The Effect of Select Shoulder Exercises on Strength, Active Angle Reproduction, Single-Arm Balance, and Functional Performance

Darin A. Padua, Kevin M. Guskiewicz, William E. Prentice, Robert E. Schneider, and Edgar W. Shields

Objective: To determine whether select shoulder exercises influence shoulder-rotation strength, active angle reproduction (AAR), single-arm dynamic stability, and functional throwing performance in healthy individuals. Design: Pretest–posttest. Setting: Laboratory. Participants: 54, randomly placed in 4 training groups. Intervention: Four 5-week training protocols. Main Outcome Measures: Average shoulder-rotation torque, AAR, single-arm dynamic stability, and functional throwing performance. Results: Repeated-measures ANOVAs revealed a significant group-by-test interaction for average torque (P > .05). Post hoc analyses revealed significantly increased average torque in the open kinetic chain and proprioceptive neuromuscular facilitation (PNF) groups after training. AAR and sway velocity were not affected in any of the groups (P > .05), but functional performance revealed a significant group-by-test interaction (P < .05). Post hoc analysis demonstrated that the PNF group significantly improved after training (P < .05). Conclusions: Shoulder strength can be improved in healthy individuals, but improvements depend on the exercise performed. Shoulder proprioception and neuromuscular control were unchanged in all groups, but functional performance improved in the PNF group. Key Words: glenohumeral, PNF, training

Traditionally, shoulder rehabilitation and injury-prevention techniques have focused on increasing strength of select muscles through the cardinal planes of motion and improving flexibility. This form of training, however, does not address the coordinated muscle activity necessary to produce functional patterns of motion and maintain joint stability. Currently, therapeutic exercise takes a more encompassing approach and attempts to address issues including proprioception, neuromuscular control, and functional performance. Unfortunately, the ability to improve shoulder strength, proprioception, neuromuscular control, and functional performance
through therapeutic exercise has not been well researched and is often based on clinical theory.

Recently, shoulder-exercise programs have taken on a multifaceted approach by employing various therapeutic exercise techniques such as closed kinetic chain (CKC), open kinetic chain (OKC), and proprioceptive-neuromuscular-facilitation (PNF) exercise. Much of the therapeutic-exercise information relative to the shoulder is theoretical, however, and lacks conclusive research, especially in regard to measures of proprioception, neuromuscular control, and functional performance. It is unclear how different forms of therapeutic exercise might individually influence measures of shoulder strength, proprioception, neuromuscular control, and functional performance. Such information would provide valuable clinical insight into the proper selection of therapeutic exercises for a specific rehabilitation goal. Therefore, the purpose of this study was to determine the outcomes of CKC, OKC, and PNF exercise techniques performed at the shoulder on strength, active angle reproduction, sway velocity, and functional performance over a 5-week training period.

Methods

A mixed-model factorial design with repeated measures was used in this study. We compared the effects of different shoulder-exercise programs on the following dependent variables: shoulder internal- and external-rotation torque (concentric and eccentric), active angle reproduction (assessed across 3 separate reference angles), single-arm dynamic stability, and the functional-throwing-performance index. All subjects were tested before and after the training protocols. Thus, the independent variables of this study were shoulder-exercise group and test session.

Subjects

Fifty-seven physically active, college-age men and women volunteered for participation (Table 1). Inclusion criteria included no history of injury to the upper extremity within the preceding 12 months, no history of glenohumeral subluxation or dislocation, and no current involvement in a formal shoulder-exercise program. Subjects were randomly assigned to 1 of 4 groups: a control group (CON), a CKC exercise group, an OKC exercise group using dumbbells, or a PNF exercise group. Two of the 57 subjects had previously participated in organized overhead sports (baseball). One of these was randomly assigned to the CON group, and the other was randomly assigned to the CKC group. Neither individual had actively participated in organized overhead sports for 2 years at the time of testing. We do not think that including these individuals influenced the findings of this study. Before participation, all subjects read and signed an informed-consent form approved by the committee for protection of human subjects at the University of North Carolina at Chapel Hill.
Testing Procedures

All testing was performed in a sports-medicine research laboratory. Testing and training were performed over a 7-week period. The first and seventh weeks of the study were reserved for testing (pretraining and posttraining), and weeks 2–6 represented the 5-week training period. During their initial visit to the laboratory, subjects completed a questionnaire to ensure compliance with the inclusion criteria, determine current physical activity levels, and determine each subject’s skill-dominant arm. Before testing, subjects received an explanation of all testing procedures and were allowed practice trials to become acquainted with the testing procedures. An initial warm-up was performed before both testing sessions, which involved a 2-minute bout on an Airdyne™ bicycle using only the arms. All testing was conducted on each subject’s skill-dominant arm, which was defined as the self-selected arm from which the subject would perform an overhand throw for maximal distance. Testing order was determined in a simple randomized fashion.

Strength Testing

Shoulder internal- and external-rotation-torque production were measured using the LIDO Multi-Joint II isokinetic dynamometer (Loredan Biomedical, Inc, Sacramento, Calif). We calibrated the isokinetic dynamometer before testing and employed the gravity-correction procedure described by the manufacturers. Concentric and eccentric measures of shoulder internal- and external-rotation torque were recorded. Subjects performed a concentric–eccentric protocol for shoulder internal and external rotation, separately. For example, testing of shoulder internal rotation consisted of subjects first performing a concentric contraction into shoulder internal rotation, which was immediately followed by an eccentric shoulder internal-rotation contraction. Thus, 1 repetition for shoulder internal-rotation-strength testing consisted of completing concentric shoulder internal rotation immediately followed by eccentric shoulder internal rotation.

Table 1  Physical Characteristics of Subjects, mean (SD)*

<table>
<thead>
<tr>
<th>Group</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>Age, y</th>
</tr>
</thead>
<tbody>
<tr>
<td>CON (n = 15)</td>
<td>178.97 (10.31)</td>
<td>70.60 (9.42)</td>
<td>20.73 (1.62)</td>
</tr>
<tr>
<td>CKC (n = 13)</td>
<td>173.10 (6.45)</td>
<td>68.81 (9.77)</td>
<td>21.07 (2.10)</td>
</tr>
<tr>
<td>OKC (n = 13)</td>
<td>172.90 (9.58)</td>
<td>67.45 (9.11)</td>
<td>21.38 (1.80)</td>
</tr>
<tr>
<td>PNF (n = 13)</td>
<td>171.15 (11.61)</td>
<td>66.85 (11.35)</td>
<td>21.90 (1.93)</td>
</tr>
</tbody>
</table>

*CON indicates control; CKC, closed kinetic chain exercise; OKC, dumbbell exercises in open kinetic chain; and PNF, proprioceptive-neuromuscular-facilitation exercise.
The isokinetic dynamometer was arranged to measure shoulder internal and external rotation, in a position of 90° of shoulder abduction and 90° of elbow flexion with the subject in a supine position. Subjects were stabilized in the chair according to the manufacturer’s guidelines, with straps securing the humerus, chest, and waist. They were uniformly provided with standard commands to ensure the starting test position, initiation of testing, and end of testing. All testing was performed at a velocity of 90°/s. Testing was performed through a range of 80° external rotation to 70° internal rotation, allowing for 150° of shoulder rotation to occur.

A warm-up and familiarization period was provided, during which subjects performed 6 graded submaximal repetitions, progressing from 50% to 80% of maximal voluntary efforts at 90°/s. This was followed by 3 maximal repetitions at 90°/s. One minute of rest was allowed after the warm-up period. The order of shoulder-rotation (internal vs external rotation) testing was randomized. Five maximal concentric followed by eccentric contractions were performed without interruption for both shoulder internal and shoulder external rotation. A 1-minute rest period was provided between shoulder-rotation-direction tests.

A total of 4 average torque-production scores were recorded: concentric internal rotation, eccentric internal rotation, concentric external rotation, and eccentric external rotation. Intrasession reliability for each of the average torque-production measures was high, with ICC2,1 values ranging from .88 to .92.

**Active Angle Reproduction**

Active-angle-reproduction (AAR) testing assessed proprioception using the LIDO Multi-Joint II isokinetic dynamometer. AAR is a measure of active joint-position sense, which is a submodality of proprioception.\(^{14}\) The dynamometer speed was set at 300°/s to ensure that there was no resistance during rotation. Subjects were placed in a supine position with their shoulder in 90° abduction and elbow in 90° flexion. They were blindfolded to eliminate visual input and wore headphones to minimize auditory cues. A pneumatic sleeve was placed around each subject’s forearm to reduce peripheral afferent activity of the cutaneous receptors.

From the starting angle of 0° humeral rotation, the subject’s shoulder was passively rotated by the examiner into 1 of 3 reference angles at speeds varying from 1° to 5°/s in an attempt to prevent anticipation. Once the specific reference angle was obtained the position was held statically for 10 seconds before being passively returned to the starting angle. The subject was then instructed to actively reproduce the previously presented reference angle. AAR reference angles included 30° internal rotation (30 IR), 30° external rotation (30 ER), and 75° external rotation (75 ER). Three trials were performed at each reference angle. The reference angles were presented in a randomized fashion. The 3 reference angles were selected to represent both directions of humeral rotation, as well as the midrange and
end range of motion. Similar absolute reference angles have been previously reported in the literature.\textsuperscript{15-17}

The absolute error between the reference angle and the subject’s reproduced angle was measured using the electrogoniometer of the isokinetic dynamometer. We calculated the average absolute error score from the 3 trials performed at each reference angle. Intrasection reliability for measures of AAR was high, with ICC\textsubscript{2,1} values ranging from .85 to .90.

**Single-Arm Dynamic Stability**

The SMART Balance Master® long force-plate system (NeuroCom® International, Inc, Clackamas, Ore) using the New Balance Master Version 6.1 software package (NeuroCom) provided an objective assessment of single-arm dynamic stability (SADS). The SADS test determined subjects’ ability to maintain dynamic stability through the shoulder in response to an unstable support surface. Subjects were first placed in a quadruped position with their dominant hand placed over the center of the force platform. The subjects’ feet were placed over the center of a multidirectional unstable platform (Dynamic Stabilization Trainer, DST 360, Exertool, San Carlos, Calif), thus creating a situation in which their shoulder was the primary mechanism for maintaining dynamic stability (Figure 1). Consistent positioning of the subjects’ feet on the unstable platform in relation to the shoulder was achieved by measuring subject height from the acromioclavicular articulation to the floor. Subjects were verbally instructed to remain as steady as possible during testing. They were not provided with any other

---

**Figure 1** Subject positioning during the single-arm dynamic-stabilization test for neuromuscular control.
instructions in order to avoid a coaching effect. After verbal instruction, subjects placed themselves in the push-up position with elbows and knees fully extended, shoulders level, back flat, and head in line with their body. After saying “Ready,” subjects removed their nondominant arm from the force platform and placed it behind their back as the investigator simultaneously started the test. Keeping their eyes closed, the subjects attempted to remain stable without breaking the testing position for 10 seconds, which was ended by a tone. Three test trials, with 30-second rest intervals between, were performed during testing. Before testing, subjects were allowed a practice session followed by a 1-minute rest period before test initiation.

Sway velocity was recorded as the dependent measure during SADS testing. It was calculated from sway-amplitude measurements divided by time. Sway amplitude is defined as the distance (°) an individual travels away from his or her center-of-pressure position, and time is the length of the trial (10 seconds). During pilot testing several subjects fell while performing the SADS test. If a subject was unable to maintain the testing position and fell, the test was automatically stopped, and the SMART Balance Master calculated no sway-velocity score. We did not discard the trials during which a subject fell, because we anticipated that before training some subjects might have difficulty in maintaining the testing position and might improve after training. For subjects who fell, we estimated their sway-velocity score to be 3.55°/s. This estimated sway-velocity value was derived after pilot testing of 12 subjects who were instructed to remain as unstable as possible without falling, as well as performing several falls on the force plate. Thus, the estimated sway-velocity score for subjects who fell represents a conservative estimate of their true sway-velocity measure during the actual trial. Only 2 subjects actually fell during the pretraining testing period; none fell at posttesting. We do not think that this conservative estimate of sway velocity influenced our findings, given the limited number of subjects who actually fell.

The average sway velocity from the 3 trials was used for analyses. A separate reliability study using intraclass correlation coefficients (ICCs) over 2 testing sessions 48 hours apart was conducted on 18 healthy college-age subjects. The results revealed an ICC$_{2,1}$ of .80 with an SEM of .253, suggesting moderate to high reliability for the SADS test.

**Functional Performance**

The Functional Throwing Performance Index (FTPI) served as an indicator of subjects’ functional-performance levels. The FTPI demonstrated good intrasession reliability (ICC$_{2,1} = .86$), which is in agreement with previous research reporting the FTPI to be reliable in healthy subjects. Testing materials and methods consisted of a 1-ft by 1-ft square target placed 4 ft high on the wall. Subjects stood 15 ft from the target square behind a line marked on the floor and attempted to throw a rubber ball (21-in circumfer-
ence) within the target square as many times as possible in a 30-second time period.

The subjects were instructed to throw with a natural overhand throwing motion, similar to that used by pitchers. The established protocol required that subjects throw the ball under control as fast and accurately as possible, while also catching the thrown ball’s rebound as quickly as possible.

Each subject performed 3 graded submaximal warm-up throws (25%, 50%, and 75% of maximal volitional effort) and then three 30-second tests in which they threw the ball as many times as possible with control and accuracy. A 1-minute rest period was allowed between tests. The total number of throws, as well as the number of accurate throws landing within the target square, was counted. Throws landing within the target square (not on the line) were defined as accurate throws. Results were determined by dividing the number of accurate throws by the total number of throws, producing a percentage score.7,18 We calculated the average percentage score from the 3 trials.

Training Protocol

Exercise groups (CKC, OKC, and PNF) trained 3 times per week for 5 weeks, for an average duration of 25 min/day. An initial warm-up was performed before all training sessions, which involved a 2-minute bout on an Airdyne bicycle, using only the arms. CON subjects were instructed to maintain their normal activities of daily living and to not participate in any form of upper extremity exercise training. All training sessions were supervised by the principal investigator of the study to ensure compliance with the training protocols.

CKC Group. Subjects were instructed to keep their elbows extended, shoulders flat, hips level, and knees extended during all 3 exercises. When subjects were able to perform 1 repetition of a specific exercise using proper form and not falling, they were progressed to performing 2 repetitions of the specific exercise. A 1-minute rest period between sets and a 90-second rest period before progressing to the next exercise were allowed. This type of exercise progression was used for all CKC exercises.

For the BAPS-board exercise (Figure 2), subjects began using both hands and progressed to a single-hand position over the center of the BAPS board as performance improved over time. Body position progressed from a quadruped position to a modified push-up position (on knees) to a single-arm push-up position (skill-dominant arm). Initially, subjects performed 1 repetition for 10 seconds and progressed to 3–5 repetitions for 30–45 seconds. Once able to perform 5 repetitions for 45 seconds each repetition, an individual was progressed to the more challenging body position. Subjects were not progressed until they were able to perform 5 repetitions for 45 seconds.
For step-ups (Figure 3), using both arms, the subject stepped up onto and down off of a 12-in box in a lateral direction. Exercise progression consisted of 1 set of 10–12 repetitions and progressed to 3–5 sets of 15–20 repetitions.
For the balance exercise (Figure 4), subjects balanced on a 48-in exercise ball. The exercise was progressed from both hands on a single ball to each hand on a separate ball to the skill-dominant hand only on a single ball. Body positions and exercise repetition were progressed as described in the BAPS-board exercise.

**OKC Group.** Subjects in the OKC-exercise group performed OKC isotonic dumbbell exercises using both concentric and eccentric contractions. Subjects performed 3 sets of 10 repetitions using variable resistance: 1 set at 50% of the 10-repetition maximum (RM), 1 at 75% of the 10 RM, and 1 at 100% of the 10 RM. A 1-minute rest period between sets and a 90-second rest period before progressing to the next exercise were allowed. At the end of each week the 10 RM was reevaluated and increased as subjects’ strength increased. All exercises were performed using dumbbells at a slow, controlled speed.

The 4 exercises were sitting scaption with the arm in 30° of horizontal abduction and internally rotated (thumb down), prone-lying horizontal abduction with arm externally rotated (thumb up), prone-lying single-arm...
rowing, and supine-lying single-arm bench press (using a dumbbell). These exercises were chosen because they have been previously described as eliciting high levels of electromyographic activity and as being a significant challenge for the surrounding shoulder musculature.3,4

**PNF Group.** The PNF-exercise protocol consisted of the D1 and D2 patterns of motion for the shoulder joint. Subjects actively moved against manual resistance provided by the principal investigator using a modified progressive resistance-exercise progression during the training sessions, similar to that described for the OKC-exercise training protocol. The principal investigator was the sole individual to perform the PNF exercises with the subjects. Subjects performed 3 sets of 10 repetitions using variable maximal voluntary effort (MVE): 1 set at 50% of the subject’s MVE, 1 at 75% MVE, and 1 at 100% MVE. MVE was estimated by instructing subjects to exert 50%, 75%, or 100% of their maximal force production in the desired pattern of motion. The investigator then matched subjects’ voluntary force production. A 1-minute rest period between sets and a 90-second rest period before progressing to the next exercise were allowed. The repeated contraction-strengthening technique was used during PNF training. Repeated contraction is a PNF strengthening technique requiring active contraction in the desired pattern of motion. Data extrapolation from previous studies revealed that the exercises used with the OKC-exercise group and the PNF-exercise group actively elicit the use of similar glenohumeral musculature.4,19,20 The basic procedures of PNF were closely followed.11,13 The D1 and D2 patterns of motion were as follows:

- Extension/Abduction/Internal rotation—D1
- Flexion/Adduction/External rotation—D1
- Extension/Adduction/Internal rotation—D2
- Flexion/Abduction/External rotation—D2

**Statistical Analysis**

Separate mixed-model repeated-measures ANOVAs were performed for functional-throwing-performance and SADS measures. Each analysis involved group as the between/independent factor (4 levels: CON, CKC, PNF, OKC) and test as the within/repeated factor (2 levels: pretraining, posttraining). Mixed-model repeated-measures MANOVAs were performed for AAR and average torque measures. Group was the between/independent factor for both analyses. The within/repeated factors differed depending on the parameter tested. AAR testing involved 2 within/repeated factors: test and angle (3 levels: 30 IR, 30 ER, 75 ER). Average torque measures involved 3 within/repeated factors: test, rotation (2 levels: internal, external), and contraction (2 levels: concentric, eccentric). Tukey post hoc analysis was performed to investigate all significant main effects and interactions. The level of significance for all statistical analyses was set a priori at $\alpha < .05$. 
Results

Originally, 57 subjects volunteered to participate in this study (CON = 15, OKC = 14, CKC = 14, PNF = 14). In order for the training-group subjects to remain in the study they must have participated in 95% of their scheduled training sessions. Three of the training group subjects, 1 from each training group, did not attend 95% of their sessions and were eliminated from the study. Thus, only 54 subjects were included in the data analysis (CON = 15, OKC = 13, CKC = 13, PNF = 13).

Strength: Average Torque

Means and standard deviations for average torque production for external- and internal-rotation measures are presented in Tables 2 and 3, respectively. There was a significant group-by-test interaction ($F_{3,50} = 3.197, P = .031$; Figure 5). Tukey post hoc analyses of the group-by-test interaction revealed that before training there were no significant differences between groups for average torque measures (collapsed across rotation direction and contraction type). After training, both the OKC and the PNF group demonstrated a significant increase in average torque measures (collapsed across rotation direction and contraction type) from their pretraining measures. No such changes were demonstrated in the CON and CKC groups. In addition, average torque measures (collapsed across rotation direction and contraction type) for the OKC and PNF groups at posttraining were significantly greater than those for the CON group at posttraining. There was no significant difference between the OKC and PNF groups at posttraining.

<table>
<thead>
<tr>
<th>Contraction type</th>
<th>Group</th>
<th>Pretraining</th>
<th>Posttraining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric</td>
<td>CON</td>
<td>27.47 (12.48)</td>
<td>26.93 (10.90)</td>
</tr>
<tr>
<td></td>
<td>CKC</td>
<td>28.46 (13.58)</td>
<td>30.38 (15.48)</td>
</tr>
<tr>
<td></td>
<td>OKC</td>
<td>27.76 (15.44)</td>
<td>30.76 (15.33)</td>
</tr>
<tr>
<td></td>
<td>PNF</td>
<td>29.15 (14.85)</td>
<td>33.69 (14.40)</td>
</tr>
<tr>
<td>Eccentric</td>
<td>CON</td>
<td>31.46 (13.84)</td>
<td>32.20 (12.90)</td>
</tr>
<tr>
<td></td>
<td>CKC</td>
<td>32.61 (13.51)</td>
<td>33.30 (13.70)</td>
</tr>
<tr>
<td></td>
<td>OKC</td>
<td>31.53 (15.03)</td>
<td>38.69 (18.19)</td>
</tr>
<tr>
<td></td>
<td>PNF</td>
<td>31.38 (14.89)</td>
<td>36.46 (12.90)</td>
</tr>
</tbody>
</table>

*CON indicates control; CKC, closed kinetic chain exercise; OKC, dumbbell exercises in open kinetic chain; and PNF, proprioceptive-neuromuscular-facilitation exercise.
Table 3  Average External-Rotation Torque (ft-lb) for Concentric and Eccentric Contractions During Pretraining and Posttraining Conditions, mean (SD)*

<table>
<thead>
<tr>
<th>Contraction type</th>
<th>Group</th>
<th>Pretraining</th>
<th>Posttraining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric</td>
<td>CON</td>
<td>18.53 (7.53)</td>
<td>19.26 (7.52)</td>
</tr>
<tr>
<td></td>
<td>CKC</td>
<td>18.23 (8.64)</td>
<td>21.23 (9.77)</td>
</tr>
<tr>
<td></td>
<td>OKC</td>
<td>19.07 (9.65)</td>
<td>22.07 (8.53)</td>
</tr>
<tr>
<td></td>
<td>PNF</td>
<td>18.07 (9.55)</td>
<td>21.92 (7.77)</td>
</tr>
<tr>
<td>Eccentric</td>
<td>CON</td>
<td>22.13 (7.99)</td>
<td>22.66 (8.34)</td>
</tr>
<tr>
<td></td>
<td>CKC</td>
<td>21.38 (7.25)</td>
<td>23.38 (8.59)</td>
</tr>
<tr>
<td></td>
<td>OKC</td>
<td>21.84 (9.43)</td>
<td>27.07 (10.85)</td>
</tr>
<tr>
<td></td>
<td>PNF</td>
<td>20.46 (11.12)</td>
<td>24.00 (6.90)</td>
</tr>
</tbody>
</table>

*CON indicates control; CKC, closed kinetic chain exercise; OKC, dumbbell exercises in open kinetic chain; and PNF, proprioceptive-neuromuscular-facilitation exercise.

Figure 5  Significant group-by-test interaction on average torque, N·m (collapsed across rotation direction and contraction type). CKC indicates closed kinetic chain.

*Significant increase in average torque measures for the open kinetic chain (OKC) and proprioceptive-neuromuscular-facilitation (PNF) groups at posttraining compared with pretraining. †Significant increase in average torque measures for the OKC and PNF groups at posttraining compared with the control (CON) group at posttraining.
Proprioception: Active Angle Reproduction

Descriptive statistics for absolute angular error, as measured through AAR, are presented in Table 4. There were no significant main effects or interactions involving group or test ($P > .05$). Thus, AAR was not influenced by any of the exercise protocols in this study.

Neuromuscular Control: SADS Test

Means and standard deviations for the SADS-test sway-velocity measures are reported in Table 5. Statistical analysis revealed no significant main effects or interactions for group or test ($P > .05$). These findings indicate that single-arm dynamic stabilization was not significantly affected by any of the exercise protocols.

Functional Performance: FTPI

FTPI descriptive statistics are presented in Table 6. There was a significant group-by-test interaction ($F_{3,50} = 3.84$, $P = .015$). Post hoc analysis revealed that there was a significant difference between posttest measurements

### Table 4  Active Angle Reproduction (absolute angular error) for the 30 IR, 30 ER, and 75 ER Reference Angles During Pretraining and Posttraining Conditions, mean (SD)*

<table>
<thead>
<tr>
<th>Reference angle</th>
<th>Group</th>
<th>Pretraining</th>
<th>Posttraining</th>
</tr>
</thead>
<tbody>
<tr>
<td>30° IR</td>
<td>CON</td>
<td>4.71 (1.44)</td>
<td>4.13 (1.98)</td>
</tr>
<tr>
<td></td>
<td>CKC</td>
<td>4.61 (2.69)</td>
<td>4.03 (1.59)</td>
</tr>
<tr>
<td></td>
<td>OKC</td>
<td>4.18 (2.09)</td>
<td>4.51 (2.29)</td>
</tr>
<tr>
<td></td>
<td>PNF</td>
<td>4.18 (2.23)</td>
<td>3.33 (2.19)</td>
</tr>
<tr>
<td>30° ER</td>
<td>CON</td>
<td>4.24 (1.44)</td>
<td>4.53 (1.98)</td>
</tr>
<tr>
<td></td>
<td>CKC</td>
<td>4.95 (2.78)</td>
<td>4.17 (2.48)</td>
</tr>
<tr>
<td></td>
<td>OKC</td>
<td>5.36 (2.56)</td>
<td>4.74 (2.75)</td>
</tr>
<tr>
<td></td>
<td>PNF</td>
<td>4.23 (2.68)</td>
<td>3.26 (2.92)</td>
</tr>
<tr>
<td>75° ER</td>
<td>CON</td>
<td>6.27 (2.45)</td>
<td>5.91 (2.74)</td>
</tr>
<tr>
<td></td>
<td>CKC</td>
<td>6.49 (3.36)</td>
<td>5.21 (1.79)</td>
</tr>
<tr>
<td></td>
<td>OKC</td>
<td>5.89 (3.29)</td>
<td>5.67 (3.29)</td>
</tr>
<tr>
<td></td>
<td>PNF</td>
<td>6.26 (3.03)</td>
<td>5.05 (1.62)</td>
</tr>
</tbody>
</table>

*IR indicates internal rotation; ER, external rotation; CON, control; CKC, closed kinetic chain exercise; OKC, dumbbell exercises in open kinetic chain; and PNF, proprioceptive-neuromuscular-facilitation exercise.
among the 4 groups. The PNF-exercise group demonstrated significantly greater scores after training than at pretraining ($P < .05$; Table 5).

**Discussion**

We had hypothesized that shoulder strength, proprioception, neuromuscular control, and functional performance would be affected differently depending on the type of exercise performed. Proprioception and neuromuscular control were unchanged in all exercise groups after the training period. Shoulder-rotation average torque was significantly improved, however, in the OKC and PNF groups after the 5-week training period. Functional performance was significantly improved in the individuals per-
forming PNF exercise. No changes in functional performance were observed, however, in the CON, OKC, and CKC groups.

**Closed Kinetic Chain Exercise**

CKC exercises are described as a means to increase strength\(^3\)\(^4\) while balancing glenohumeral compression and shear forces. This is believed to limit translation and strengthen the shoulder, with less resulting tensile stress on the capsuloligamentous complex.\(^7\) Our findings support the role of CKC exercise in improving shoulder-rotation strength. Specifically, CKC exercises are effective in improving concentric shoulder-rotation strength. The ability of CKC exercise to improve eccentric shoulder-rotation strength is unclear. Although our results revealed a significant test main effect for ER\(_ECC\) strength, the CKC group only increased ER\(_ECC\) torque output by 8.5% from pretraining to posttraining. In comparison, the OKC and PNF groups increased ER\(_ECC\) torque output by 20% and 15%, respectively. Thus, we feel that the OKC and PNF groups were primarily responsible for the significant test main effect for ER\(_ECC\) strength. There was no increase in eccentric internal-rotation-strength measures for the CKC group. We are unable to compare our findings with those of previous research, because research has not investigated the influence of CKC exercise on shoulder strength. This appears to be the first research to demonstrate the ability of CKC exercise to influence the rotation strength of the shoulder.

CKC exercises have been described as a means to enhance or restore dynamic shoulder stability by facilitating shoulder-muscle coactivation resulting from joint approximation.\(^7\)\(^10\) Joint approximation is believed to stimulate peripheral afferent activity, which then stimulates reflexive muscle stabilization and helps improve shoulder proprioception and neuromuscular control.\(^6\)\(^7\)\(^10\)\(^13\)\(^21\) Previous research has indicated that CKC exercise appears to be effective in improving shoulder-joint proprioception\(^22\) and neuromuscular control\(^23\) in healthy individuals. Our findings, however, do not support the use of CKC exercise as a means of improving either proprioception (ie, joint-position sense) or neuromuscular control (ie, single-arm dynamic balance) in healthy individuals. Potential reasons for the disagreement between our findings and those of previous research might include the type of CKC exercises performed and the testing procedures.

Rogol, Ernst, and Perrin\(^22\) incorporated a CKC-exercise program with standard push-ups and reported improved proprioception after 6 weeks of training. In the current study, subjects performed dynamic-balance exercises while in a push-up position on an unstable surface, as well as step-up maneuvers, for 5 weeks. Perhaps CKC exercises that involve dynamic balance are less effective in improving proprioception than are more dynamic CKC exercises such as a standard push-up. Ubinger, Guskiewicz, and Prentice\(^23\) demonstrated improved neuromuscular control (ie, single-arm dynamic balance) after 6 weeks of CKC-exercise training. The CKC-
exercise programs in the current study and that of Ubinger et al are nearly identical, but the 2 studies incorporated different methods of assessing neuromuscular control. We placed subjects in an unstable position by setting their feet on an unstable platform as they attempted to maintain dynamic balance while in a single-arm push-up position. Ubinger et al incorporated a similar test position but did not use an unstable platform. In addition, we assessed sway velocity using the NeuroCom long force plate as a measure of neuromuscular control, whereas Ubinger et al assessed individuals’ stability index using the FASTEX. According to Ubinger et al, the stability index is calculated by measuring the number of times the ground-force oscillations exceed a preset voltage while the subject is in the single-arm push-up position. A lower stability-index value indicates better dynamic balance in the test position. Although the testing positions and CKC exercises were fairly similar between the current study and that of Ubinger et al, differences in neuromuscular-control assessment make direct comparisons difficult.

We think that CKC exercise should not be discounted as an effective method to facilitate proprioception and neuromuscular control, even though our findings did not demonstrate significant improvements in either. Future research incorporating different types of CKC exercise, as well as different methods for assessing proprioception and neuromuscular control, is needed to better address the effectiveness of CKC exercise.

Open Kinetic Chain Exercise

OKC exercise typically involves the use of dumbbells. These exercises are described as placing resistive, distraction, and rotary forces on the shoulder, which might facilitate a stable base of support, peripheral afferent deformation, concentric acceleration, eccentric deceleration, and assimilation of function. Traditionally, OKC exercise with dumbbells has been performed to strengthen shoulder muscles. Our findings support OKC exercise with dumbbells as an effective method of improving shoulder-rotation strength. It is difficult to compare our findings with those of other research because the latter has focused on EMG activity elicited from different dumbbell exercises. These studies have identified specific exercises that elicit high muscle activity of select muscle groups important for shoulder function and that have been recommended to form the core of shoulder-rehabilitation programs. These studies, however, did not investigate whether the recommended exercises actually facilitate shoulder-strength gains after a training period. Recent research by Moncrief et al investigated the effects of prone horizontal-abduction exercises over 4 weeks on average and peak torque during shoulder internal and external rotation. These authors reported significant increases for internal- and external-shoulder-rotation torque measures (8% to 10% increase for average and peak torque). Our findings agree with those of Moncrief et al; we observed similar in-
creases in shoulder-rotation strength in the OKC group (15% increase). Thus, our findings provide additional insight into the effectiveness of OKC shoulder exercise with dumbbells.

More recently, OKC exercise has been suggested to address proprioception and neuromuscular control by emphasizing joint-position awareness. The exercises performed by our OKC group did not emphasize joint-position awareness but, rather, emphasized increasing strength of select shoulder muscles. Thus, we did not expect to see improved shoulder proprioceptive ability or neuromuscular control in the OKC group. Surprisingly, other research incorporating strength training with dumbbells has revealed improved shoulder proprioceptive ability. Rogol et al. demonstrated improved joint-position sense in subjects performing supine dumbbell-press exercises over a 6-week period. It is difficult to know why a training protocol involving only supine dumbbell-press exercises facilitated improved proprioception, but an exercise program incorporating multiple exercises did not alter proprioception.

The OKC group demonstrated no improvement in functional performance after training. At first glance, our results appear to contrast with those of other research investigating strength training and functional performance. Ellenbecker, Davies, and Rowinski reported that a concentric-strength-training program for rotator-cuff musculature significantly increased tennis-serve speed, but eccentric training did not improve it. The authors suggested that the difference between the concentric- and eccentric-training groups’ functional performance might be explained by the concept of exercise specificity. Eccentric rotator-cuff training might specifically affect only the deceleration phase of the motion, whereas concentric training of the rotator cuff affects the acceleration phase, thus determining the trajectory and velocity components of the performance. When considering the concept of exercise specificity, we did not expect to see improved functional performance in the OKC group. The functional task performed in this study involved repeated overhand throws that require speed and accuracy. The exercises performed in the OKC group did not simulate the throwing motion and were not performed with speed or accuracy requirements. Thus, our findings appear to agree with those of Ellenbecker et al. in that we did not see improved functional performance in the groups whose exercises were not similar to the functional task performed.

**Proprioceptive-Neuromuscular-Facilitation Training**

The spiral and diagonal motion patterns incorporated during PNF shoulder exercise share biomechanical characteristics similar to the overhand throwing motion. This might allow for improved muscle strength and coordination during functional-movement patterns. PNF exercises are also believed to enhance motor learning by incorporating functional-motion patterns. Basic principles of PNF state that joint approximation and
traction should occur throughout the patterns of motion.\textsuperscript{14,16} As previously stated, joint approximation is believed to stimulate cocontraction,\textsuperscript{6,7,10,13,21} which might enhance shoulder neuromuscular control and dynamic stability, similar to CKC exercise.

Although PNF exercises performed at the shoulder would seem an effective means of improving proprioception, neuromuscular control, and functional performance, we were unable to find published research to either support or refute this theory. To our knowledge, this is the first study to prospectively examine PNF exercise at the shoulder joint. Our results revealed that the PNF group demonstrated functional-performance capabilities (FTPI scores) superior to those of the other groups after completing the 5 weeks of training.

Improved functional performance in the PNF group might be partially explained by theories related to neural adaptation, motor learning, and the concept of exercise specificity. There are several similarities between the D2 pattern during PNF shoulder exercise and the overhand throwing motion. During the windup and cocking phases of throwing the shoulder moves into external rotation, abduction, and flexion. Progressing into the acceleration and follow-through phases, the shoulder undergoes internal rotation and adduction and moves into extension. Examining the D2-flexion PNF pattern, the shoulder undergoes similar motions to those of the windup and cocking phases of throwing. The D2-extension pattern consists of internal rotation, adduction, and extension, similar to the acceleration and follow-through phases of throwing.\textsuperscript{5} Through proper training, the nervous system is able to more efficiently activate involved muscles in specific movement patterns and better coordinate the activation of all synergistic and antagonistic muscles involved throughout the motion.\textsuperscript{28} Over the training period the PNF group repeatedly performed the D2 patterns, and it is likely that neural adaptation and motor learning occurred, hence strengthening the individuals’ general motor program for the overhead throwing motion. This might have enabled the PNF group to more efficiently recruit and activate muscles involved with the overhand throwing motion and inhibit those not involved, thereby improving functional performance. Therefore, our results support those of previous studies that found that training protocols using muscle groups and motion patterns similar to the desired movement produce the most significant performance gains.\textsuperscript{29,30}

The PNF-exercise group demonstrated improved functional performance, as well as improved shoulder-rotation strength. Increases in shoulder-rotation strength in the PNF-exercise group (15% increase) were identical to those observed in the OKC-exercise group. Thus, the PNF exercises performed in this study were as effective at increasing shoulder-rotation strength as the OKC exercises used in this study. Active angle reproduction and SADS-test performance were not improved in subjects performing PNF exercise. Thus, the PNF-exercise protocol used in this study does not appear to be effective in improving active angle reproduction and single-arm dynamic stability in healthy individuals. By improving shoulder-
rotation strength, as well as functional performance, PNF exercise appears to be the most efficient of the training methods used in this study. Nonetheless, it should be noted that the PNF exercises were the only exercises that incorporated movement-specific patterns similar to overhand throwing. Thus, the comparison of PNF with other training techniques is limited. OKC exercise that involved more dynamic, throwing-like motions might have also resulted in improved FTPI scores.

**Limitations**

Our findings should be considered within the study’s limitations. One major limitation was the use of healthy subjects. Different results might occur when performing the identical testing and training procedures in a group of injured subjects. Future research should consider the use of injured subjects with different diagnoses. Another limitation involves the length of the training period and the specific exercises performed. A longer training period, different types of exercises, or both might produce different results. In the future, researchers might consider investigating different forms of shoulder-related exercise for a longer training period. This might be especially important for variables such as AAR and single-arm dynamic stability, which were not revealed to be significantly influenced by any of the training procedures in this study. It is possible that training periods longer than 5 weeks are needed to elicit significant changes in these variables. It is also important to note that the findings of this study are limited to the specific testing procedures (AAR, SADS test, FTPI) we used to assess proprioception, neuromuscular control, and functional performance. It is not known how the training protocols used in this study would influence other testing procedures used to assess these measures.

A final limitation of this study was the amount of resistance given to the PNF group when they performed exercises at 50% and 75% of maximal effort. It is possible that the PNF group was working at near maximal effort during all sets of PNF exercises. If this occurred, the PNF group might have experienced greater muscle overload and possibly biased the PNF group toward greater strength gains. There was no difference, however, in muscle-strength gains between the PNF and OKC groups. As such, we believe that the PNF and OKC groups experienced similar muscle overload. It is possible that the CKC group did not experience the same overload as the PNF and OKC groups, hence influencing their lack of significant strength gains. Future research comparing different exercise routines should attempt to standardize the amount of work performed at the joint across the different exercise conditions.

**Summary**

Only the subjects performing OKC exercise with dumbbells and PNF exercise demonstrated significant gains in average torque production during
shoulder rotation. Proprioception (active angle reproduction) and neuromuscular control (single-arm dynamic stability) were not altered in any of the training groups after the 5-week training period. Significant improvements in functional performance (FTPI scores) were revealed in the PNF group. This study demonstrates that shoulder-rotation strength might be improved through OKC exercise with dumbbells and PNF exercise. PNF exercise was the only effective method of improving shoulder functional performance. We think that PNF exercise was the most efficient method of training, given its ability to improve shoulder-rotation strength, as well as functional performance of the shoulder.

References


