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# Three-Dimensional Scapular and Clavicular Kinematics and Scapular Muscle Activity During Retraction Exercises

Proper movement of the scapula and clavicle is essential in minimizing stress applied to tissues surrounding the glenohumeral joint during overhead movements.<sup>15,29,32,36,39,40,56,61</sup> Scapular/clavicular movement maintains line of pull and length-tension relationship of the rotator cuff muscles throughout humeral range of motion.<sup>31,33,39,64</sup> This enables the rotator cuff muscles to produce joint compression while minimizing translation of the humeral head, which helps reduce tensile stress to inert tissues surrounding the joint.<sup>31,33,64</sup> Movement of the scapula and clavicle also influences the width of

the subacromial space.<sup>15,56</sup> Studies using magnetic resonance imaging (MRI) have demonstrated that the subacromial width narrows with protraction<sup>56</sup> and humeral

elevation.<sup>15</sup> Coordinated movement between the scapula and humerus that maximizes subacromial width at higher humeral elevation angles is thought to minimize impingement and subsequent damage to the subacromial tissues due to compressive stress.<sup>15,29,39,56</sup>

Given the importance of the scapular and clavicular movement in minimizing stress imposed on soft tissues surrounding the glenohumeral joint, abnormal scapulohumeral movement may result in accumulation of stress to surrounding tissues over time, and therefore may lead to development of soft tissue injuries.<sup>16,36,39,40,53,61,62</sup> This relationship between scapular and clavicular movements and shoulder injuries is supported by the findings from previous studies demonstrating altered scapular and clavicular kinematics in individuals with pathologic conditions.<sup>32,37,43,51,61</sup> McClure et al<sup>43</sup> demonstrated altered scapular and clavicular kinematics in patients with subacromial impingement syndrome. Similarly, Ludewig et al<sup>37</sup> reported alteration in scapular kinematics and muscle activity in construction workers with subacromial impingement syndrome. Others have also demonstrated scapular kinematic alterations in baseball players with posterior impingement,<sup>32</sup> patients with multidirectional instability,<sup>51</sup> and full-thickness rotator cuff tears.<sup>54</sup> Although there are some

- **STUDY DESIGN:** Controlled laboratory study.
- **OBJECTIVES:** To describe and compare scapular and clavicular kinematics and muscle activity during 6 retraction exercises in young healthy adults (mean ± SD age, 23.2 ± 2.4 years).
- **BACKGROUND:** Based on the association between shoulder injuries and scapular/clavicular movement, muscle activity during various exercises that target muscles surrounding the scapula have been investigated. However, the scapular and clavicular movements occurring during these exercises remain uninvestigated. Evaluation of the scapular and clavicular kinematics in addition to muscle activity provides additional information that allow clinicians to select exercises that best meet the patient's needs.
- **METHODS:** Three-dimensional scapular and clavicular kinematics and scapular muscle activity data were collected while the participants performed 6 scapular retraction exercises. One-way repeated-measures ANOVA and post hoc analyses

were used to determine differences in scapular/clavicular kinematics and activation levels of the upper, middle, and lower trapezius and serratus anterior muscles occurring during the exercises.

- **RESULTS:** The general pattern of the kinematics observed during all retraction exercises was scapular external rotation, scapular upward rotation, scapular posterior tilting, clavicular retraction, and clavicular depression. However, the exercises resulted in varying amounts of scapular movement and muscle activity.

- **CONCLUSION:** Clinicians can select appropriate exercises for their patients based on their need to strengthen specific retractor muscles and to improve specific scapular and clavicular movement patterns, pre-existing conditions, and available range of motion. *J Orthop Sports Phys Ther* 2010;40(3):169-179. doi:10.2519/jospt.2010.3018

- **KEY WORDS:** rehabilitation, scapular dyskinesis, shoulder injury

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inconsistencies, the general pattern of the scapular movement seen in these pathologic populations is decreased upward rotation, external rotation, and posterior tilt.<sup>36,40,51</sup> This suggests that exercises that improve these movements may have the potential to effectively restore the normal scapular movement in patients with shoulder injuries, although this has not been demonstrated with research.

The association between altered scapular and clavicular movement and shoulder injuries suggests that restoring normal scapular and clavicular kinematics may be indicated in rehabilitation of patients with shoulder pathologies.<sup>12,30,36,39,56,61</sup> Therefore, rehabilitation exercises that target activation of the scapular muscles have been evaluated using electromyography (EMG) in a number of studies.<sup>8,10,11,13,20,22,30,34,35,38,41,47,50</sup> While these previous studies provided useful information regarding the muscles being activated during various exercises, they did not document the associated scapular kinematics. Measurement of the scapular and clavicular movement, along with muscle activity during exercises, will provide additional information clinicians can use to select exercises based on their patient's needs.<sup>58</sup> Thigpen et al<sup>58</sup> compared the scapular kinematics and muscle activity during the full-can versus empty-can supraspinatus exercises and determined that while the 2 exercises resulted in a comparable level of muscle activity, the scapular kinematic analysis suggested that full-can exercise may be performed without compromising the subacromial space compared to the empty-can exercise. Evaluation of the scapular/clavicular kinematics, in addition to muscle activity, in their study provided authors additional information that allowed them to recommend the full-can exercise over the empty-can exercise. McCann et al<sup>41</sup> have also attempted to capture movement of the scapula and the humerus during rehabilitation exercises using a camera system. However, the instrumentation they employed did not allow them to measure 3-dimensional scapular/clavicular kine-

matics. Unfortunately, no other studies have evaluated scapular/clavicular kinematics during rehabilitation exercises.

A set of strengthening exercises for the posterior rotator cuff muscles introduced by Blackburn et al<sup>1</sup> in 1990 have been modified and widely used to strengthen scapular retractor muscles as a result of the growing awareness of the importance of scapular kinematics in shoulder function.<sup>2</sup> These exercises are performed while subjects lay prone, and consist of contractions of the scapular retractors with the upper limb in varying positions.<sup>1</sup> Different rotator cuff muscles were preferentially activated when various exercises were performed in different upper-limb positions.<sup>1</sup> Similarly, contraction of the scapular retractors in different upper-limb positions may result in preferential activation of specific retractor muscles. Although EMG of the rotator cuff muscles during the retraction exercises has been investigated in a previous study,<sup>1</sup> activity of the retractor muscles was not evaluated. The upper, middle, and lower trapezius and serratus anterior muscles highly influence the scapular movement through its broad attachments.<sup>3,5,8,10,11,23,30,37,38,46</sup> These muscles are also located superficially, allowing examination of the muscle activity using surface EMG electrodes.

Understanding variations in retractor muscle activity and scapular/clavicular movement among retraction exercises may help guide clinicians to select exercises that are most appropriate for each patient. Therefore, the purpose of this study was to describe and compare how scapular/clavicular kinematics and retractor muscle activity during exercise differ among the 6 retraction exercises, using an electromagnetic tracking device and EMG. Specifically, scapular external/internal rotation, scapular upward/downward rotation, scapular anterior/posterior tilt, clavicular protraction/retraction, and clavicular elevation/depression, as well as activity of the upper, middle, and lower trapezius and serratus anterior muscles were evaluated. It was hypothesized that the amount of scapular/clavicular kine-

matics and muscle activity would differ among the 6 retraction exercises.

## METHODS

### Participants

**T**WENTY-FIVE HEALTHY MALES AND females (14 males, 11 females; mean  $\pm$  SD age, 23.2  $\pm$  2.4 years; height, 173.7  $\pm$  9.9 cm; mass, 74.9  $\pm$  18.0 kg; all right-handed), participated in this study. The dominant limb was determined as the arm used to throw a ball. Subjects with a previous history of shoulder surgery or traumatic injury (dislocation, subluxation, or acromioclavicular [AC] joint sprain) were excluded from this study. Participants with shoulder or elbow pain within 6 months prior to the testing were excluded from the study as well.

### Instrumentation

The Motion Star electromagnetic tracking device (Ascension Technologies, Burlington, VT) and Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL) were used to assess 3-dimensional scapular/clavicular kinematics. The device consists of an extended range transmitter that creates an electromagnetic field and standard receivers (dimensions, 25.4  $\times$  25.4  $\times$  20.3 mm) that detect the electromagnetic field emitted by the transmitter. The receivers were attached to specific body segments as described in previous literature.<sup>26</sup> The electromagnetic tracking device recorded the position and the orientation of the receivers about the *x*, *y*, and *z* axes relative to the transmitter (global coordinate system). By digitizing the anatomical landmarks with a stylus, the orientation of one body segment was calculated with respect to the other. The data were collected at 100 Hz.

All kinematic assessments were performed with the subject's upper body, positioned 1 m away from the transmitter, as it was previously determined in our laboratory that this region of the measurement space demonstrated the least amount of position (0.7 mm) and orientation (0.27°) error.<sup>48</sup> The assessment of

scapular kinematics with an electromagnetic tracking device has been validated against a measurement using a bone pin in a previous study,<sup>26</sup> which used sensors of a different size than those used in this study. Additionally, reliability for scapulothoracic motion has been established: an intrasession intraclass correlation coefficient (ICC) of 0.97 and a standard error of measurement (SEM) of 0.94°, and an intersession ICC of 0.89 and an SEM of 2.11°. Muscle activity was collected using the Noraxon Telemetry 900 (Noraxon, Scottsdale, AZ) EMG system. The signal was passed through a single-ended amplifier (gain, 500) to two 8-channel frequency modulation transmitters. The signals were then sent to the receiver, where the signal was amplified (gain, 500) and filtered (15- to 500-Hz band-pass Butterworth filter, common-mode rejection ratio of 130 dB). The signal was then converted to digital data via a DT3010/32 (32-channel, 24-bit) A/D board (Data Translation Inc, Marlboro, MA) and recorded using the Motion Monitor software. The EMG data were collected at 1000 Hz.

### Procedures

All testing in the current study was performed in a university medical center biomechanics research laboratory. Prior to testing, each participant provided informed consent, as required by The University of Pittsburgh Institutional Review Board.

Four pairs of 30 × 22-mm silver-silver chloride surface electrodes (AMBU Blue Sensor N; AMBU, Glen Burnie, MD) were placed on the upper, middle, and lower trapezius, and serratus anterior muscles on the dominant-side shoulder, after the skin was abraded and cleaned with alcohol prep pads to minimize skin impedance. Electrodes were placed in line with the muscle fibers over the following locations: upper trapezius, slightly lateral to one half the distance between the spinous process of the seventh cervical vertebra and the acromion; middle trapezius, medial to the medial border of the spine of the scapula at the level of the spinous pro-



**FIGURE.** The figure above shows a participant performing exercises 1 through 6 (A-F). All exercises were performed while the participant lay prone on the treatment table. During exercises 1 through 6, participant's upper limbs were positioned as follows: (A) exercise 1, 90° abduction and neutral humeral rotation (palm facing floor); (B) exercise 2, 90° abduction and external rotation (thumb pointing toward ceiling); (C) exercise 3, 120° abduction and neutral humeral rotation (palm facing floor); (D) exercise 4, 120° abduction and external rotation (thumb pointing toward ceiling); (E) exercise 5, abducted 45° with 90° of elbow flexion; (F) exercise 6, full extension. For all exercises, participants were instructed to lift the arms toward the ceiling and hold while squeezing the shoulder blades together.

cess of the third thoracic vertebra; lower trapezius, medial to the medial scapular border, 5 cm below the scapular spine at approximately 55° oblique angle; serratus anterior, below the axilla, at the level of the inferior angle of the scapula and medial to the latissimus dorsi muscle.<sup>7</sup> The interelectrode distances were approximately 22 mm for all muscles.<sup>7</sup> The reference electrode was placed over the olecranon process. The electrodes were secured onto the skin using 3M Micropore surgical tape (3M Health Care, St Paul, MN). Once the electrodes were secured, participants performed a 5-second maximal voluntary isometric muscle contraction for each muscle, using the manual muscle testing procedures described by Kendall et al.<sup>28</sup> The EMG signal during performance of the maximal voluntary muscle contraction for each muscle was recorded and used to normalize muscle activity during the exercises.

A total of 6 receivers were used for bilateral scapular/clavicular kinematics assessment (FIGURE). The first receiver was attached to the spinous process of the seventh cervical vertebra. Two receivers were attached bilaterally on the flat portion of the acromion processes, and 2 receivers were attached bilaterally to the mid-shaft

of the posterior humerus. All receivers were secured on the skin using double-sided adhesive disks (3M Health Care), prewrap, athletic tape, and a Velcro strap to minimize skin-receiver movement. The sixth receiver was attached to the stylus that was used to palpate and digitize the anatomical landmarks on the upper arm, scapula, and thorax. The following anatomical landmarks were digitized: the spinous process of the eighth thoracic vertebra, xiphoid process, the spinous process of the seventh cervical vertebra, jugular notch, sternoclavicular (SC) joint, the AC joint on the medial scapular border where it intersects with the scapular spine, inferior angle, posterior lateral acromion, medial epicondyle, lateral epicondyle, and the glenohumeral joint center. The SC joint on the thorax segment and the AC joint on the scapular segment were digitized in addition to the landmarks necessary to define the scapular and thorax local coordinate systems, to calculate indirect clavicular kinematics.<sup>26,43,49</sup> Landmarks on the humerus and the scapula were digitized bilaterally. However, only the data from the dominant shoulder were used for analyses. Because the glenohumeral joint center cannot be digitized, it was estimated as the point that moves least with respect to

the scapula when the humerus is passively moved through several short arcs.<sup>44</sup> Digitization of these anatomical landmarks on each body segment allowed construction of the local coordinate system for the thorax, scapula, and humerus. Using local coordinate systems, the position and orientation of the scapula with respect to the thorax were calculated.<sup>49</sup>

The order of the exercises was randomized by using cards numbered 1 through 6. The exercises were performed in the order the cards appeared after the examiner shuffled them for each participant. All exercises were performed while the participants lay prone on the treatment table (FIGURE). During exercises 1 to 6, participant's upper limbs were positioned as follows: exercise 1, 90° abduction and neutral humeral rotation; exercise 2, 90° abduction and external rotation; exercise 3, 120° abduction and neutral humeral rotation; exercise 4, 120° abduction and external rotation; exercise 5, abducted 45°, with 90° of elbow flexion; exercise 6, full extension. To maintain the humerus in neutral rotation during the exercises 1 and 3, participants were instructed to "keep the palm facing down." Similarly, participants were instructed to "point your thumbs toward the ceiling" to maintain the humerus in external rotation during exercises 2 and 4. For all exercises, participants were instructed to "lift the arms toward the ceiling and hold while squeezing the shoulder blades together." The examiner demonstrated each exercise for each participant to make sure the subjects understood the differences among the 6 exercises. Verbal feedback was provided by the examiner during trials, as needed, when the subject's humeral abduction angle appeared to be too low or high on visual inspection. Although subjects did not practice the exercises before the test trial, very few required the verbal feedback. The participants performed 3 repetitions of 6-second muscle contractions for each exercise, with 10 seconds of rest in between. The 6 seconds were counted from the moment the humerus started moving to the upper limb posi-

tions described above. The speed at which subjects moved their arm from the resting position to the testing position was not standardized. During the rest periods, subjects rested their arms by letting them hang off the side of the table. The durations of each repetition and rest periods were guided by the metronome (1 beat per second). Approximately 3 minutes of rest were provided between the performances of each exercise to minimize the effect of muscle fatigue. None of the subjects complained of fatigue. The preparation and placement of the EMG electrodes and sensors for the electromagnetic tracking system, as well as instruction to subjects were conducted by the same examiner for all participants. The maximal voluntary isometric contraction trials were conducted by a second examiner for all subjects.

### Data Reduction

Raw scapular kinematic data were filtered with a low-pass 10-Hz Butterworth filter. The position and orientation data of the receivers and the digitized anatomical landmarks were used to construct local coordinate systems for thorax, scapula, and humerus. The coordinate systems used were in accordance with recommendations from the International Shoulder Group of the International Society of Biomechanics (ISB).<sup>63</sup> When the subject stood in an anatomical position, the coordinate system for each segment was vertical (*y*-axis), horizontal to the right (*z*-axis), and anterior (*x*-axis). The orientation of the scapula was determined as rotation about the *y*-axis of the scapula (internal/external rotation), rotation about the *x*-axis of the scapula (upward/downward rotation), and rotation about the *z*-axis of the scapula (anterior/posterior tilting). Euler angle decompositions were used to determine scapular and humeral orientation with respect to thorax (scapulothoracic movement, *y-x-z* order; humerothoracic movement, *y-x-y* order). The rotation sequence of the Euler angle was chosen based on the recom-

mendation of the International Shoulder Group.<sup>63</sup>

The scapula is attached to the thorax via the clavicle, a rigid body with a fixed length; therefore, the position of the scapula could be described as the orientation of the clavicle with respect to the thorax. Anatomically, the vector extending from the SC to the AC joint represents the orientation of the clavicle.<sup>26,43</sup> The clavicular protraction/retraction angle was calculated as the angle formed between the vector extending from the SC to the AC joint projected onto the transverse plane of the thorax, and the clavicular elevation/depression angle was calculated as an angle formed between the vector projected onto the frontal plane of the thorax.<sup>26,43,49</sup> The clavicular protraction/retraction and elevation/depression angles represent the position of the scapula relative to the thorax.<sup>26,43,49</sup> Orientations of the scapula and clavicle in neutral stance were defined as the scapular and clavicular kinematic values while the participants stood still with their arm resting by their side.

The scapular neutral stance data were acquired during the digitization process, and the neutral stance data for clavicular orientations were acquired while the participants were instructed to stand still, with their arms resting by their side. The start and finish of each repetition were identified through the visual inspection of the humeral kinematic data in the transverse plane (horizontal abduction/adduction angles). During rest periods, the arms were horizontally adducted as they hung from the side of the treatment table. The time points at which the humeral horizontal abduction was initiated (start) and returned to the resting position (finish) were identified for each repetition through visual inspection of the data within the Motion Monitor software. The period between the start and finish time points was determined as the exercise period. The mean of the scapular/clavicular orientations during the exercise periods from 3 repetitions were calculated for statistical analyses.

<b>TABLE 1</b>		<b>SUMMARY OF HUMERAL ELEVATION ANGLE, SCAPULAR/CLAVICULAR KINEMATICS, AND MUSCLE ACTIVITY DURING NEUTRAL STANCE AND EXERCISES 1 THROUGH 6*</b>					
	<b>Neutral</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>
<b>Scapular/clavicular kinematics (deg)</b>							
Humeral elevation angle		90.0 ± 11.7	81.2 ± 8.6	114.0 ± 8.8	112.4 ± 9.7	59.0 ± 11.4	66.2 ± 21.5
Internal rotation	27.3 ± 7.6	13.2 ± 10.1	9.1 ± 12.9	18.0 ± 22.1	15.1 ± 21.4	2.4 ± 13.6	17.6 ± 8.7
Upward rotation	0.9 ± 4.3	11.2 ± 10.9	20.2 ± 8.5	42.6 ± 14.7	40.0 ± 19.9	19.7 ± 8.5	1.5 ± 10.6
Posterior tilt	-16.1 ± 5.5	-9.1 ± 9.4	0.9 ± 8.0	5.2 ± 13.9	6.2 ± 19.9	8.5 ± 6.7	-15.8 ± 10.5
Retraction	16.2 ± 4.6	24.1 ± 6.4	29.2 ± 5.2	34.2 ± 5.7	33.0 ± 5.8	31.3 ± 5.7	17.1 ± 5.7
Elevation	8.2 ± 6.8	-9.7 ± 14.4	-2.5 ± 13.8	4.2 ± 16.5	6.1 ± 17.1	-2.4 ± 13.6	-8.2 ± 15.7
<b>Muscle activity (%MVIC)</b>							
Upper trapezius		40.9 ± 25.6	49.0 ± 28.8	68.4 ± 39.0 <sup>†</sup>	72.2 ± 39.2 <sup>†‡</sup>	45.4 ± 27.3	15.1 ± 9.4
Middle trapezius		53.1 ± 12.1	65.8 ± 20.4 <sup>§</sup>	70.8 ± 25.0 <sup>§</sup>	77.4 ± 26.5 <sup>  </sup>	66.0 ± 25.1 <sup>§</sup>	25.5 ± 13.8
Lower trapezius		37.1 ± 20.6	43.1 ± 23.0	67.8 ± 23.5 <sup>†</sup>	71.9 ± 27.4 <sup>†*</sup>	50.3 ± 24.7	50.5 ± 35.4
Serratus		10.3 ± 12.6	9.7 ± 12.7	18.9 ± 14.5	21.2 ± 12.8	16.7 ± 19.5	21.3 ± 30.3

*Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.*  
*\* Data are mean ± SD.*  
<sup>†</sup> Significantly higher upper trapezius activation compared to 6.  
<sup>‡</sup> Significantly higher upper trapezius activation compared to 1.  
<sup>§</sup> Significantly higher middle trapezius activation compared to 6.  
<sup>||</sup> Significantly higher middle trapezius activation compared to 1.  
<sup>\*</sup> Significantly higher lower trapezius activation compared to 1.  
<sup>\*</sup> Significantly higher lower trapezius activation compared to 2.

<b>TABLE 2</b>		<b>PAIRWISE COMPARISONS FOR SCAPULAR INTERNAL (+)/EXTERNAL (-) ROTATION AMONG THE NEUTRAL STANCE AND EXERCISES 1 THROUGH 6*</b>					
	<b>Neutral</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>
1	-14.1 <sup>†</sup> (P = .0022)						
2	-18.3 <sup>†</sup> (P < .001)	4.2° (P = .3412)					
3	-9.4° (P = .0423)	4.7° (P = .2831)	8.9° (P = .0439)				
4	-12.3° (P = .0078)	1.8° (P = .6759)	6.0° (P = .1716)	-2.9° (P = .5114)			
5	-24.9 <sup>†</sup> (P < .0001)	-10.8° (P = .0143)	-6.7° (P = .1298)	-15.6 <sup>†</sup> (P = .0005)	-12.7° (P = .0043)		
6	-9.7° (P = .0349)	4.4° (P = .3215)	8.5° (P = .0531)	-0.361° (P = .9344)	2.5° (P = .5656)	15.2 <sup>†</sup> (P = .0007)	

*\* The value in each cell represents the difference between the 2 intersecting conditions (row condition - column condition). Negative values indicate greater external rotation.*  
<sup>†</sup> Statistically significant at  $\alpha < .0023$  (.05/21 comparisons).

Based on recommendations from the ISB,<sup>63</sup> scapular movements in internal rotation, downward rotation, and posterior tilt directions are indicated by positive values. However, upward/downward rotation values were multiplied by -1 to make scapular upward rotation a positive movement, for ease of clinical interpretation. Because the scapula is internally rotated in a neutral stance position, scapular movement into external rotation results in reduction of the internal rotation values.

EMG data were exported and

smoothed by a 50-millisecond moving root-mean-square window using a custom-made program. The muscle activity for each muscle during the exercise periods was calculated as the average EMG signal amplitude normalized to the maximal voluntary contraction. The average of the values from 3 repetitions were used for all analyses. All calculations and data reduction were performed using Matlab 12 (The MathWorks Inc, Natick, MA).

### Data Analysis

Scapular/clavicular kinematics and mus-

cle activation data from each participant's dominant shoulder were used for analyses. Muscle activation levels during exercises and scapular/clavicular orientations at neutral stance and during exercises 1 to 6 were compared using 1-way repeated-measures analysis of variance (ANOVA), followed by pairwise comparisons with linear contrasts using pooled error to determine the differences in scapular kinematics among the exercises. The level of significance was set at an alpha level of .05 prior to the study. For the pairwise comparisons of the kinematic variables,

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TABLE 3		PAIRWISE COMPARISONS FOR SCAPULAR UPWARD (+)/DOWNWARD (-) ROTATION AMONG THE NEUTRAL STANCE AND EXERCISES 1 THROUGH 6*					
	Neutral	1	2	3	4	5	6
1	10.3° (P = .0047)						
2	19.3°† (P < .0001)	9.0° (P = .0121)					
3	41.7°† (P < .0001)	31.4°† (P < .0001)	22.4°† (P < .0001)				
4	38.7°† (P < .0001)	28.5°† (P < .0001)	19.5°† (P < .0001)	-3.0° (P = .4066)			
5	18.7°† (P < .0001)	8.5° (P = .0179)	-0.5° (P = .8844)	-22.9°† (P < .0001)	-20.0°† (P < .0001)		
6	0.5° (P = .8821)	-9.8° (P = .0067)	-18.8°† (P < .0001)	-41.2°† (P < .0001)	-38.2°† (P < .0001)	-18.2°† (P < .0001)	

\* The value in each cell represents the difference between the 2 intersecting conditions (row condition - column condition). Positive values indicate greater upward rotation.  
 † Statistically significant at  $\alpha < .0023$  (.05/21 comparisons).

TABLE 4		PAIRWISE COMPARISONS FOR SCAPULAR POSTERIOR (+)/ANTERIOR (-) TILT AMONG THE NEUTRAL STANCE AND EXERCISES 1 THROUGH 6*					
	Neutral	1	2	3	4	5	6
1	7.0° (P = .0419)						
2	17.0°† (P < .0001)	10.1° (P = .0036)					
3	21.4°† (P < .0001)	14.4°† (P < .0001)	4.3° (P = .2053)				
4	22.3°† (P < .0001)	15.3°† (P < .0001)	5.2° (P = .1253)	0.9° (P = .7880)			
5	24.6°† (P < .0001)	17.6°† (P < .0001)	7.6° (P = .0278)	3.2° (P = .3438)	2.3° (P = .4973)		
6	0.3° (P = .9141)	-6.7° (P = .0512)	-16.7°† (P < .001)	-21.1°† (P < .0001)	-22.0°† (P < .0001)	-24.3°† (P < .0001)	

\* The value in each cell represents the difference between the 2 intersecting conditions (row condition - column condition). Positive values indicate greater posterior tilt.  
 † Statistically significant at  $\alpha < .0023$  (.05/21 comparisons).

an alpha level of .0023 (.05/21 pairwise comparisons) was used to adjust for an inflation of the type I error due to multiple comparisons (Bonferroni correction). Similarly, alpha level of .0033 (.05/15 pairwise comparisons) was used for the pairwise comparisons of the muscle activation levels. SAS 9.1 (SAS Inc, Cary, NC) was used to run statistical analysis for all variables.

## RESULTS

THE DATA FROM 2 SUBJECTS WERE eliminated from the analysis because some of the kinematic values were more than 3 standard deviations away from the group means. We believe this occurred as a result of the unexpected movements of the thorax sensor during data collection. Therefore, data from 23 subjects were analyzed. A summary of the scapular/clavicular kinematics

and muscle activity is presented in **TABLE 1**. Main effects for repeated-measures ANOVA were significant for all kinematic variables ( $F_{1,22} = 11.7-71.6, P < .001$ ). The results of the pairwise comparisons for kinematic variables appear in **TABLES 2** through **6**. Main effects were significant for upper, middle, and lower trapezius muscle activation level ( $F_{1,22} = 4.62-8.07, P < .01$ ) but not for the serratus anterior muscle ( $F_{1,22} = 1.95, P = .08$ ).

Significant scapular external rotation movement from neutral occurred with exercises 1, 2, and 5 (**TABLE 2**). Exercise 5 resulted in significantly greater external rotation compared to exercises 3 and 6. There was no significant difference in external rotation among exercises 1, 2, and 5. Significant scapular upward rotation from neutral occurred with exercises 2, 3, 4, and 5 (**TABLE 3**). Furthermore, exercises 3 and 4 resulted in significantly greater upward rotation compared to all

other exercises, and exercises 2 and 5 resulted in significantly greater upward rotation compared to exercise 4. Significant scapular posterior tilt movement from neutral occurred with exercises 2, 3, 4, and 5 (**TABLE 4**). The amount of posterior tilt was not significantly different among exercises 2, 3, 4, and 5. Exercises 1 and 6 resulted in less posterior tilt compared to exercises 3, 4, and 5, while exercise 6 resulted in less posterior tilt compared to exercises 2. Significant clavicular retraction movement from neutral occurred in all exercises, except for exercise 6 (**TABLE 5**). Exercise 6 resulted in significantly less retraction compared to all other exercises, and exercise 1 resulted in significantly less retraction compared to exercises 2, 3, 4, and 5. There was no significant difference in retraction among exercises 2 through 5. Significant clavicular depression movement from neutral occurred only in exercises 1 and 6 (**TABLE 6**). Ex-

TABLE 5

PAIRWISE COMPARISONS FOR CLAVICULAR RETRACTION (+)  
AMONG THE NEUTRAL STANCE AND EXERCISES 1 THROUGH 6

	Neutral	1	2	3	4	5	6
1	79 <sup>†</sup> ( $P < .0001$ )						
2	13.0 <sup>†</sup> ( $P < .0001$ )	5.1 <sup>†</sup> ( $P = .0023$ )					
3	18.0 <sup>†</sup> ( $P < .0001$ )	10.1 <sup>†</sup> ( $P < .0001$ )	5.0 <sup>†</sup> ( $P = .0033$ )				
4	16.8 <sup>†</sup> ( $P < .0001$ )	8.9 <sup>†</sup> ( $P < .0001$ )	3.8 <sup>†</sup> ( $P = .0254$ )	-1.2 <sup>†</sup> ( $P = .4971$ )			
5	15.1 <sup>†</sup> ( $P < .0001$ )	7.2 <sup>†</sup> ( $P < .0001$ )	2.0 <sup>†</sup> ( $P = .2201$ )	-2.9 <sup>†</sup> ( $P = .0813$ )	-1.7 <sup>†</sup> ( $P = .3066$ )		
6	0.9 <sup>†</sup> ( $P = .5732$ )	-7.0 <sup>†</sup> ( $P < .0001$ )	-12.2 <sup>†</sup> ( $P < .0001$ )	-17.1 <sup>†</sup> ( $P < .0001$ )	-15.9 <sup>†</sup> ( $P < .0001$ )	-14.2 <sup>†</sup> ( $P < .0001$ )	

\* The value in each cell represents the difference between 2 intersecting conditions (row condition - column condition). Greater positive values indicate greater clavicular retraction.

<sup>†</sup> Statistically significant at  $\alpha < .0023$  (.05/21 comparisons)

TABLE 6

PAIRWISE COMPARISONS FOR CLAVICULAR ELEVATION (+)  
AMONG THE NEUTRAL STANCE AND EXERCISES 1 THROUGH 6

	Neutral	1	2	3	4	5	6
1	-17.6 <sup>†</sup> ( $P < .0001$ )						
2	-10.2 <sup>†</sup> ( $P = .0069$ )	7.4 <sup>†</sup> ( $P = .0933$ )					
3	-3.4 <sup>†</sup> ( $P = .2480$ )	14.2 <sup>†</sup> ( $P = .0013$ )	6.8 <sup>†</sup> ( $P = .1118$ )				
4	-1.7 <sup>†</sup> ( $P = .4717$ )	15.9 <sup>†</sup> ( $P = .0003$ )	8.5 <sup>†</sup> ( $P = .0428$ )	1.7 <sup>†</sup> ( $P = .6583$ )			
5	-10.5 <sup>†</sup> ( $P = .0076$ )	7.1 <sup>†</sup> ( $P = .0865$ )	-0.3 <sup>†</sup> ( $P = .9711$ )	-7.1 <sup>†</sup> ( $P = .1201$ )	-8.8 <sup>†</sup> ( $P = .0466$ )		
6	-15.9 <sup>†</sup> ( $P < .0001$ )	1.7 <sup>†</sup> ( $P = .7276$ )	-5.7 <sup>†</sup> ( $P = .1823$ )	-12.5 <sup>†</sup> ( $P = .0038$ )	-14.2 <sup>†</sup> ( $P = .0009$ )	-5.4 <sup>†</sup> ( $P = .1708$ )	

\* The value in each cell represents the difference between 2 intersecting conditions (row condition - column condition). Negative values indicate greater clavicular depression.

<sup>†</sup> Statistically significant at  $\alpha < .0023$  (.05/21 comparisons).

ercise 1 resulted in greater depression than exercises 3 and 4, while exercise 6 resulted in greater depression than exercise 4. There was no statistically significant difference in depression between exercises 1 and 6.

Upper trapezius muscle activation was significantly higher in exercises 3 and 4 compared to exercise 6 ( $P < .0001$ ). Additionally, upper trapezius activation during exercise 4 was significantly higher than during exercise 1 ( $P = .0003$ ). Middle trapezius muscle activation was significantly higher in exercises 2 ( $P < .0001$ ), 3 ( $P < .0001$ ), 4 ( $P < .0001$ ), and 5 ( $P = .0004$ ) compared to 6. Additionally, middle trapezius activity during exercise 4 was higher than during exercise 1. Lower trapezius muscle activation was significantly higher in exercise 4 compared to exercises 1 ( $P = .0023$ ) and 2 ( $P = .0005$ ), and in exercise 3 compared to exercise 1 ( $P = .0027$ ).

## DISCUSSION

THE RETRACTION EXERCISES EVALUATED in this study are widely used among clinicians treating patients with shoulder pathologies in an aim to strengthen scapular retractor muscles and to restore normal scapular movement.<sup>2</sup> However, specific scapular/clavicular movement during exercises, and differences in movements among exercises was unknown. Furthermore, differences in muscle activity of the trapezius and serratus anterior muscles among the exercises had not been investigated. Therefore, the goal of this study was to explore and describe how scapular/clavicular kinematics and muscle activity differ among 6 scapular retraction exercises.

The general pattern/direction of the scapular/clavicular kinematics observed in most exercises was scapular external rotation, upward rotation, posterior tilt,

clavicular retraction, and depression. However, there were variations in scapular/clavicular movements and muscle activation levels among the exercises, which may provide insight on how clinicians may choose appropriate exercises for their patients based on pre-existing conditions (eg, subacromial impingement), available range of motion, or focus on targeting specific muscles or kinematic movements.

Exercises 2 (90° elevation with thumbs pointing up) and 5 (45° elevation with 90° elbow flexion) resulted in the greatest number of significant scapular/clavicular kinematic differences from neutral (4 out of 5 motions measured). Specifically, these exercises resulted in significant external rotation, upward rotation, posterior tilt, and retraction movement from neutral. Therefore, if the goal of the rehabilitation is to mobilize the scapula about multiple axes, exercises 2 and 5 may be recommended.

## RESEARCH REPORT

Exercises 1 and 2 are both performed with 90° humeral elevation, while exercise 1 is performed with neutral humeral rotation (palm facing down) and exercise 2 with humeral external rotation (thumb pointing up). A previous study demonstrated that performance of the exercises with humeral external rotation resulted in greater activation of the supraspinatus, infraspinatus, and teres minor muscles compared to when performed with neutral humeral rotation.<sup>1</sup> However, the effect of humeral rotation on scapular movement and activation of the muscles around the scapula had not been studied. Our results demonstrated that exercise 2 (performed with thumb pointing up) resulted in significantly greater retraction compared to exercise 1 (performed with palm facing down). Additionally, while both exercises 1 and 2 resulted in significant scapular external rotation and retraction from neutral, exercise 2 also resulted in significant upward rotation and posterior tilt from neutral. The muscle activation levels were not significantly different between the exercises. Therefore, exercise 2 may be superior to exercise 1 when the goal is to optimize clavicular retraction and produce significant scapular upward rotation and posterior tilt. One consideration that needs to be taken into account is that the average humeral elevation during exercise 2 was 81.1°, which is short of the targeted 90°. This may have potentially contributed to the difference in kinematics between exercises 1 and 2. Therefore, caution needs to be taken when comparing the 2 exercises.

In addition to producing significant external rotation, upward rotation, posterior tilt, and retraction from neutral, exercise 5 resulted in significant external rotation compared to exercises 3 (120° elevation with palm facing down) and 4 (120° elevation with thumb pointing up). This indicates that exercise 5 may be an appropriate choice of exercise to target scapular external rotation movement. Because exercise 5 can be performed with the arm placed at a relatively low humeral

elevation angle, the exercise is suitable for patients with range-of-motion restrictions. Additionally, because greater humeral elevation angle is associated with decreased subacromial space,<sup>15</sup> exercise 5 may be indicated for individuals with subacromial impingement.

Retraction exercises 3 (120° elevation with palms facing down) and 4 (120° elevation with thumbs pointing up) resulted in significant upward rotation, posterior tilt, and retraction from neutral, yet did not result in significant external rotation or depression. Furthermore, exercises 3 and 4 resulted in significantly greater upward rotation compared to all other exercises, and greater retraction compared to exercise 1. Because exercises 3 and 4 were performed at greater humeral elevation compared to the others, observation of greater scapular upward rotation in these exercises is consistent with the literature demonstrating that scapula upwardly rotates with increasing humeral elevation angle.<sup>25,26</sup>

Exercise 4 resulted in higher activation of the upper and middle trapezius compared to exercises 1 and 6, and higher activation of the lower trapezius compared to exercises 1 and 2. Therefore, exercise 4 may be recommended when the goal is to produce high activation level of the trapezius. However, exercises in this study were performed at a varying humeral elevation angle, which results in changes in scapula position, length-tension relationships of the muscles assessed, movement of skin over the muscles, and consequently in acquisition of EMG activity signals from different motor units.<sup>21</sup> Therefore, controlled comparisons can only be made at the same humeral elevation angle. While the difference in humeral rotation (external versus neutral rotation) resulted in varying scapular/clavicular kinematics between exercises 1 and 2, there were no differences in kinematics or muscle activity between exercises 3 and 4. This indicates that retraction exercises at 120° may be performed with either humerus in neutral or external rotation.

The scapular/clavicular kinematics

and muscle activity during exercise 6 (full extension) were dissimilar to those observed in exercises 1 through 5, in that the exercise resulted in only change in 1 out of 5 scapular kinematic variables. Specifically, exercise 6 only resulted in significant depression from neutral. Additionally, upper trapezius activation during exercise 4 was significantly lower compared to exercises 3 and 4, and middle trapezius activation was lower than exercises 2 to 5. Excessive activity of the upper trapezius muscle and decreased activation of the middle and lower trapezius muscles have been associated with abnormal scapular movement in previous studies.<sup>5,6,37,39,55,59</sup> Based on findings of these studies, Cools et al<sup>4</sup> recommended exercises that minimize upper trapezius while preferentially increasing lower and middle trapezius activation for those individuals with abnormal scapular motion. Exercise 6 resulted in a 15.1% of MVIC effort of the upper trapezius and 50.5% effort of the lower trapezius muscle. This indicates that exercise 6 may be indicated when the goal is to activate lower trapezius muscle while maintaining relatively low upper trapezius activation.

The general pattern or direction of the scapular movement observed in most exercises coincided with the pattern of the scapular kinematics during pitching, recently studied using an electromagnetic tracking device.<sup>45</sup> During the late-cocking phase of pitching, when the humerus is maximally externally rotated and horizontally abducted, the scapula moves into upward rotation, posterior tilting, and external rotation.<sup>45</sup> The clavicle also retracts as the humerus externally rotates.<sup>29,43</sup> This pattern of scapular movement is thought to minimize excessive angulation of the humerus on the glenoid fossa, protecting the anterior shoulder structures from excessive tensile stress during the late-cocking and acceleration phase of pitching motion.<sup>29</sup> Retraction during the late-cocking phase of pitching is also considered to minimize impingement and subsequent fraying of the posterior rotator cuff muscles between the



posterior glenoid rim and the humerus, a phenomenon referred to as posterior or internal impingement.<sup>32,52,60</sup> Therefore, the retraction exercises may be recommended to baseball players, as well as to other overhead throwing athletes, to potentially facilitate the scapular movement necessary to perform their sports activity.

The general pattern of scapular/clavicular movement observed during retraction exercises also coincided with scapular/clavicular movements that tend to be reduced in patients with shoulder pathologies.<sup>37,40,51</sup> Therefore, performance of retraction exercises by patients with scapular movement dysfunction may potentially help restore normal scapular/clavicular movements. However, whether performance of the exercises can improve scapular kinematics has not been determined. McClure et al<sup>42</sup> implemented a 6-week rehabilitation exercises program in patients with impingement syndrome and did not observe changes in scapular kinematics after the intervention.

All participants in this study were young and healthy adults with no known shoulder dysfunction. It is known from previous studies that patients with shoulder pathologies have pain, altered scapular control, and/or muscle imbalance.<sup>9,14,16,17,24,27,37,40,43,46,54,55,57</sup> Therefore, scapular kinematics and muscle activity occurring with the retraction exercises may differ in individuals with pre-existing shoulder injuries and scapular dysfunction. Therefore, caution needs to be taken when applying the results of this study to pathologic population. Further study is needed to assess scapular kinematics and muscle activity during exercises in a patient population. Shoulder pain alone (in the absence of tissue damage) has been reported to alter muscle activation pattern.<sup>14,18,19</sup> Therefore, it is important that these exercises are performed pain free by adjusting humeral elevation angle and resistance. On the other hand, previous studies<sup>30,38</sup> have reported no difference in muscle activity between symptomatic and asymptomatic individuals during

performance of the therapeutic exercises. Therefore, retraction exercises may still be viable to potentially improve scapular movements in patients, although further investigation is required to demonstrate this effect.

Scapulothoracic movement is a combination of movement at the SC and AC joints. Because the scapular/clavicular kinematics were assessed using an indirect method based on relative position/orientation of the thorax and scapular local coordinate systems, we were unable to distinguish between the movement at the 2 joints.<sup>36,49</sup> The relative contribution of each joint to the overall movement may be of great importance.<sup>36</sup> Additionally, the indirect method of clavicular kinematics measurement does not allow calculation of axial rotation of the clavicle, which may potentially be a critical movement in overall scapulothoracic kinematics.<sup>36</sup> Further study investigating movements at the SC and AC joints independently may provide further insight into the kinematics of various exercises.

There are limitations to this study. There were disparities between observed and the target humeral elevation angles due to lack of quantitative feedback during the testing (exercise 2, 80.1° versus 90.0°; exercise 5, 59.1° versus 45.0°). This disparity was due to reliance of the humeral positioning on examiner's visual inspection. Use of real-time feedback using the electromagnetic tracking device would have assured appropriate humeral positioning during the exercises. Although this disparity may have some influence on the results of the study, we do not believe that it affected the overall outcome of the study. Although assessments of the scapular kinematics using an electromagnetic tracking device has been validated against a measurement using a bone pin,<sup>26</sup> the electromagnetic tracking system and size of the sensors used in the validation study were different from the ones used in the current study. Additionally, the validation was conducted while subjects were placed in an upright position. In the current study,

scapular/clavicular kinematics were recorded lying prone on the treatment table. These factors may have introduced measurement errors and may potentially invalidate the values obtained from the study. However, the values obtained were within the expected range based on the previous studies.<sup>26,49</sup> Even with some potential systematic/random errors, the authors believe the data from this study provide useful information to clinicians. The rhomboid major/minor and levator scapular muscles are also critical muscles that influence scapular movement; however, these muscles were not evaluated in this study because they could not be studied using surface electrodes.

## CONCLUSION

**T**HE 6 RETRACTION EXERCISES RESULTED in varying scapular movements and muscle activity. The general pattern/direction of the scapular/clavicular kinematics observed in most exercises was scapular external rotation, upward rotation, and posterior tilt, and clavicular retraction and depression. Clinicians can choose appropriate exercises for each patient based on pre-existing conditions (eg, subacromial impingement), available range of motion, or focus on targeting specific muscles or kinematic movements. The pattern of the scapular kinematics and muscle activity observed in this study suggest that retraction exercises may be beneficial in improving scapular retractor strength and potentially scapular kinematics. However, further investigation is required to demonstrate this effect. ●

## KEY POINTS

**FINDINGS:** The 6 retraction exercises resulted in varying scapular movement and muscle activity. The general pattern/direction of the scapular/clavicular kinematics observed in most exercises was scapular external rotation, upward rotation, posterior tilt, clavicular retraction, and depression.

**IMPLICATION:** Clinicians can select appro-

appropriate exercises for their patients based on their need to strengthen specific retractor muscles and to improve specific scapular kinematics based on pre-existing conditions and available range of motion.

**CAUTION:** The study was conducted using young healthy adults. Therefore, results may vary in patients or individuals of different age groups. Whether performance of the exercise over time can improve scapular kinematics has not been examined.

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