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Scapular Kinematics During Supraspinatus Rehabilitation Exercise

A Comparison of Full-Can Versus Empty-Can Techniques

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Background: Supraspinatus strengthening is an important component of shoulder rehabilitation. Previous work has determined that the full-can and empty-can exercises elicit the greatest amount of supraspinatus activity. However, scapular kinematics has not been considered when prescribing supraspinatus exercises.

Hypothesis: Scapular downward rotation, internal rotation, and anterior tipping during the empty-can exercise are increased when compared with the full-can exercise.

Study Design: Descriptive laboratory study.

Methods: Twenty participants performed full-can and empty-can exercises while an electromagnetic tracking system was used to collect three-dimensional scapular kinematic data. Scapular angles at 30°, 60°, and 90° of the ascending and descending phases of humeral elevation were compared using 2-way repeated measures analysis of variance.

Results: There was more scapular anterior tipping and internal rotation during the empty-can exercise at all sampled humeral elevation angles except at 30° of the descending phase for anterior/posterior tipping ($P < .05$).

Conclusion: Scapular anterior tipping and internal rotation are increased during the empty-can exercise, whereas scapular upward rotation was not different between exercises.

Clinical Relevance: Increased scapular internal rotation and anterior tipping decrease the volume of the supraspinatus outlet during the empty-can exercise. When maintenance of the subacromial space is important, use of the full-can exercise seems most appropriate for selective strengthening of the supraspinatus muscle.

Keywords: shoulder; rotator cuff; motion analysis; therapy

Supraspinatus muscle injuries may exist with a number of shoulder conditions. Thus, rehabilitation of shoulder injuries commonly focuses on the supraspinatus musculotendinous unit.[7,24] Rotator cuff tears most commonly occur in the supraspinatus tendon,[16] and shoulder impingement syndrome typically involves the supraspinatus tendon.[40] Loss of normal supraspinatus muscle function will limit the effectiveness of the force couple formed with the middle deltoid to initiate humeral elevation and decrease the compressive force required to prevent excessive humeral head translation.[17,49] In addition, muscle activity as measured by electromyography (EMG) suggests that the supraspinatus is important during all phases of glenohumeral motion as a humeral rotator and as a dynamic humeral stabilizer.[11,42] Thus, restoration and maintenance of supraspinatus strength are important components in achieving optimal shoulder function, and strengthening of the supraspinatus is an important component of shoulder rehabilitation.[7,24] Two specific exercises have been suggested for strengthening the supraspinatus: the full-can[5,27] (humeral elevation in the

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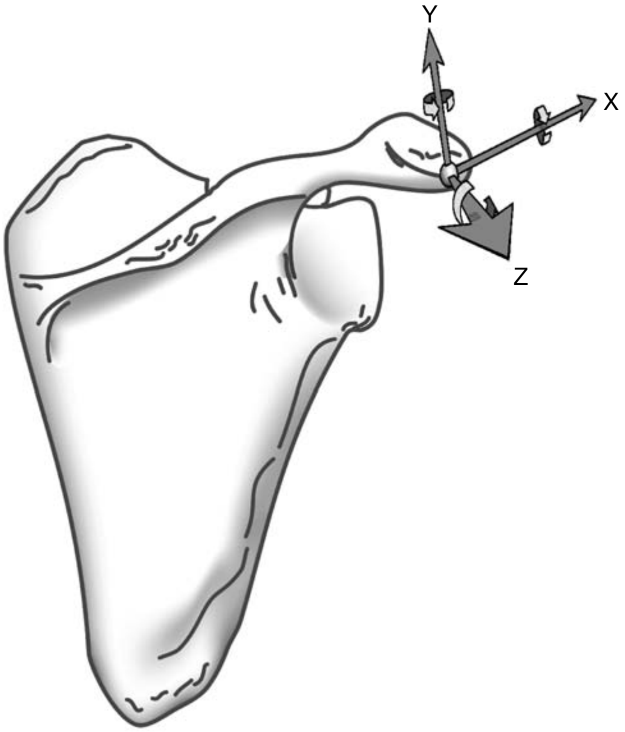

Figure 1. Local coordinate system for the scapula. The x-axis denotes anterior/posterior tipping of the scapula. The y-axis indicates internal/external rotation of the scapula. The z-axis denotes upward/downward rotation of the scapula. By convention, the direction of the arrow is considered "positive" for each axis of rotation. Thus, posterior tip, internal rotation, and upward rotation would result in positive rotational displacements for the x-axis, y-axis, and z-axis, respectively.

scapular plane with the thumb up) and the empty-can (thumb down) exercises.[24,50]

Muscle activation as determined by EMG and MRI analyses has been the primary criteria used for selecting exercises to strengthen the supraspinatus.[5,24] Jobe and Moynes[24] suggested use of the empty-can exercise to strengthen the supraspinatus based on increased muscle activity in one patient. In another EMG analysis, Townsend et al[50] found increased muscle activation during the empty-can exercise and concluded that this position best isolated the supraspinatus. Conversely, Malanga et al[33] saw no difference in EMG activity between the full-can and empty-can positions. In addition, MRI evaluation has not revealed differences in supraspinatus muscle relaxation time[46] or signal intensity[21] when comparing the full-can and empty-can exercises. The results of these studies suggest that both the full-can exercise and the empty-can exercise are appropriate for strengthening the supraspinatus. Therefore, other contributing factors should be considered to determine which exercise is most appropriate when selectively strengthening the supraspinatus.

Scapular kinematics may be an important factor to consider when selecting shoulder rehabilitation exercises. Decreases in scapular upward rotation, posterior tilt, and external rotation have been identified as patterns of dysfunction in patients with impingement syndrome (Figure 1).[30,32] Scapular dyskinesis has also been reported in patients with shoulder instability,[54] rotator cuff tears,[41] and adhesive capsulitis.[52] Although it is unclear if these alterations are a cause or an effect of shoulder dysfunction, research suggests that these changes in scapular kinematics influence the position and size of the supraspinatus outlet.[12,14] Considering that the full-can and empty-can exercises are commonly used in both nonoperative and postsurgical shoulder rehabilitation, understanding the influence of the full-can and empty-can exercises on scapular kinematic patterns would provide valuable information to clinicians.

The purpose of this study was to evaluate and compare three-dimensional scapular kinematic patterns during full-can and empty-can shoulder exercises. We hypothesized that scapular upward rotation, external rotation, and posterior tipping would be decreased during the empty-can exercise when compared with the full-can exercise. These changes in scapular kinematics were expected because of the anatomical relationships of the glenohumeral joint and the scapula. Specifically, the posterior capsule and rotator cuff originate from the posterior glenoid and scapular fossa. It is reasonable to assume then that humeral internal rotation will tension the posterior capsule and rotator cuff and pull the scapula into a more internally rotated and anteriorly tipped position. Knowledge of scapular motion patterns during these shoulder exercises will assist clinicians in recommending appropriate strengthening exercises for patients undergoing shoulder rehabilitation.

METHODS

Participants

Ten male (age, 24 ± 7 years; height, 181 ± 8 cm; mass, 64 ± 8 kg) and 10 female (age, 21 ± 0.7 years; height, 171 ± 9 cm; mass, 77 ± 15 kg) participants were recruited for this study. Participants were eligible for the study if they were older than 18 years without a history of shoulder injury or current shoulder pain requiring treatment by a medical professional. Before participation in the study, participants read and signed an informed consent form approved by the University of North Carolina Medical School Committee for the Protection of Human Participants.

Testing Procedures

All testing was performed during a single session, approximately 60 minutes in length, at the University of North Carolina Sports Medicine Research Laboratory. On arrival at the laboratory, participants completed a questionnaire to ensure compliance with the exclusion criteria. Before testing, participants received an explanation of all testing procedures and performed a standardized warm-up consisting of 5 minutes of exercise on an Air-dyne ergometer (Schwinn Bicycle Company, Chicago, Ill) using only their arms. After warm-up, participants performed the testing protocol. Participants were allowed practice trials to become

Figure 2. Full-can exercise. The thumb is pointed upward while the arm is moved in the scapular plane.

Figure 3. Empty-can exercise. The thumb is pointed downward while the arm is moved in the scapular plane.

acquainted with all testing procedures. The dominant arm was used for all data collection.

Three-dimensional kinematic analysis of the shoulder complex was performed as participants completed the empty-can and full-can humeral elevation exercises in the scapular plane. The scapular plane was defined as 40° anterior to the frontal plane of the thorax. Participant positioning was standardized, as all motions were completed from a standing position, with the participant's eyes fixed forward and feet at a comfortable width apart. A guiding pole, made of 2-in polyvinyl chloride pipe, was aligned in the scapular plane and used during all trials to ensure the participants performed humeral elevation in the scapular plane. Participants performed the full-can and empty-can exercises in a randomized order and were instructed to follow the guiding pole with the tips of their fingers.

During the full-can exercises, the participants were instructed to follow the guiding pole while keeping their thumb pointed toward the ceiling. In doing so, the participants maintained their humerus in a position of external rotation during the full-can exercise (Figure 2). Participants performed the exercises with an adjustable handheld weight equal to 5% of the participant's body weight. The exercise began with the participant's arm by his or her side. Participants then elevated their humerus to 120° and then lowered it back to the starting position. Participants performed 3 sets of 3 trials for the full-can exercise. A 30-second rest period was allowed between each set to minimize any fatigue effects. Three trials were performed consecutively at a controlled movement velocity by having participants move in time with a digital metronome set at 1 Hz and completed the movement in 6 seconds. Participants performed an identical protocol during the empty-can exercise, except their thumb pointed toward the floor (Figure 3). This position ensured that participants maintained the humerus in relative internal rotation during the empty-can exercise by pointing the thumb to the ground. A 1-minute rest period was allowed between exercise conditions.

A Flock of Birds (Ascension Technologies Inc, Burlington, Vt) electromagnetic motion analysis system controlled by the Motion Monitor (Innovative Sports Training Inc, Chicago, Ill) software was used to assess shoulder complex kinematics at a sampling rate of 50 Hz. This electromagnetic tracking system is accurate within 1.8 mm for linear displacements and 0.5° for angular displacements.[2] We have shown between-trial root mean square errors to be less than 1.7° for all scapular motions for between trials when using the acromial method.[47] Separate electromagnetic sensors were attached to the thorax, scapula, and humerus. The thorax sensor was placed over the spinous process of the seventh cervical vertebrae (C7), and the scapula receiver was placed over the broad flat surface of the posterolateral acromion (Figure 4). The humeral sensor was placed over the posterior aspect of the humerus distal to the triceps muscle belly with the sensor over the area of least muscle mass. Sensor data were used for the calculation of position and orientation of the scapula, thorax, and humerus. All sensors were attached using double-sided tape. An elastic

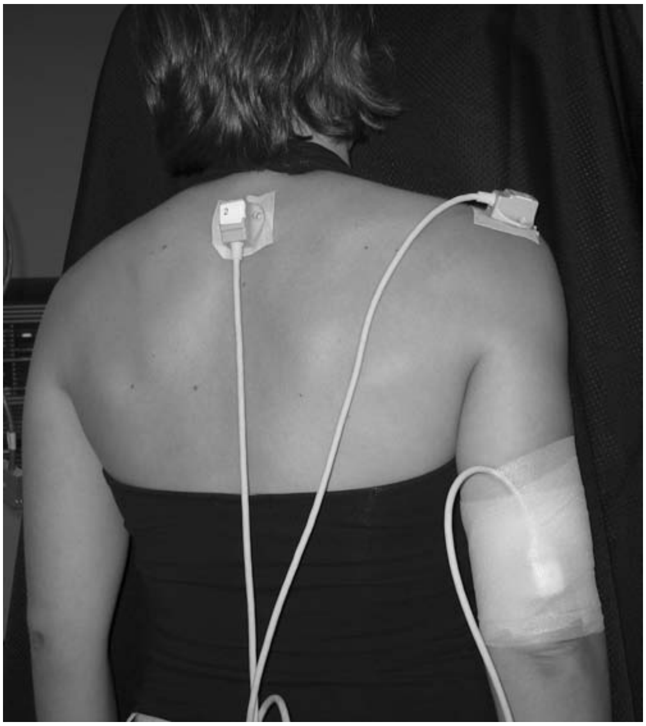

Figure 4. Position of the electromagnetic sensors on the arm, spine, and acromion.

wrap was used to further secure the humerus sensor. Before sensor application, the skin was dried and spray adhesive was applied to improve adherence.

The participants then stood in a relaxed posture with their palm flat against their thigh. Bony landmarks were then digitized by palpation using a mobile sensor attached to a stylus. The digitized bony landmarks included the spinous process of the 12th thoracic vertebrae, spinous process of C7, spinous process of the 8th thoracic vertebrae, distal point of the xiphoid process, suprasternal notch, medial epicondyle, lateral epicondyle, the posterior acromion at the posterior lateral curvature of the scapular spine, the root of the scapular spine at the medial scapular border in line with the scapular spine, and the inferior angle of the scapula at the most inferior point of the scapula. These landmarks were selected based on the International Society of Biomechanics Shoulder Group recommendations and have been used in previous studies.[26,31,36] The glenohumeral joint center was defined by the point that moves least with respect to the scapula when the humerus is moved through short arcs (≤45°) as calculated by a least squares algorithm.[51] The setup was completed by having the participants stand with their palm flat against their thigh while the system was calibrated to the neutral position. These landmarks were used to create local coordinate axes systems for each segment. Generally, the first 2 points for each segment described the longitudinal axis, and a third point defined the plane. The second axis was defined perpendicular to this axis and the third axis perpendicular to the first 2 axes. The orthogonal coordinate system for each segment was vertical (y-axis), horizontal to the right (x-axis), and posterior (z-axis). A 4×4 position and orientation matrix was yielded after matrix transformations from the global to the local coordinate systems for each segment.

Data Reduction

Three-dimensional coordinates of the digitized bony landmarks were calculated using the Motion Monitor software. Segment reference frames were defined according to the recommendations set forth by the Shoulder Group of the International Society of Biomechanics.[23] Humeral motions were calculated as the Euler angles of the humerus relative to the thorax reference frame in the following order of rotations: plane of elevation about the x-axis, amount of elevation about the z-axis, and internal-external rotation about the y-axis.[1] Scapular motions were calculated as the Euler angles of the scapula relative to the thorax reference frames in the following order of rotations: internal/external rotation about the y-axis, upward-downward rotation about the z-axis, and posterior-anterior tipping about the x-axis (Figure 1).[25] Data were smoothed through a Butterworth low-pass digital-filter (fourth-order, recursive, zero phase lag) at an estimated optimum cutoff frequency of 6.6 Hz.[55]

Three-dimensional scapular angles (anterior/posterior tipping, internal/external rotation, upward/downward rotation) served as the dependent variables in this study. Scapular angles were calculated at the humeral elevation positions of 30°, 60°, and 90° during the ascending and descending movement phases of the full-can and empty-can exercises. The mean humeral and scapular angles were calculated from the middle repetition for each of the 3 exercise sets. This mean value was used for analyses to assess the steady state movement patterns of the scapula. A repeated measures analysis of variance (ANOVA) on these mean values across trials was performed to calculate the interclass correlations coefficients (ICC) and associated standard error of measurement (SEM) for each scapular rotation. The $ICC_{(2,1)}$ values ranged from 0.91 to 0.98 for each scapular rotation; SEM values ranged from 1.8° to 2.7° for upward rotation and internal rotation and 2.7° to 3.5° for posterior tipping. These values are similar to previously reported $ICC_{(2,1)}$ and SEM values during humeral elevation in the scapular plane.[31,36,37]

Data Analysis

Separate repeated measures ANOVA (exercise × humeral elevation angle) were used to compare scapular angles (dependent variable) between the full-can and empty-can exercises (independent variables). Each analysis involved exercise (2 levels: full-can and empty-can exercises) and humeral elevation angle (6 levels: ascending and descending at 30°, 60°, and 90°) as within participant factors. Statistical significance was set a priori at $\alpha < .05$ for all analyses. Tukey post hoc analyses were performed to investigate significant main effects and interactions. SPSS for Windows software (version 11.5, SPSS Inc, Chicago, Ill) was used for all statistical analyses.

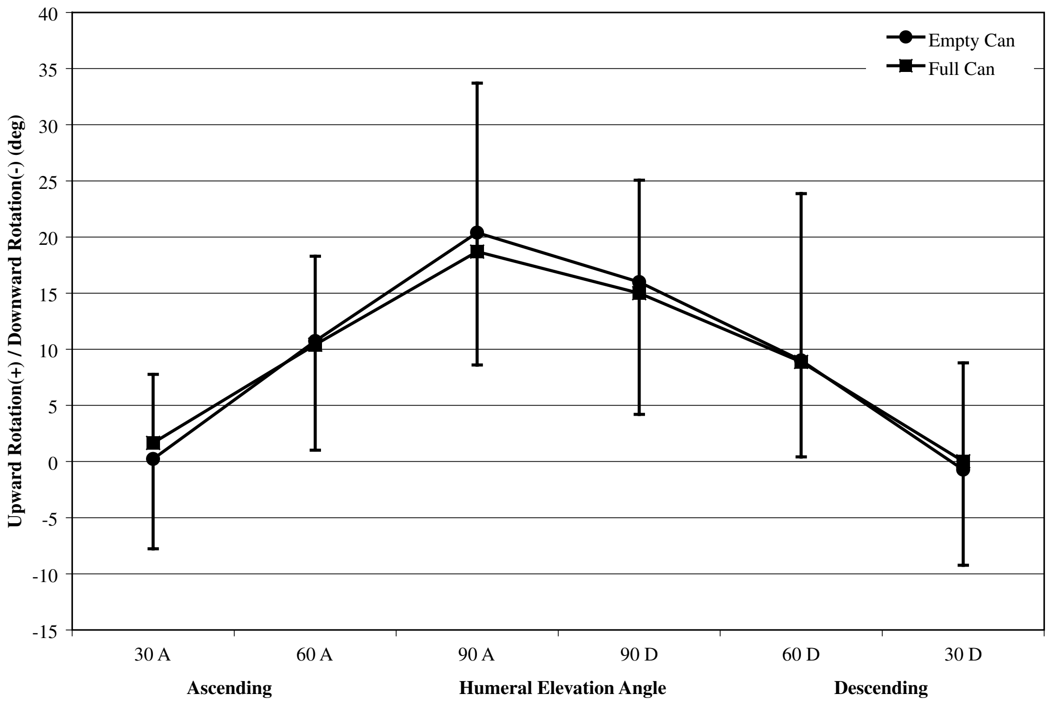

Figure 5. Scapular upward(+)/downward(–) rotation for full-can and empty-can exercises. Error bars represent 1 standard deviation above and below the group mean for each exercise.

RESULTS

On average, the scapula rotated upwardly and internally and tilted posteriorly during humeral elevation for both the full-can and empty-can exercises.

Scapular Upward/Downward Rotation

There was no significant main effect for type of exercise (empty-can vs full-can) on scapular upward rotation ($F_{1,19}$ = 0.10, P = .75). There was a significant interaction effect between humeral elevation angle by type of exercise ($F_{5,95}$ = 3.07, P = .01). However, post hoc testing did not reveal significant differences between exercises at any angle interval (mean significant difference [MSD] = 2.22). These results indicate there was no significant difference in scapular upward rotation at 30°, 60°, and 90° of the ascending and descending phases of humeral elevation between full-can and empty-can exercises (Figure 5).

Scapular Internal/External Rotation

There was a significant main effect for exercise on scapular internal rotation ($F_{1,19}$ = 19.89, P = .01). There was a significant interaction effect between humeral elevation angle and the type of exercise on scapular internal rotation angle ($F_{5,95}$ = 5.23, P = .01). Tukey post hoc test revealed significant differences between exercises and individual humeral elevation intervals (MSD = 1.41). These results indicate that the scapula was more internally rotated for the empty-can exercise at 30°, 60°, and 90° of the ascending and descending phase of humeral elevation in comparison with the full-can exercise (Figure 6). The mean difference between exercises of scapular internal rotation ranged from 4° to 6°.

Scapular Anterior/Posterior Tipping

There was a significant main effect for exercise on scapular posterior tipping ($F_{1,19}$ = 8.16, P = .01). There was a significant interaction effect between humeral elevation angle and the type of exercise on scapular posterior tipping ($F_{5,95}$ = 3.65, P = .01). The Tukey post hoc test revealed significant differences between exercises and individual humeral elevation intervals (MSD = 1.96). These results indicate that the scapula was more anteriorly tipped for the empty-can exercise at 30°, 60°, and 90° of the ascending phase and 90° and 60° of the descending phase of humeral elevation in comparison with the full-can exercise. There was no significant difference between exercises at 30° of descending humeral elevation (Figure 7). The mean difference between exercises of scapular posterior tipping ranged from 2° to 4°.

DISCUSSION

Traditionally, scapulohumeral rhythm has been the primary factor described and investigated when considering scapular motion.[3,9,12] The coupled nature of scapular upward rotation and humeral elevation has been well documented.[22,35] Three-dimensional analysis of scapular upward rotation has shown

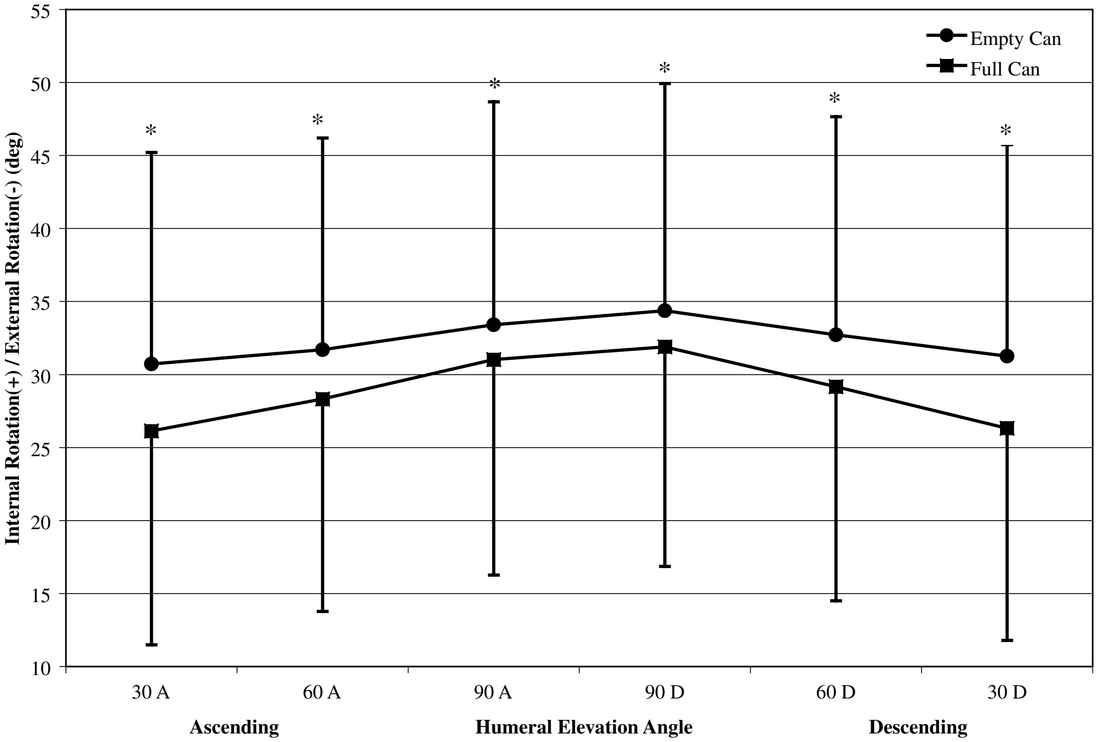

Figure 6. Scapular internal(+)/external(–) rotation for full-can and empty-can exercises. *Indicates angles were significantly different when compared between exercises (minimum significant difference = 1.4). Error bars represent 1 standard deviation above and below the group mean for each exercise.

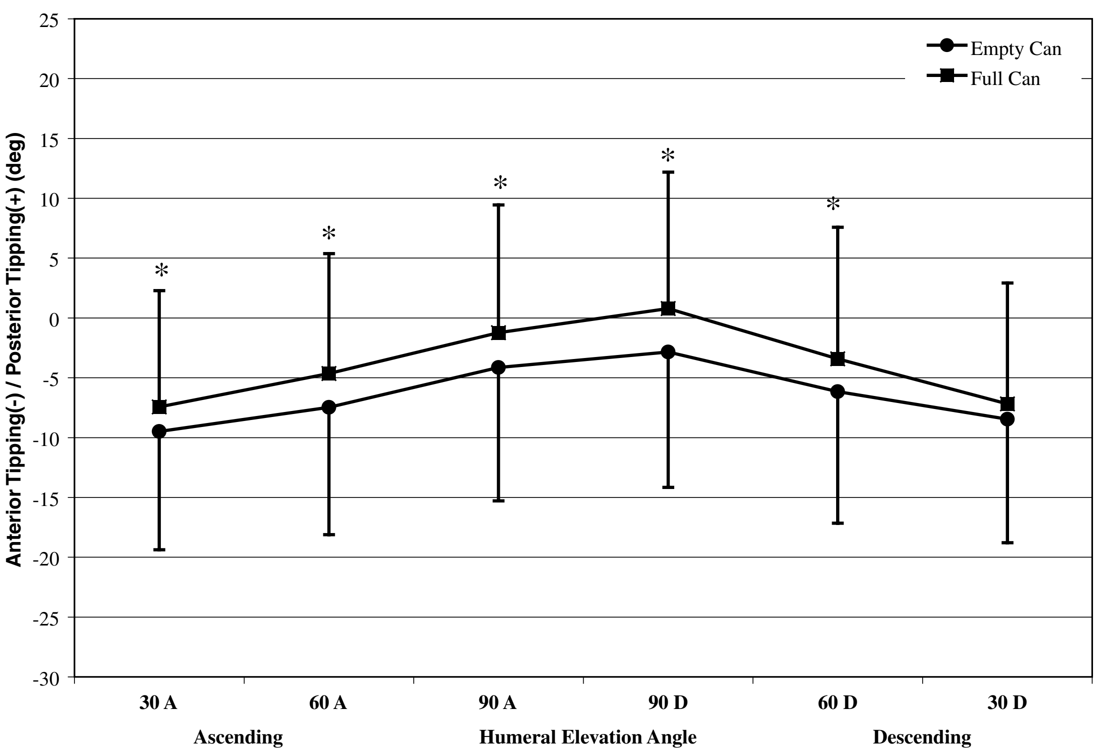

Figure 7. Scapular anterior(–)/posterior(+) tipping for full-can and empty-can exercises. *Indicates angles were significantly different when compared between exercises (minimum significant difference = 1.9). Error bars represent 1 standard deviation above and below the group mean for each exercise.

this relationship to be more complex than the generally described 2:1 scapulohumeral rhythm ratio.[20,29] Scapular upward rotation has been shown to begin between 30° and 60° of humeral elevation and to increase 1° for every 2° of humeral elevation until 120° and then upwardly rotate 1° for every 1° of humeral elevation through maximum elevation.[35] In addition, other scapular displacements (internal/external rotation and anterior/posterior tipping) have been described during humeral elevation.[35] Differences in scapular internal/external rotation and scapular anterior/posterior tipping during humeral elevation tasks in patients with shoulder impingement syndrome have been consistently reported.[20,31] Hebert et al[20] suggested that depending on the plane of humeral motion, scapular internal/external rotation and anterior/posterior tipping are coupled with humeral motion. This conclusion was based on the observed changes in anterior/posterior tipping and internal/external rotation between planes of elevation while upward/downward rotation remained constant across planes. Together these studies suggest that three-dimensional scapular kinematics is important to understanding shoulder function.

Therefore, the purpose of this study was to compare three-dimensional scapular kinematics between full-can and empty-can shoulder rehabilitation exercises. Humeral motion during both the full-can and empty-can exercises resulted in scapular upward rotation, internal rotation, and posterior tipping during humeral elevation in the scapular plane. We only analyzed data for the 2 exercises between 30° and 90° of humeral elevation. This range was selected because of the demonstrated variability in scapular motion below 30° of humeral elevation.[3,22] In addition, we only analyzed below 90° of humeral elevation, as this elevation is the common upper limit for the empty and full-can exercises when prescribed for supraspinatus strengthening. The results of this study support our hypothesis that there is more scapular internal rotation and anterior tipping during the empty-can exercise. However, we did not note any differences in scapular upward rotation when comparing the 2 rehabilitation exercises.

The plane and angle of humeral elevation were controlled in this study. Therefore, observed increases in scapular internal rotation and anterior tipping were because of the differences in humeral rotation between exercises. Our results show that scapular internal rotation and anterior tipping increased with the concomitant humeral internal rotation of the empty-can technique. As the humerus internally rotates, it tensions the posterior capsule and rotator cuff, thus pulling the scapula into a position of more internal rotation and anterior tilt. Specifically, as the humerus internally rotates, the posterior inferior capsule is "wound up," much like the anterior band of the inferior glenohumeral ligament during humeral external rotation.[53] The posterior rotator cuff is also tensioned during humeral internal rotation. Thus, these structures tighten with increasing humeral internal rotation while the scapula is pulled into a more internally rotated and anteriorly tipped position.

The observed increase in scapular internal rotation and anterior tilt may have important clinical implications. Changes in scapular position have also been shown to alter the size of the subacromial space and therefore the volume of the supraspinatus outlet.[13,15,18,38,45,56] Scapular protraction is essentially a combination of scapular internal rotation and anterior tilt.[45] Increases in scapular protraction have been shown to decrease the size of the subacromial space, thereby decreasing the volume of the rotator cuff outlet.[45] Similar increases in the subacromial space have also been reported with increases in scapular retraction, which is analogous to scapular external rotation.[38] Furthermore, decreases in the subacromial space have been observed concurrent with increases in acromial tilt, which is analogous to anterior tipping.[56] This concept is further supported by associated changes in acromiohumeral distance as a result of altered scapular motion in patients with shoulder impingement.[15] Although these changes are relatively small decreases in acromiohumeral distance (3-8 mm) in patients with symptomatic shoulder impingement syndrome,[13,18] the decreased subacromial space seems to have clinical importance. Graichen and coauthors[15] noted that even the smallest observed decrease of 3 mm in acromiohumeral distance resulted in a concomitant 68% decrease of the subacromial space. This significant decrease in the subacromial space is thought to contribute to compression of the underlying structures. When considered together, these studies suggest that even small changes in scapular motion may significantly decrease the supraspinatus outlet volume.

Humeral abduction coupled with humeral internal rotation has also been shown to decrease the size of the subacromial space.[10,14,44] This position has also been shown to maximally approximate the supraspinatus to the anterior acromion.[12,13,44] The size of supraspinatus outlet has also been shown to decrease during frontal and sagittal plane elevation.[38] The importance of this information becomes clear when one considers the mechanics of the humerus during the empty-can exercise. Considering the demonstrated effects of humeral rotation, humeral elevation, and scapular internal rotation and anterior tipping on the supraspinatus outlet, it is likely that the volume of the supraspinatus outlet decreases during the empty-can exercise.

Changes in scapular motion in patients with shoulder impingement syndrome have been consistently reported in the literature.[6,19,30,32] Of interest is that treatment of posterior capsule tightness is recommended in the nonoperative management of shoulder impingement syndrome.[34] Thus, it would seem prudent to avoid positions that increase tension in the posterior capsule, such as the empty-can technique. Furthermore, scapular dyskinesis and labral tears have been described in athletes with glenohumeral internal rotation deficits.[8,28] Again, the association between tightness in the posterior capsule and clinical abnormalities makes obvious the desire to limit positions such as the empty-can exercise that might promote tension in the posterior capsule and exacerbate conditions of the supraspinatus tendon.

The combined change in angular position of exercises that increase scapular anterior tipping and internal rotation places the acromion in a more inferior and anterior position. Altered scapular positioning concurrent with an increase in humeral internal rotation would locate the greater tuberosity under the acromion, placing the subacromial tissues at risk for compression. In light of previous studies, our results suggest that the empty-can technique might serve to decrease the size of the subacromial space. This finding may be important when treating patients with shoulder impingement syndrome, adhesive capsulitis, partial rotator cuff tears, or shoulder instability, as previous studies have reported similar increases in scapular internal rotation and anterior tipping.[30,41,43,48] Exercises that potentially facilitate these scapular motions, thereby decreasing the subacromial space, should be avoided when treating patients already at risk for mechanical impingement and/or with injured or inflamed subacromial tissues.

There were limitations to our study. Our sample was a homogeneous group of healthy, young students. It is unclear if our results can be applied across populations. However, there are no studies to suggest scapular kinematics changes during the lifespan or that the anatomy will respond differently to the imposed demands of tensioning the posterior capsule. Future researchers should investigate the effect of exercises on scapular kinematics during the lifespan as well as in patients with symptomatic shoulders. Another limitation was that the skin-based sensors give only a representation of scapular and humeral kinematics. However, this method has been validated and shown to be reliable within humeral elevation ranges from 30° to 120°.[4,31,36] The sampled ranges of humeral elevation were within these limits; thus, we are confident they are an accurate representation of scapular motion. The lack of a direct measure of supraspinatus outlet volume limits absolute conclusions based on our results. However, our conclusions are based on the integration of our results with the current literature available, and it is reasonable to conclude that the supraspinatus outlet volume is likely decreased during the empty-can exercise.[10,15,44] Finally, the observed scapular internal rotation during humeral elevation during both the empty-can and full-can exercises is consistent with some authors[36,39] but not with others[31,35] who have reported scapular external rotation during humeral elevation. Variability due to skin artifact, selection of bony landmarks, plane and range of humeral elevation, as well as Euler angle decomposition have been suggested as reasons for these differences in scapular internal/external rotation within the literature.[20,25,30,35] In addition, scapular external rotation usually begins above 90° of humeral elevation, and we analyzed arcs between 30° and 90°.[30,35] The observed differences in scapular internal/external rotation across studies are therefore most likely caused by the differences in humeral elevation angles across studies.

CONCLUSION

This study is the first to compare three-dimensional scapular kinematics between full-can and empty-can supraspinatus strengthening. The differences we observed in scapular motion between the full-can and empty-can exercises should be considered when selecting rehabilitation exercises for shoulder injuries. The empty-can exercise places the humerus in internal rotation, thus increasing scapular internal rotation and anterior tipping, two kinematic patterns associated with impingement and decreased volume of the subacromial space. Given the lack of convincing electromyographic evidence supporting the empty-can exercise for supraspinatus activation, our kinematic data suggest that the full-can exercise should be the preferred technique for supraspinatus muscle strengthening during shoulder rehabilitation.

REFERENCES

1. An KN, Browne SO, Korinek S, Tanaka S, Morrey BF. Three-dimensional kinematics of glenohumeral elevation. *J Orthop Res*. 1991;9:143-149.
2. Ascension Technology Corporation. Technical specifications for Flock of Birds. Available at: http://www.ascension-tech.com/products/flockofbirds.php. Accessed June 15, 2002.
3. Bagg SD, Forrest WJ. A biomechanical analysis of scapular rotation during arm abduction in the scapular plane. *Am J Phys Med Rehabil*. 1988;67:238-245.
4. Barnett ND, Duncan RD, Johnson GR. The measurement of three-dimensional scapulohumeral kinematics: a study of reliability. *Clin Biomech*. 1999;14:287-290.
5. Blackburn TA, McLeod WD, White B, et al. EMG analysis of posterior rotator cuff exercises. *Athletic Training*. 1990;25:40-47.
6. Borstad JD, Ludewig PM. Comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane. *Clin Biomech (Bristol, Avon)*. 2002;17:650-659.
7. Burke WS, Vangsness CT, Powers CM. Strengthening the supraspinatus: a clinical and biomechanical review. *Clin Orthop Relat Res*. 2002;402:292-298.
8. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology, III: the sick scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy*. 2003;19:641-661.
9. Codman EA. Normal motion of the shoulder joint. In: Codman EA, ed. *The Shoulder: Rupture of the Supraspinatus Tendon and Other Lesions in or About the Subacromial Bursa*. 1st ed. Boston, Mass: T. Todd Co; 1934:52-55.
10. De Wilde L, Plasschaert F, Berghs B, Van Hoecke M, Verstraete K, Verdonk R. Quantified measurement of subacromial impingement. *J Shoulder Elbow Surg*. 2003;12:346-349.
11. Glousman R, Jobe F, Tibone J, Moynes D, Antonelli D, Perry J. Dynamic electromyographic analysis of the throwing shoulder in glenohumeral instability. *J Bone Joint Surg Am*. 1988;70:220-226.
12. Graichen H, Bonel H, Stammberger T, Englmeier KH, Reiser M, Eckstein F. Subacromial space width changes during abduction and rotation: a 3-D MR imaging study. *Surgical Radiological Anatomy*. 1999;21:59-64.
13. Graichen H, Bonel H, Stammberger T, et al. A technique for determining the spatial relationship between the rotator cuff and the subacromial space in arm abduction using MRI and 3D image processing. *Magn Reson Med*. 1998;40:640-643.
14. Graichen H, Bonel H, Stammberger T, et al. Three-dimensional analysis of the width of the subacromial space in healthy subjects and patients with impingement syndrome. *AJR Am J Roentgenol*. 1999;172:1081-1086.
15. Graichen H, Stammberger T, Bonel H, et al. Three-dimensional analysis of shoulder girdle and supraspinatus motion patterns in patients with impingement syndrome. *J Orthop Res*. 2001;19:1192-1198.
16. Gschwend N, Ivosevic-Radovanovic D, Patte D. Rotator cuff tear—relationship between clinical and anatomopathological findings. *Arch Orthop Trauma Surg*. 1988;107:7-15.
17. Halder AM, Zhao KD, O'Driscoll SW, Morrey BF, An KN. Dynamic contributions to superior shoulder stability. *J Orthop Res*. 2001;19:206-212.
18. Hebert LJ, Moffet H, Dufour M. Acromiohumeral distance in a seated position in persons with impingement syndrome. *J Magn Reson Imaging*. 2003;18:72-79.

19. Hebert LJ, Moffet H, McFadyen BJ, Dionne CE. Scapular behavior in shoulder impingement syndrome. *Arch Phys Med Rehabil*. 2002; 83:60-69.
20. Hebert LJ, Moffet H, McFadyen BJ, St-Vincent G. A method of measuring three-dimensional scapular attitudes using the opotrak probing system. *Clin Biomech (Bristol, Avon)*. 2000;15:1-8.
21. Horrigan JM, Shellock FG, Mink JH, Deutsch AL. Magnetic resonance imaging evaluation of muscle usage associated with three exercises for rotator cuff rehabilitation. *Med Sci Sports Exerc*. 1999; 31:1361-1366.
22. Inman VT, Saunders JB, Abbott L. Observations of the function of the shoulder joint. *J Bone Joint Surg Am*. 1944;26:1-30.
23. International Society of Biomechanics Shoulder Group. Standardization of joint rotation (ISG 2002). Available at: http://www.wbmt.tudelft.nl/mms/dsg/intersg/ISGproposal.pdf. Accessed May 1, 2003.
24. Jobe F, Moynes D. Delineation of diagnostic criteria and a rehabilitation program for rotator cuff injuries. *Am J Sports Med*. 1982;10: 336-339.
25. Karduna AR, McClure PW, Michener LA. Scapular kinematics: effects of altering the Euler angle sequence rotations. *J Biomech*. 2000;33: 1063-1068.
26. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. *J Biomech Eng*. 2001;123:184-190.
27. Kelly BT, Kadramas WR, Speer KP. The manual muscle examination for rotator cuff strength: an electromyographic investigation. *Am J Sports Med*. 1996;24:581-588.
28. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med*. 1998;26:325-337.
29. Koh TJ, Grabiner MD, Brems JJ. Three-dimensional in vivo kinematics of the shoulder during humeral elevation. *J Appl Biomech*. 1998;14: 312-326.
30. Ludewig P, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther*. 2000;80:276-291.
31. Ludewig P, Cook TM, Nawoczenski DA. Three-dimensional scapular orientation and muscle activity at selected positions humeral elevation. *J Orthop Sports Phys Ther*. 1996;24:57-65.
32. Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. *J Orthop Sports Phys Ther*. 1999;29:574-583.
33. Malanga GA, Jenp Y-N, Growney ES, An KN. EMG Analysis of shoulder positioning in testing and strengthening the supraspinatus. *Med Sci Sports Exerc*. 1996;28:661-664.
34. McClure PW, Flowers KR. Treatment of limited shoulder motion: a case study based on biomechanical considerations. *J Orthop Sports Phys Ther*. 1992;72:929-936.
35. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *J Shoulder Elbow Surg*. 2001;10:269-277.
36. McQuade KJ, Dawson J, Smidt GL. Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. *J Orthop Sports Phys Ther*. 1998;28:74-80.
37. McQuade KJ, Hwa Wei S, Smidt GL. Effects of local muscle fatigue on three-dimensional scapulohumeral rhythm. *Clin Biomech (Bristol, Avon)*. 1995;10:144-148.
38. Meskers CGM, van der Helm FCT, Rozing PM. The size of the supraspinatus outlet during elevation of the arm in the frontal and sagittal plane: a 3-D model study. *Clin Biomech (Bristol, Avon)*. 2002; 17:257-266.
39. Meskers CGM, Vermeulen HM, de Groot JH, van Der Helm FC, Rozing PM. 3D shoulder position measurements using a six-degree-of-freedom electromagnetic tracking device. *Clin Biomech (Bristol, Avon)*. 1998;13:280-292.
40. Michener L, Walsworth M, Burnet E. Effectiveness of rehabilitation for patients with subacromial impingement syndrome: a systematic review. *J Hand Ther*. 2004;17:152-164.
41. Paletta GA Jr, Warner JJP, Warren RF, Deutsch A, Altchek DW. Shoulder kinematics with two-plane x-ray evaluation in patients with anterior instability or rotator cuff tearing. *J Shoulder Elbow Surg*. 1997;6:516-527.
42. Pearl ML, Perry J, Torburn L, Gordon LH. An electromyographic analysis of the shoulder during cones and planes of arm motion. *Clin Orthop Relat Res*. 1992;284:116-127.
43. Price CIM, Franklin P, Rodgers H, Curless RH, Johnson GR. Active and passive scapulohumeral movement in healthy persons: a comparison. *Arch Phys Med Rehabil*. 2000;81:28-31.
44. Roberts CS, Davila JN, Hushek SG, Tillett ED, Corrigan TM. Magnetic resonance imaging analysis of the subacromial space in the impingement sign positions. *J Shoulder Elbow Surg*. 2002;11:595-599.
45. Solem-Bertoft E, Thuomas K-A, Westerberg C-E. The influence of scapular retraction and protraction on the width of the subacromial space. *Clin Orthop Relat Res*. 1993;296:99-103.
46. Takeda Y, Kashiwaguchi S, Endo K, Matsuura T, Sasa T. The most effective exercise for strengthening the supraspinatus muscle. *Am J Sports Med*. 2002;30:374-381.
47. Thigpen CA, Gross MT, Karas SG, et al. Repeatability of scapular rotation for three planes of humeral elevation. *Research in Sportsmedicine*. 2005;13:181-198.
48. Thigpen CA, Padua DA, Karas SG. Comparison of scapular kinematics between individuals with and without multidirectional shoulder instability. Paper presented at: America Orthopaedic Society for Sports Medicine Annual Meeting; July 14-17, 2005; Keystone, CO.
49. Thompson WO, Debski RE, Boardman ND III, et al. A biomechanical analysis of rotator cuff deficiency in a cadaveric model. *Am J Sports Med*. 1996;24:286-292.
50. Townsend H, Jobe F, Pink MM, Perry J. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. *Am J Sports Med*. 1991;19:264-272.
51. Veeger HEJ. The position of the rotation center of the glenohumeral joint. *J Biomech*. 2000;33:1711-1715.
52. Vermeulen HM, Stokdijk M, Eilers PHC, Meskers CG, Rozing PM, Vliet Vlieland TP. Measurement of three-dimensional shoulder movement patterns with an electromagnetic tracking device in patients with a frozen shoulder. *Ann Rheum Dis*. 2002;61:115-120.
53. Warner JJP. The gross anatomy of the joint surfaces, ligaments, labrum, and scapula. In: Matsen FA III, Hawkins RJ, eds. *The Shoulder: A Balance of Mobility and Stability*. Rosemont, Ill: American Academy of Orthopedic Surgeons; 1993:7-27.
54. Warner JJP, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Scapulothoracic motion in normal shoulders and shoulders with glenohumeral instability and impingement syndrome. *Clin Orthop Relat Res*. 1992;285:191-199.
55. Yu B, Andrews J. The relationship between free limb motions and performance in the triple jump. *J Appl Biomech*. 1999;14:223-237.
56. Zuckerman J, Kummer F, Cuomo F, et al. The influence of coracoacromial arch anatomy on rotator cuff tears. *J Shoulder Elbow Surg*. 1992; 1:4-14.