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Bending the Elbow During Shoulder Flexion Facilitates Greater Scapular Upward Rotation and a More Favorable Scapular Muscle Activation Pattern

Alon Rabin, Brakha R. Tabi, Timothy L. Uhl, and Zvi Kozol

Context: Decreased scapular upward rotation (UR) and diminished activation of the serratus anterior (SA) and lower trapezius (LT) are often observed among patients with subacromial impingement syndrome. Maintaining the elbow fully flexed during shoulder flexion may limit glenohumeral motion due to passive insufficiency of the triceps brachii and therefore facilitate greater scapular UR and increased scapular muscle activation. ***Objectives:*** To compare scapular UR, SA, upper trapezius (UT), middle trapezius, and LT activation levels between shoulder flexion with the elbow extended (Flexion-EE) to shoulder flexion with the elbow fully flexed (Flexion-EF). This study hypothesized that Flexion-EF would result in greater scapular UR, greater SA and LT activation, and a lower UT/SA and UT/LT activation ratio compared with Flexion-EE. ***Design:*** Cross-sectional study. ***Setting:*** A clinical biomechanics laboratory. ***Participants:*** Twenty-two healthy individuals. ***Main Outcome Measures:*** Scapular UR and electromyography signal of the SA, UT, middle trapezius, and LT, as well as UT/SA and UT/LT activation ratio were measured during Flexion-EE and Flexion-EF. ***Results:*** Flexion-EF resulted in greater scapular UR compared with Flexion-EE ($P < .001$). Flexion-EF resulted in greater SA activation, lower UT activation, and a lower UT/SA activation ratio compared with Flexion-EE ($P < .001$). ***Conclusions:*** Fully flexing the elbow during shoulder flexion leads to increased scapular UR primarily through greater activation of the SA. This exercise may be of value in circumstances involving diminished scapular UR, decreased activation of the SA, and an overly active UT such as among patients with subacromial impingement syndrome.

Keywords: scapula, subacromial impingement syndrome, serratus anterior, trapezius

Scapular dysfunction including diminished upward rotation (UR), posterior tilt, and medial rotation may lead to secondary subacromial impingement among athletes or overhead workers.[1–3] A possible cause for insufficient scapular UR is impaired function of the primary movers of the scapula, namely the serratus anterior (SA), upper trapezius (UT), and lower trapezius (LT). Accordingly, decreased activation of the SA and LT along with increased activation of the UT has often been reported among patients with subacromial impingement syndrome (SAIS).[4] Decreased strength of the SA and LT has also been linked to decreased scapular UR among healthy athletes.[5] These findings have sparked an interest in the development of exercises for promoting greater activation of the SA and LT while avoiding excessive activation of the UT. Several scapular muscle strengthening exercises have been suggested to promote optimal UT/LT and UT/SA activation ratios (ie, greater LT or SA activation relative to UT activation).[6,7] Others have suggested motor control strategies consisting of conscious correction of scapular position during shoulder movement. Accordingly, cueing the scapula into a more retracted position has typically induced greater activation of the trapezius muscle with a less consistent effect on UT/LT and UT/SA activation ratios.[8–10] Cueing the scapula into a more protracted position has typically led to increased SA activation,[11,12] and consequently a lower UT/SA activation ratio.[11] Finally, cueing the scapula into a more elevated position (shoulder shrug) has been associated with greater UT activity,[12,13] and consequently a less favorable (higher) UT/LT activation ratio.[13]

Another approach to increase scapular muscle activation as well as to promote greater scapular UR is to limit glenohumeral joint excursion during motion of the entire shoulder complex. Given that shoulder movement occurs simultaneously at the sternoclavicular, scapulothoracic, and glenohumeral articulations,[14] restricting movement of the glenohumeral joint may lead to compensatory increased scapulothoracic movement with an associated increased activation of the scapular upward rotators. Bending the elbow during shoulder flexion is one way of restricting glenohumeral motion presumably due to passive insufficiency of the triceps brachii.[15] Furthermore, the attachment of the long head of the triceps to the inferior glenohumeral capsule,[16,17] may further limit glenohumeral joint excursion when the elbow is fully bent.

The purpose of this study was to assess the effects of bending the elbow during shoulder flexion on scapular UR range of motion as well as scapular muscle activation. We hypothesized that flexing the shoulder while maintaining the elbow fully flexed would result in a greater scapular UR, greater SA and LT activation, and a lower UT/SA and UT/LT activation ratio.

Methods

Participants

A sample of convenience comprised of 22 healthy participants (7 females) was recruited from a university campus. The mean (SD) age, height, and weight of participants were 26.8 (8.8) years, 173.9 (6.9) cm, and 74.2 (12.7) kg, respectively. Twenty (91%) participants were right-hand dominant. Inclusion criteria were being

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18 years or older, shoulder flexion range of motion ≥160°, and full elbow flexion range of motion on both sides. Participants were excluded if they currently or over the previous 2 years had shoulder or elbow pain, a previous history of shoulder or elbow dislocation, fracture, or surgery. Participants were also excluded if they had a history of any neurological condition affecting either upper-extremity. The study was approved by the Institutional Review Board of Ariel University, and all participants provided informed consent prior to participating in any of the procedures of the study.

Sample size calculation was performed using G*Power (version 3.1; Heinrich Heine University Düsseldorf, Düsseldor, Germany). Based on the intent to detect a moderate effect size (≥0.25) for SA activation between the different shoulder flexion conditions using a 2-tailed test, a P value ≤ .05 and a desired power (β) of 80%, the required sample size was estimated to be 21 participants.

Examiners

Data collection was performed by 2 licensed physical therapists: one with over 35 years of experience in teaching kinesiology, electromyography (EMG), and neurological rehabilitation, while the other with over 20 years of experience in teaching and managing musculoskeletal disorders.

Procedures

Following informed consent and documentation of demographic information, participants were taught the 2 exercises to be performed in the study. Both exercises were performed bilaterally to 120° of shoulder flexion, and all measurements were performed on the dominant side of each participant. The order of exercise condition (shoulder flexion with the elbow flexed [Flexion-EF] or extended [Flexion-EE]) was randomized based on a preprepared sequence (WWW.random.org).

1. Flexion-EE: From a standing position with the arms by the side and the elbows extended, participants were asked to flex both shoulders forward while maintaining the elbows straight and the thumbs pointing up (Figure 1A).
2. Flexion-EF: From a standing position with both arms by the side and the elbows fully flexed, participants were asked to flex both shoulders forward while maintaining their elbows pointing forward throughout the motion (Figure 1B).

In order to reach a consistent forward flexion angle during the Flexion-EE, participants were first asked to flex their shoulder to 120° with elbows extended while facing a wall. Shoulder flexion angle was measured by an Acumar™ digital inclinometer (model ACU 360; Lafayette instrument Company, Lafayette, IN) placed over the dorsal aspect of the arm just distal to the deltoid tuberosity.[18] The wall was marked with a 1-cm-thick black tape at a level corresponding to the participant's index finger. In order to reach a consistent forward flexion angle during the Flexion-EF, participants were asked to flex their shoulders to 120° with the elbows fully flexed while facing the wall. Flexion angle was similarly measured with the digital inclinometer, and the wall was marked with a centimeter black tape corresponding the participant's olecranon process. Once both wall marks were placed, each participant practiced flexing his/her shoulder to the appropriate level under each motion condition (Flexion-EE and Flexion-EF) until he/she could consistently achieve a sagittal plane shoulder angle of 120°.

Scapular Upward Rotation

Scapular UR was measured using the EasyAngle electric goniometer (Meloq AB, Stockholm, Sweden). This measurement has been previously shown to possess good intrarater and interrater reliability as well as moderate validity compared with 3D motion capture.[19] First, the rectangular base of the device was placed along the spine of the scapula with its lateral corner corresponding to the posterolateral corner of the acromion (Figure 2A). The device was zeroed with the participant assuming a relaxed standing position with the arms by the side and the elbows extended. The device was then removed, and the participant flexed his/her arm to the 120° position using the designated exercise condition (Flexion-EE and Flexion-EF). The electric goniometer was then repositioned over the exact same location to measure scapular UR which was recorded in degrees (Figure 2B). This procedure was repeated on all participants by a second examiner to determine interrater reliability of the measurement as performed in this investigation. The intraclass correlation coefficient and 95% confidence interval for scapular UR was .71 (.42–.87) for Flexion-EE and .80 (.57–.91) for Flexion-EF, representing good to excellent interrater agreement.[20]

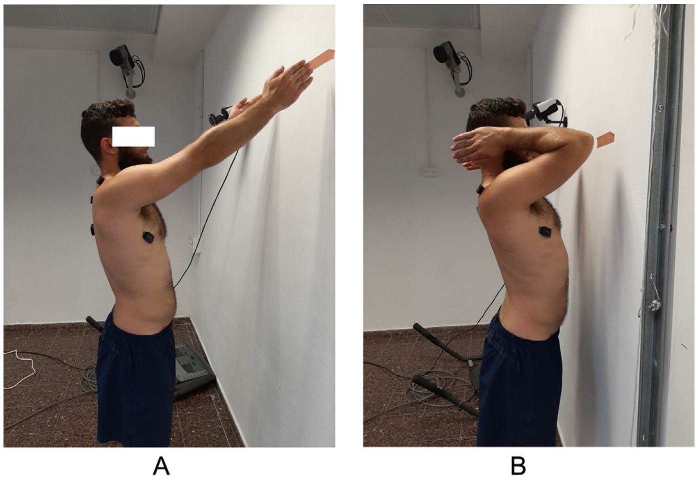

Figure 1 — (A) Shoulder flexion with the elbow extended. (B) Shoulder flexion with the elbow fully flexed.

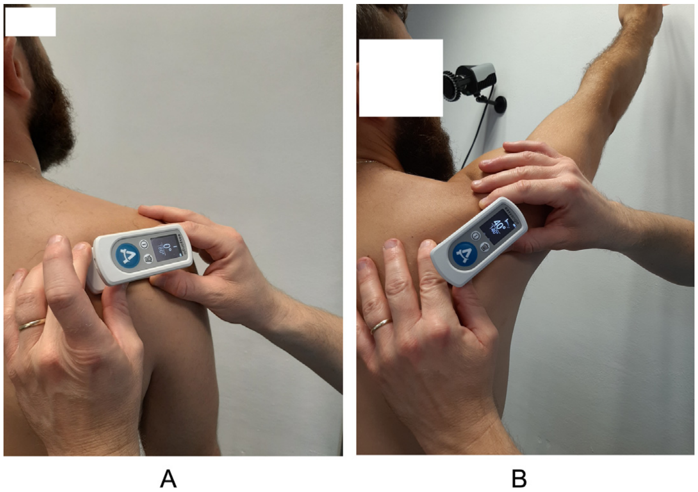

Figure 2 — (A) Scapular upward rotation—Starting position. (B) Scapular upward rotation—Final position.

Scapular Muscle Electromyography

Scapular neuromuscular activity of the UT, middle trapezius (MT), LT, and SA was measured via surface EMG during the 2 shoulder flexion exercise conditions. First, participants' skin was prepared for surface electrode placement, shaved if needed, lightly debrided with fine sandpaper, and cleaned with alcohol.[21,22] Wireless EMG sensors (Delsys Inc, Natick, MA) with a fixed interelectrode distance of 10 mm were placed in parallel to the muscle fibers of the UT, MT, LT, and SA. For the UT, electrodes were placed halfway between the seventh cervical vertebra spinous process and the posterior tip of the acromion along the UT muscle fibers.[23] For the MT, electrodes were placed on a horizontal line halfway between the root of spine of the scapula and the third thoracic spinous process.[6] For the LT, electrodes were placed obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process.[6] For the SA, electrodes were placed with the arm flexed 125° over the seventh intercostal space and in parallel to the muscle fibers just anterior to the fibers of the latissimus dorsi.[24] Electrode placement and quality of the EMG signal were visually verified through resisted contraction of all instrumented muscles. As a normalization procedure, the EMG amplitude from each muscle was collected during two 5-second maximum voluntary isometric contractions (MVIC) with a 30-second rest interval in between. For the MVIC of the UT, the participant was seated in an upright position with the tested shoulder abducted 90° in the frontal plane and the thumb pointing up.[25] Resistance was applied by the examiner just proximal to the participant's elbow. For the MVIC of the MT, the participant abducted the arm to 90° while in a prone lying position with the thumb pointing up while resistance was applied by the examiner just proximal to the elbow.[26] For the MVIC of the LT, the participant abducted the arm to approximately 140° in line with the fibers of the LT while in a prone lying position with the thumb pointing up. Resistance was applied by the examiner just proximal to the elbow.[26] For the MVIC of the SA, the participant flexed the shoulder 125° in the sagittal plane with full scapular protraction while seated upright.[7] Resistance was applied by the examiner just proximal to the elbow and over the lateral border of the scapula. The same examiner (A.R.) performed all MVIC trials.

Once the EMG setup and normalization was completed, participants were asked to perform 3 consecutive repetitions of each exercise condition in random order to minimize effects of learning and fatigue. Forward flexion to 120° was performed at a constant rate using a metronome set at 40 beats per minute. A rest period of 2 minutes was given between exercise conditions.

EMG Data Processing

The EMG signal was collected using a Delsys Trigno system and analyzed using Delsys EMGworks® (Delsys, NA) acquisition software. All raw EMG data were collected at a sampling rate of 2000 Hz. The raw data were band-pass filtered between 30 and 500 Hz using a finite impulse response filter and then further smoothed using root mean square method with a window length of 125 ms and window overlap of 62.5 ms. The MVIC was determined by identifying the highest activity during a 500-ms window during one of the two 5-second MVIC for each tested muscle. The average root mean square of the total arc of motion (concentric and eccentric phase) of the 3 test repetitions was normalized based on the MVIC and expressed as %MVIC for each muscle under each movement condition. Finally, 2 muscle activation ratios were calculated by dividing the normalized EMG activity of the UT by that of the SA (UT/SA activation ratio) and by dividing the normalized EMG activity of the UT by that of the LT (UT/LT activation ratio).

Statistical Analysis

Descriptive statistics were used to summarize scapular UR, muscle activation levels, and activation ratios with measures of central tendency and dispersion. Nonparametric analyses were performed as assumptions for normal distribution were not met based on Shapiro–Wilks tests for all dependent measures. Separate Wilcoxon signed-rank tests were performed to assess for differences in scapular UR, scapular muscle (UT, MT, LT, and SA) activation levels, and scapular muscle activation ratios (UT/SA and UT/LT) between Flexion-EE and Flexion-EF. All analyses were performed using SPSS (version 21; SPSS Inc, Chicago, IL) with an a priori level of significance of $P \leq .05$.

Results

Scapular Upward Rotation

Scapular UR as measured by each examiner under the different shoulder flexion conditions is summarized in Table 1. Statistically significant greater scapular UR was measured by each examiner during Flexion-EF compared with Flexion-EE ($P < .001$).

Muscle Activation Levels

The normalized muscle activation measurements and muscle activation ratios are summarized in Table 2. The UT activation was significantly lower ($P < .001$), while SA activation was significantly greater ($P < .001$) during Flexion-EF compared with Flexion-EE. No differences were found in activation levels of the MT and LT between exercise conditions. The UT/SA activation ratio was significantly lower during Flexion-EF compared with Flexion-EE ($P < .001$), while the UT/LT activation ratio did not differ between exercise conditions.

Discussion

Maintaining the elbow fully flexed during shoulder flexion results in greater scapular UR, increased activation of the SA, decreased activation of the UT, and a resultant lower UT/SA activation ratio compared with Flexion-EE. These findings support the hypothesis

Table 1 Scapular UR and Reliability for the 2 Shoulder Flexion Conditions

Variable	Flexion-EE	Flexion-EF
Examiner 1, deg	32.3 (4.4)	37.6 (6.7)[a]
Examiner 2, deg	32.5 (5.1)	37.1 (5.5)[a]
ICC (95% CI)	.71 (.42–.87)	.80 (.57–.91)
MDC_{90},[b] deg	6.0	6.3

Abbreviations: CI, confidence interval; EE, shoulder flexion with the elbow extended; EF, shoulder flexion with the elbow flexed; ICC, intraclass correlation coefficient; MDC, minimal detectable change; UR, upward rotation. Note: The values are presented as mean (SD).

[a] Significantly greater than Flexion-EE ($P < .001$). [b] Calculated based on the formula: $MDC_{90} = SD \times \sqrt{(1 - ICC)} \times \sqrt{2} \times 1.65$.

Table 2 Scapular Muscle Activation (%MVIC) and Activation Ratio During Each Shoulder Flexion Condition

Muscle	Flexion-EE	Flexion-EF	*P* value
SA, %MVIC	12.2 (7.90)	18.2 (9.20)	<.01
UT, %MVIC	11.7 (6.60)	4.10 (6.40)	<.01
MT, %MVIC	1.72 (1.70)	1.94 (1.50)	.51
LT, %MVIC	3.94 (7.20)	3.80 (4.10)	.10
UT/SA activation ratio	0.96 (0.65)	0.21 (0.39)	<.01
UT/LT activation ratio	2.16 (5.62)	1.18 (3.10)	.06

Abbreviations: EE, shoulder flexion with the elbow extended; EF, shoulder flexion with the elbow flexed; IQR, interquartile range; LT, lower trapezius; MVIC, maximal voluntary isometric contraction; MT, middle trapezius; SA, serratus anterior; UT, upper trapezius. Note: The values are presented as Median (IQR).

of this study and suggest fully flexing the elbow during shoulder flexion may be a useful exercise to promote greater scapular UR primarily through enhanced activation of the SA.

Motor control interventions are often used to improve scapular movement and muscle activation patterns. These interventions require clinicians to identify scapular position and/or movement abnormalities (ie, lack of scapular UR), which are then typically addressed in 2 stages. First, patients are taught to assume optimal scapular orientation, and second, this new scapular orientation is integrated into shoulder motion in progressively increased arcs of motion or levels of difficulty.[27–29] While changes in movement and muscle activation patterns have been observed following motor control exercises,[28,30] these interventions carry certain limitations such as heavy reliance on therapist clinical observation skills and patient motor learning capabilities, as well as the need for constant feedback requiring extensive therapist contact.[30] Furthermore, it has previously been shown that clinical improvement following exercise interventions among patients with SAIS is not contingent upon changes in scapular kinematics.[31,32] Unlike motor control training, the Flexion-EF is a relatively simple movement task that can be performed immediately to result in increased scapular UR and SA activation. The enhanced scapular UR and SA activation are most likely imposed due to a restricted glenohumeral motion, thus making the Flexion-EF more similar to a constraint induced movement intervention rather than a motor control one. By performing the Flexion-EF, participants are required to actively mobilize their scapula into greater UR most likely through increased activation of the SA. This may prove useful among patients with SAIS who have been shown to present with decreased scapular UR,[33,34] decreased SA activation,[3] and increased activation of the UT.[3,35]

The Flexion-EF may possess several advantages over other exercises purported to promote optimal scapular muscle activation ratios. For example, the UT/SA activation ratio measured during the Flexion-EF seems considerably smaller than that previously reported for the push-up plus.[7] Furthermore, the short lever arm used in the Flexion-EF may make it more suitable for use earlier in the rehabilitation process compared with the body weight resistance applied during the push up plus. Adding scapular protraction to shoulder flexion has also been shown to increase SA activation and promote a lower UT/SA activation ratio.[11,13] However, the Flexion-EF results in similar muscle activation effects while avoiding some of the undesirable effects of increased scapular protraction including hyperactivation of the deltoid and a decreased ability to generate shoulder muscle strength.[13,36,37] Finally, since Flexion-EF also resulted in increased scapular UR, it may possess a better choice in patients demonstrating diminished scapular UR.[3,33,34]

A less expected finding of this study was the decreased activation of the UT during Flexion-EF. Castelein et al[38] similarly reported lower UT activation when shoulder elevation was performed with the elbow bent.[38] The shorter lever arm of the Flexion-EF may have reduced muscular demands for shoulder elevation requiring less activation of the UT.

Although our hypothesis regarding the effect of elbow flexion on SA activation was confirmed, activation of the LT did not increase during the Flexion-EF. This may be because of the more dominant role the SA compared with the LT during sagittal plane shoulder elevation[39–41] Second, the Flexion-EF may have involved a greater degree of horizontal adduction compared with the Flexion-EE, as participants attempted to maintain the tip of their elbow pointing forward during this exercise. Shoulder horizontal adduction in a standing position has been previously shown to increase SA activation,[26,42–44] while simultaneously decrease LT activation.[42,44]

This study has several limitations. First, our sample was comprised of young and healthy individuals, and it is unknown whether similar muscle activation levels or scapular UR would occur among clinical populations. Second, the EMG amplitudes measured in this study were relatively low and may not be sufficient to invoke strength gains. This is most likely due to the lack of additional loads during both exercises, which were by design as the movement pattern was the primary question to be answered. A similar study investigating scapular muscle activation during a standing press-up exercise against minimal resistance (0.5 kg) found similar EMG activity in the SA (29% [13%] MVIC), UT (24% [8%] MVIC), and LT (9% [5%] MVIC).[45] The relatively low EMG values may have also resulted from averaging muscle activity over the entire arc of motion as opposed to only during 1 segment (eg, concentric or eccentric). Third, although differences in scapular UR between Flexion-EE and Flexion-EF are comparable and sometimes even exceed those found between healthy individuals and patients with SAIS, the magnitude of these differences still falls within the boundaries of the measurement error as determined in this study.[3,34,35] Thus, despite comparable interrater reliability with a previous investigation using a similar measurement,[19] confidence in these differences is still somewhat limited. Finally, differences in muscle activation patterns between the 2 exercises should not necessarily be attributed to differences in scapular UR. Other scapulothoracic or glenohumeral kinematic differences between exercises may provide alternative explanations.

Conclusions

Bending the elbow during shoulder flexion results in increased scapular UR, along with greater activation of the SA, decreased activation of the UT, and a more favorable UT/SA activation ratio. These findings suggest Flexion-EF may be a useful exercise for promoting increased scapular UR preferentially through increased activation of the SA. This may be desirable among certain clinical populations such as patients with SAIS.

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