values were determined from the torque curves for each respective strength measurement. For each of the three trials, five peak values were determined (one from each repetition). The lowest and highest of each trial’s values were eliminated, and the remaining three values were averaged. Peak torque was recorded from the trial with the highest average. Peak power was calculated by measuring the time needed to reach the three peak torque repetitions. The torque value (in newton-meters) was then divided by the time (in seconds) to achieve a power estimate in watts.

Dynamic single-leg balance was evaluated with the SWAY-WIN 95 software that accompanies the Accusway force plate. The 95% confidence ellipse area describes the area occupied by the center of pressure exerted against the working leg. The values for all three trials were averaged to calculate the balance proficiency of each leg. Throwing velocity was calculated by eliminating the lowest and highest values in the five-repetition trial and averaging the three middle values. Value elimination attempted to approximate “in-game” throwing performance.

*Figure 1.* Visual examples of open–kinetic chain (OKC)/closed–kinetic chain (CKC) pairs used in the training intervention.
Statistical calculations were performed using SPSS software version 14.0 (SPSS Inc., Chicago, Ill). A two-factor analysis of variance (ANOVA) with repeated measures was executed with the treatment group (CKC or OKC) as the independent variable. The dependent variable was time with two levels as pre- and posttraining test performance. Thus, there was one between-subjects factor (training group) and one within-subjects factor (time). The threshold for significance was set at the 0.05 level. Changes in throwing velocity were individually correlated to changes in all isokinetic assessments of shoulder peak torque and power. Correlation analyses were performed using SPSS software version 14.0.

RESULTS

Table 1 shows mean (± SD) pre- and posttraining data for the selected performance parameters. All CKCRT subjects improved throwing velocity, whereas the OKCRT subjects displayed variable changes in throwing velocity (Figure 2). The CKCRT group’s mean (± SD) throwing velocity improved significantly, from 58.0 (3.7) to 60.0 (2.8) mph, whereas the OKCRT group’s mean throwing velocity increased from

![Figure 2](image-url)
58.7 (7.3) to 59.0 (7.1) mph. The mixed-model ANOVA revealed a significant group \( \times \) time interaction \((p = 0.014)\) for throwing velocity. Each group significantly improved its 1RM bench press by a mean 1.9 kg \((p < 0.05)\). Mean external rotation peak torque improved 13% in the CKC group, with a 2.2% mean decrease in the OKC group \((p = 0.142\) for a group \( \times \) time interaction). The CKC group improved mean external rotation power by 21.3%, with an 8.5% mean decrease in the OKC group \((p = 0.142\) for a group \( \times \) time interaction). The CKC group improved mean peak power in shoulder flexion by 39.9%, with an observed mean 1.5% decrease in the OKC group \((p = 0.020\) for a group \( \times \) time interaction). Individual changes in 1RM bench press, external rotation peak torque, external rotation power, and flexion power are shown in Figures 3–6, respectively. Each group significantly improved dynamic single-leg balance in both legs \((p < 0.05)\). Correlation coefficients were not significant between changes in throwing velocity and any isokinetic assessment of shoulder peak torque or power.

**Discussion**

The salient findings of this investigation are (a) only CKC upper-body training led to significant improvements in throwing velocity (Table 1, Figure 2), and (b) CKC training of the upper body is as effective as OKC training in promoting maximal strength gains (Table 1, Figure 3). The results confirm two of our three hypotheses. The observed improvement in throwing velocity may have substantial performance implications. For example, the mean 3.4% increase in throwing velocity in the CKC group implies that a 200-ft throw (i.e., from the outfield to home plate) would arrive 0.09 seconds faster. The CKCRT sub-
have shown that lower-body CKCRT improved vertical jump height significantly (10%), whereas lower-body OKCRT conferred no effect. In addition, Blackburn and Morrissey (2) have shown that CKC load criteria (e.g., 1RM back squat) correlated significantly with vertical jump height, whereas OKC load criteria (e.g., 1RM leg press) did not.

To date, few published studies have evaluated training methods that affect throwing velocity and shoulder strength. Carter et al. (5) examined the effects of upper-body plyometrics (specifically, the "ballistic six") on baseball pitchers. The plyometric group experienced significant increases in throwing velocity by 2.0 mph from 83.2 to 85.2 mph, and eccentric external rotation and concentric internal rotation (at 180°·s⁻¹) peak torque. Traditionally trained subjects improved throwing velocity by 0.3 mph, from 78.9 to 79.2 mph, without improvements in shoulder rotation peak torque. Whereas the present study evaluated concentric external rotation, a similar...
trend was observed: subjects who increased external rotation peak torque also increased throwing velocity. Time to peak torque may also affect throwing performance (5). Swanik et al. (17) applied upper-body plyometric training methods similar to those of Carter et al. (5) in collegiate swimmers. The group observed a reduction in time to internal rotation peak torque at 60 and 240 but not 450 s^{-1} in the plyometric training group. The nonplyometric training group had no significant changes in time to peak torque. In the present study, the CKCRT group showed increases and the OKCRT group showed moderate decreases in shoulder power (Table 1). Perhaps a combination of the ballistic six and CKC resistance training would confer additive or even synergistic effects on throwing performance.

The present study observed statistically significant increases in throwing velocity for the CKCRT group. Many factors affect throwing velocity: proximal segment force production (8,13), postural stability (6), proximal-to-distal force transduction (6), segmental decelerative capacity (8), and segmental function. Both groups trained Olympic, lower-body, and core exercises equally. It is unlikely that proximal force production (either in maximal strength or motor unit recruitment) was affected by differences in the upper-body training protocol. Upper-body plyometric work (e.g., medicine ball throws) was trained equally in both groups, making differences unlikely in the training of the stretch-shortening cycle (SSC). Rogol et al. (14) have reported CKC and OKC exercises as being equally effective to enhance shoulder joint reposition sense. Thus, CKC training may have conferred some advantage in proximal-distal force transduction via enhanced segmental stability or functional efficiency.

The unique aspect of the rope-and-sling system of CKCRT allowed for progressive adjustments of exercise intensity. Changes in hand or foot position, the addition of external loads (via a weight vest), and incorporation of unilateral work accommodated the resistance needs of all training subjects. Perhaps the nature of the equipment enhanced activation of the musculature involved in torso and shoulder stabilization, which led to improved segmental stability during throwing. The rope-and-sling equipment is inherently unstable, meaning that CKC subjects spent more time on the eccentric portion of a given exercise (anecdotal observations). It is possible that these additional eccentric stimuli played a role in throwing velocity improvements.

An important factor in throwing velocity is throwing mechanics. All subjects received the same amount of coaching in throwing mechanics during the study. Although wide variability in the application of such advice can be a confounding variable in the present study, it is unlikely that the groups differed in this regard. More invasive methods of assessing subjects’ throwing mechanics would be required to evaluate their effects on the subject group.

In conclusion, upper-body training in the CKC for 12 weeks improved maximal strength and throwing performance (Table 1, Figure 2). The OKCRT group improved maximal strength but not throwing performance. Several shoulder strength parameters trended toward significant improvements with CKCRT, yet low statistical power and subject numbers limited the confidence with which the results can be recommended for a training population. On the basis of the current data, further investigations with greater subject numbers are warranted.

**Practical Applications**

Strength and conditioning coaches can be comfortable implementing upper-body CKCEs into a training program without sacrifices in maximal force production. Throwing performance improved significantly in the CKCRT group, likely because of neuromuscular adaptations intrinsic to CKCRT. Implementation of this CK training system allowed for periodized upper-body training, which is a critical factor in strength development and integral to the randomized controlled nature of this study. The kinetics of throwing are similar to those of other extremity performance-oriented sports. The improvements observed here may translate to other sports and extremity-based activities.

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**References**


Closed–Kinetic Chain Training and Throwing Performance


