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original research

Scapular Kinematics and Shoulder Elevation in a Traditional Push-Up

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Context: Proper scapulothoracic motion is critical for the health and function of the shoulder and represents a principal focus in the rehabilitation setting. Variants of the traditional push-up are used frequently to help restore proper scapular kinematics. To date, substantial research has focused on muscle activation levels of rotator cuff and scapular-stabilizing musculature, whereas a dearth of literature exists regarding scapular kinematics during push-up variants.

Objective: To examine the effect of shoulder position on scapular kinematics across the range of motion (ROM) of a traditional push-up.

Design: Cross-sectional study.

Setting: University laboratory.

Patients or Other Participants: Sixteen healthy participants without a history of upper extremity or spine injury requiring rehabilitation or surgery.

Intervention(s): Participants performed a traditional push-up while kinematic measurements were acquired from multiple upper extremity segments. The 3 shoulder position conditions were (1) self-selected position, (2) shoulder adducted upon ascent (at side), and (3) shoulder elevated to approximately 90°.

Main Outcome Measure(s): Scapular posterior tilt, upward rotation, and external rotation were examined across elbow-extension ROM and compared across conditions.

Results: Posterior tilt was greater in the self-selected and at-side conditions than in the elevated condition and increased linearly with elbow extension. External rotation was greater in the self-selected and at-side conditions compared with that in the elevated condition. In the at-side condition, upward rotation began lower than in the other conditions at the start of the concentric phase but increased above the others soon after the elbow started to extend.

Conclusions: Performing a traditional push-up with the shoulders elevated may place the scapula in a position of impingement. Clinicians should be cognizant of shoulder elevation when prescribing and monitoring exercise progression. The results of this study will provide further direction for clinicians in prescribing rehabilitation exercises for the upper extremity, especially closed chain exercises for shoulder conditions.

Key Words: closed kinetic chain exercises, impingement, rehabilitation

Key Points

- During a traditional push-up, scapular posterior tilt and external rotation decreased with greater shoulder elevation, and posterior tilt increased with elbow extension.
- Scapular upward rotation was greater for much of the range of motion with the shoulder in a position of less elevation.
- Increased shoulder elevation during a traditional push-up may contribute to impingement.

Proper scapulothoracic motion is critical to the health and function of the upper extremity. It is important in maintaining glenohumeral joint stability, maximizing the subacromial space, and aiding in force transfer from the lower extremities and trunk to the upper extremity.[1] During scapular-plane arm elevation in a healthy shoulder, the scapula exhibits a characteristic pattern of increasing posterior tilt (PT), upward rotation (UR), and external rotation (ER).[2] However, this pattern is altered in cases of injury, such as subacromial impingement, glenohumeral instability, and rotator cuff tears. For example, patients with symptoms of subacromial impingement syndrome exhibit smaller degrees of PT, UR, and ER[3] compared with healthy controls during shoulder elevation in the scapular plane. These changes in scapular kinematics with overhead movement result in reduced volume of the subacromial space.[4] This reduced volume has been associated with a painful arc of motion above 60° of shoulder elevation.[5]

One objective of rehabilitation programs for injury to the shoulder complex is restoration of proper scapular kinematics during humerothoracic motion. To this end, practitioners select exercises designed to strengthen the scapular-stabilizing musculature while placing the scapula in a favorable position to avoid impingement of the subacromial space. For this purpose, the push-up and its many variants are popular choices, owing to their easy adaptability to various difficulty levels and their theorized tendency to improve joint stability and proprioception during execution as a result of compression forces.[6] However, our understanding of the potential efficacy of push-up variants in strengthening and rehabilitation programs remains incomplete.

To date, the study of the potential for these exercise variants to bring about desired results in strengthening and rehabilitation settings has focused mainly on activation patterns of the prime movers, scapular-stabilizer muscles, rotator cuff muscles, and trunk musculature,[7–15] as well as forces encountered during execution.[11,16,17] Authors[8,11,14] have consistently reported that agonist muscle activation increases with the intensity of the exercise variant. However, the activation levels of the serratus anterior and upper trapezius, the primary scapular stabilizers, across push-up variants appear to depend on hand position and joint angles during the movement (resulting from changing muscle lengths and moment arms) as well as the support surface used.[9,12,15,18] Also, activation levels of the scapular-stabilizer muscles during the many push-up variants may depend on a complex interplay between the weight-bearing demand of the exercise and the degree of arm elevation.[17]

Considering the importance of scapular positioning during strengthening and rehabilitation exercises and the attention paid to corresponding activation levels of the scapular stabilizers in the literature, it is surprising that few investigators have examined scapular kinematics during push-up variants. In the only other study of scapular kinematics during a push-up exercise, Lunden et al[19] reported that, during a push-up with a plus performed against a wall, the scapula began the concentric phase in internal rotation, UR, and anterior tilt and exhibited increasing internal rotation and decreasing UR, with no significant change in PT through the plus phase. The authors cautioned that this pattern of scapular kinematics may place the supraspinatus in danger of impingement under the acromion and that this exercise may be contraindicated for early rehabilitation of shoulder injuries. These results highlight the importance of further study of the scapular kinematics of various push-up exercises.

Because the wall push-up results in a relatively high upper trapezius/serratus anterior activation ratio, the kinematics may be different than those in a traditional push-up. Given the weight-bearing demand and shoulder elevation of an exercise in determining scapular-stabilizer activation levels, the purpose of our study was to examine the effect of shoulder position on scapular kinematic patterns in a traditional push-up. Specifically, we looked at scapular UR, PT, and ER across the range of motion (ROM) of elbow extension during the concentric portion of the traditional push-up under 3 conditions of shoulder elevation: (1) a self-selected position, (2) with the elbows at the side upon ascent, and (3) with the shoulders elevated to approximately 90° upon ascent. We hypothesized that the scapula would be positioned with greater PT, UR, and ER as shoulder elevation increased in an attempt to maintain adequate subacromial space and avoid impingement. In accordance with the findings of Lunden et al[19] in the wall push-up plus, we further hypothesized that scapular ER and UR would decrease with elbow extension.

METHODS

Ethical Approval

All procedures followed in this study and described in this paper were reviewed and approved by the institutional review board for the ethical treatment of human subjects at our institution, in accordance with the latest revision of the Declaration of Helsinki. Before the study, all participants read and signed an informed consent form, approved by the same review board.

Participants

An a priori power analysis was conducted using G*Power software (version 3.1.3; Heinrich Heine University, Dusseldorf, Germany). Using an effect size of 0.53, an alpha level of .05, and a desired power level of .8, we calculated the required sample size to be 15 participants. Therefore, 16 participants (10 men, 6 women) with a mean age of 21.67 ± 2.09 years, mean body mass of 74.77 ± 20.33 kg, and mean height of 173.91 ± 11.30 cm were involved in this study. Participants were recruited from a university campus. All participants had previous experience performing the push-up exercise and were without upper extremity or spine conditions within the past year. Participants were excluded if they could not exhibit full ROM in scapular-plane (~35° anterior to the coronal plane) shoulder elevation and elbow extension.

Instrumentation

Kinematic data were collected using the Fastrak 3Space magnetic-tracking system (Polhemus, Colchester, VT) , consisting of a transmitter, 3 receivers, and a digitizer. The transmitter emits an electromagnetic field that is detected by the digitizer and receivers. The system uses the strength and orientation of these signals to determine the relative position and orientation of the receivers in space. To track the movement of the shoulder and elbow during the concentric push-up ROM, 1 receiver was taped on the sternum, approximately 2.5 cm inferior to the jugular notch,[20] and 1 on the ulna, just proximal to the styloid. In addition, 1 receiver was fastened to the scapula via a custom-machined scapular-tracking device (Figure 1).[20] The base of the scapular-tracking device was fastened to adhesive-backed hook-and-loop strips positioned on the skin above and below the spine of the scapula, while the footpad of the tracker was attached to hook-and-loop strips on the superior aspect of the acromion process. The use of this instrumentation for tracking scapular kinematics has previously been validated in vivo.[21]

After the receivers were attached, various bony landmarks were digitized on the thorax, scapula, humerus, and forearm to establish the anatomical coordinate systems for these segments, in accordance with the standard endorsed by the International Society of Biomechanics.[22] The coordinate systems for the thorax and humerus were established according to the protocol described by Suprak et al.[23] The body segments and corresponding digitization points were as follows: thorax (C7, T8, jugular notch, and xiphoid process); scapula (acromioclavicular joint, root of the spine, inferior angle, and posterolateral border of the acromion); humerus (medial epicondyle, lateral epicondyle, and humeral head); forearm (ulnar and radial styloids). All landmarks could be digitized directly, except for the humeral head. The location of the center of the humeral head was estimated using an algorithm of least squares and was defined as the point that moved the least during several low-amplitude movements.[24] Movements of each segment were represented as Euler angle sequence–dependent rotations. Scapular rotations consisted of ER, followed by UR, and then PT with respect to the thorax (Figure 2).

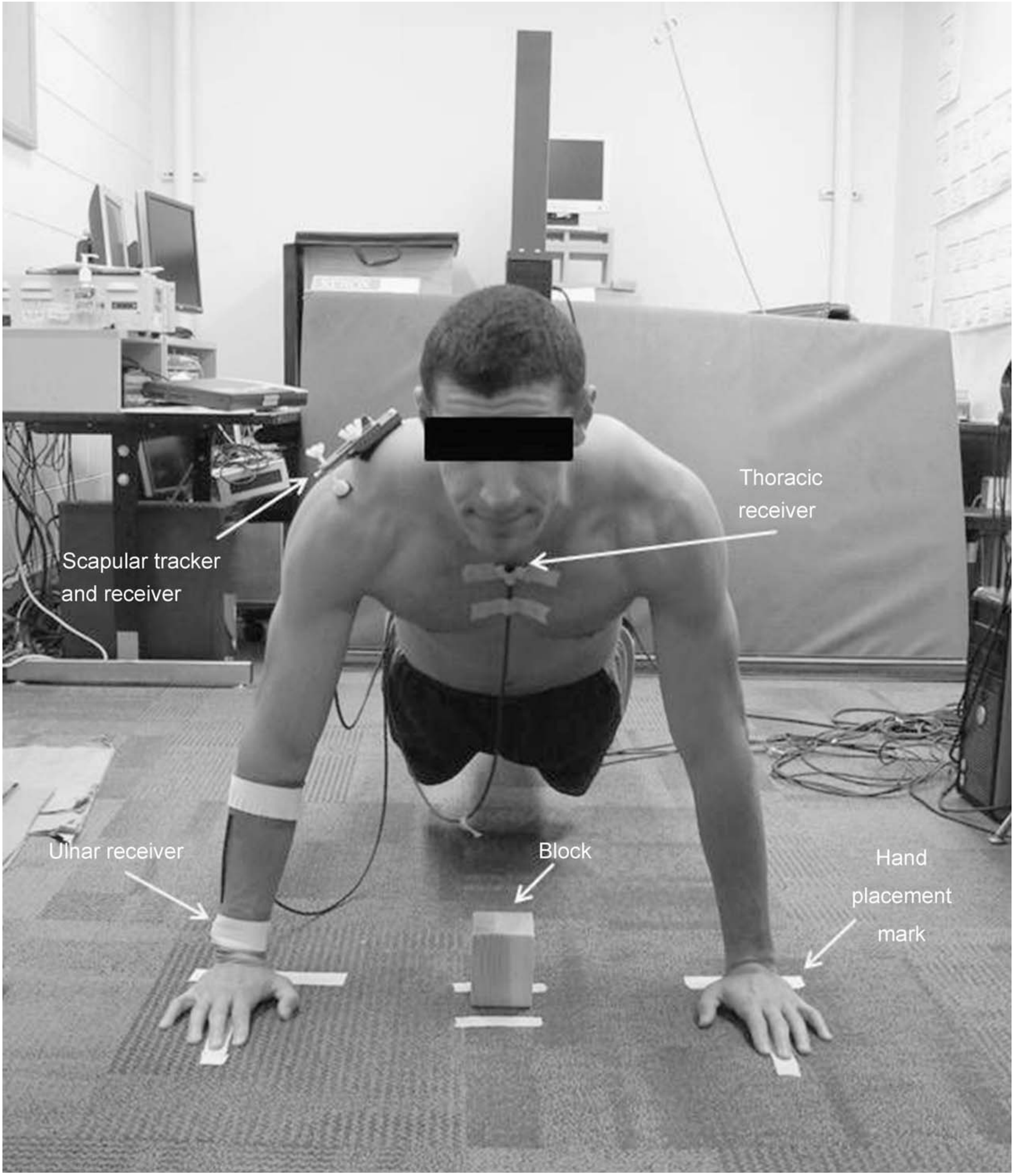

Figure 1. Experimental setup.

Rotations of the humerus with respect to the thorax consisted of the plane of elevation followed by degree of elevation. Elbow rotations were represented by a sequence of flexion, pronation, and carrying angle.[22]

Testing Procedures

All testing was completed in a single session, and data were collected from the dominant upper limb. Participants performed a standardized warm-up procedure that has been described previously.[25] The warm-up consisted of 15 repetitions each of arm circles (clockwise and counter-clockwise) and back-and-forth movement in the sagittal plane (holding a 1.13-kg weight plate), followed by static stretching of the internal and external rotators. Both arms were conditioned in this manner.

After the warm-up, participants removed their shirts (females wore sports bras) and all jewelry. They were asked to assume a traditional push-up position, supporting their weight on the hands and feet, with their hands slightly wider than shoulder width at shoulder level, the index finger aligned with the lateral portion of the acromion. The

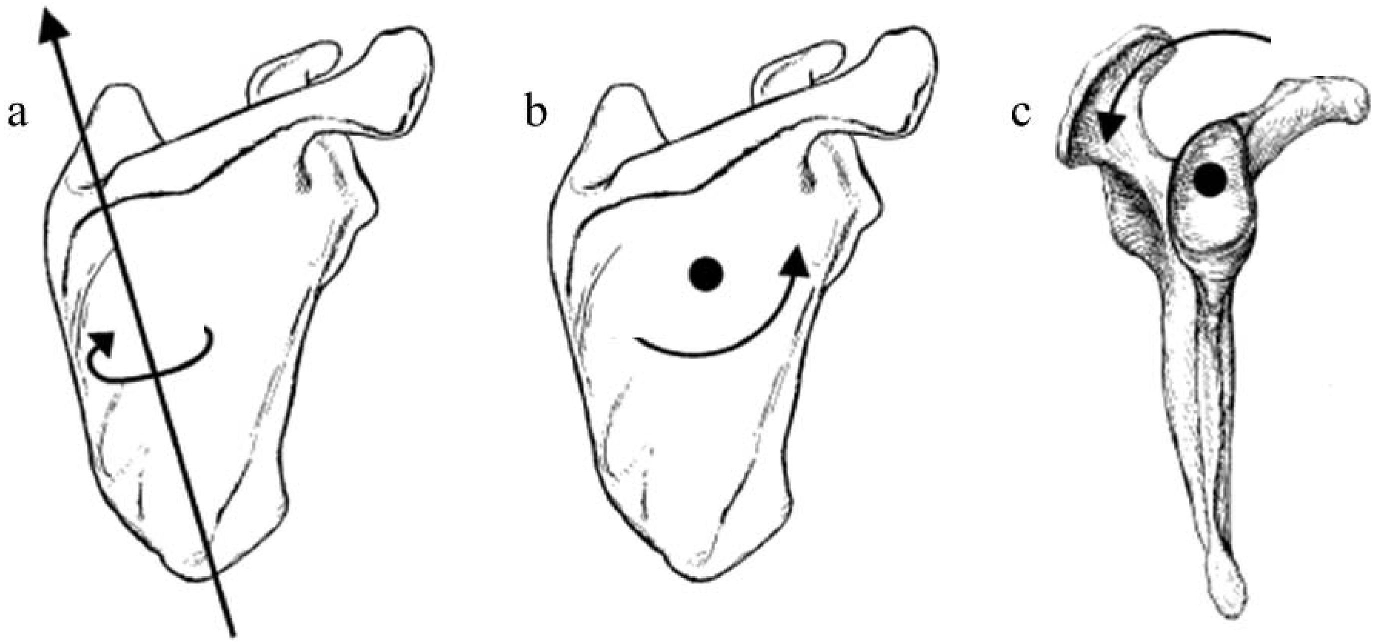

Figure 2. Depiction of scapular rotations, consisting of (A) external rotation, (B) upward rotation, and (C) posterior tilting, with respect to the thorax. Reprinted from Ebaugh DD, McClure PW, Karduna AR, Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics, *Journal of Electromyography and Kinesiology* 16:224–235, 2006, with permission from Elsevier.

position of each hand was marked on the floor with tape to standardize hand placement for each push-up trial. This was done by first placing a strip of tape horizontally (with respect to the participant's position) so that it ran along the heel of the hand making contact with the proximal borders of the thenar and hypothenar eminences). We placed another strip of tape at the end of the middle finger of each hand, which was extended to connect with the first strip of tape once the participant lifted the hand after placement. Placement of the tape was done to ensure that the hands were positioned similarly with respect to their location under the shoulders during each condition. Next, a 10-cm wood block was positioned such that when the participant was at the bottom of the push-up ROM, the block contacted the middle of the chest (Figure 1).

Once setup was complete, participants practiced performing traditional push-ups under 3 conditions of differing shoulder-elevation angles. In 1 condition, participants were asked to perform push-ups with the shoulders in a "normal," self-selected position. In the second condition, participants performed the push-up with the shoulder adducted so that the arm contacted the side of the body at the bottom of the ROM (at side). In the third condition, participants elevated the shoulder to as close to 90° as possible during the eccentric and concentric phases of the movement (elevated; Figure 3). To elevate the shoulder, most participants required some alteration of the hand position and were allowed to move so that the middle finger made an angle of up to approximately 45° with the vertically placed tape strip (Figure 3C).

In each condition of shoulder elevation, participants performed 3 repetitions to a manual count of 4 seconds (2 seconds down, 2 seconds up), contacting the block lightly at the bottom of the ROM and fully extending the elbows at the top of the ROM on each repetition. The order of presentation of each condition was randomized according to a balanced Latin square design. Conditions were separated by at least 1 minute to avoid the effects of fatigue. Few participants needed more than 1 minute of rest between trials, although some took up to 1.5 minutes of rest between trials. No participant reported any feelings of fatigue after any trial.

Data Reduction

Mean scapular rotations (PT, UR, and ER) with respect to the thorax, averaged across the 3 repetitions, were determined at 5° increments across the greatest common elbow-extension ROM (105°–35°) during the concentric portion of the push-up exercise for each condition.

Statistical Analysis

We used SPSS (version 20.0; IBM Corporation, Armonk, NY) for statistical analysis. Three 2-way repeated-measures analyses of variance (ANOVAs; 1 for each of the dependent variables, scapular PT, UR, and ER) were conducted to determine the effect of shoulder elevation and elbow position on scapular orientation. In the case of a significant interaction effect, simple effects analyses were conducted. In the case of a nonsignificant interaction and a significant main effect, post hoc analyses with a Bonferroni correction were applied.

RESULTS

Shoulder Elevation

Although we attempted to position participants in approximately 90° of shoulder elevation in the elevated condition, in practice, that was difficult to regulate

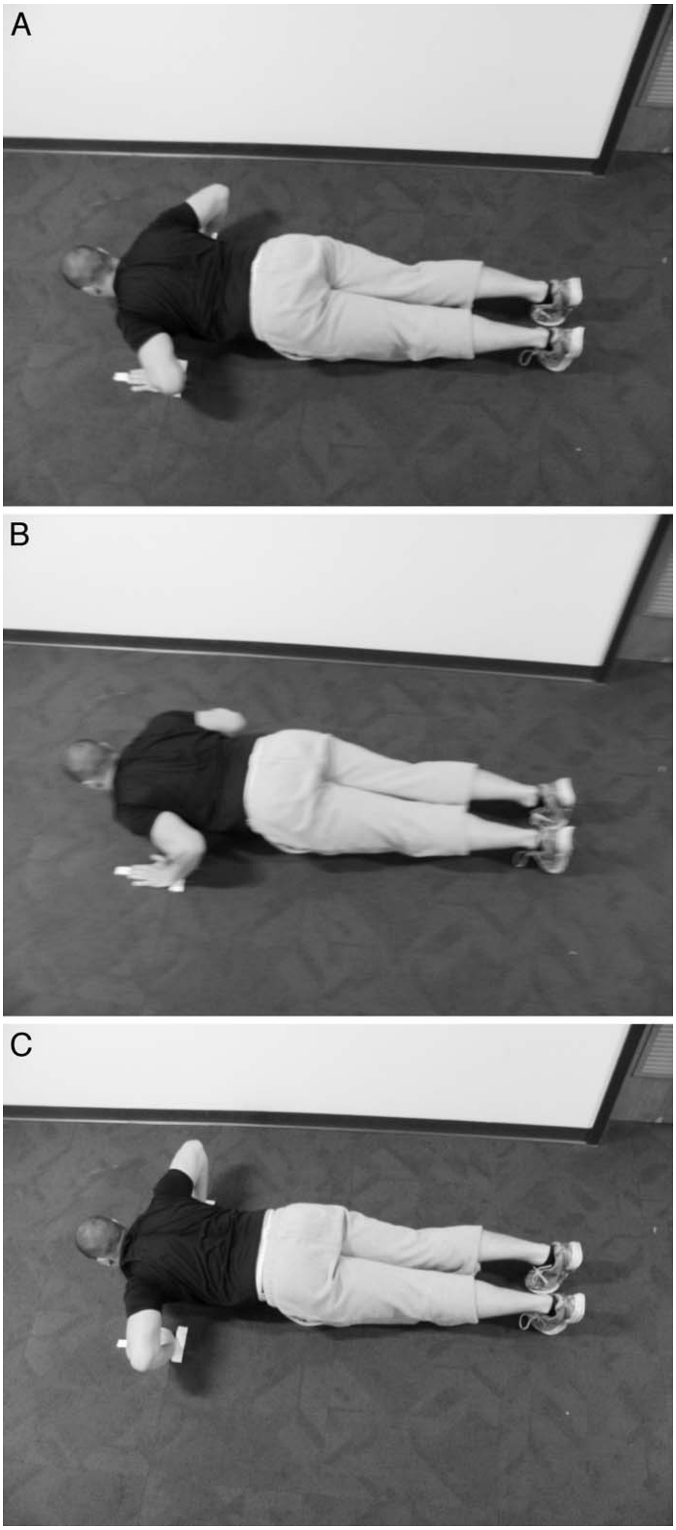

Figure 3. Shoulder positions in the (A) self-selected, (B) at-side, and (C) elevated conditions.

throughout the entire ROM. During the concentric portion of the push-up in the elevated condition, participants maintained their shoulders in an elevation angle of 64.83° ± 0.72° (mean range, 63.99°–66.04°) throughout the ROM. Participants maintained shoulder-elevation angles of 53.59° ± 1.59° (mean range, 51.07°–56.44°) and 35.54° ± 4.86° (mean range, 29.84°–44.59°) in the self-selected and at-side conditions, respectively.

Scapular Rotations

Scapular PT, UR, and ER in 10° increments across elbow ROM during the concentric portion of the push-up exercise in each condition are shown in the Table. Individual results pertaining to each of the scapular rotations are presented below.

Posterior Tilt

No interaction was found between shoulder elevation and elbow position for PT ($F_{28,420} = 0.777$, $P = .788$; Figure 4). The Mauchly test revealed that the data for scapular PT violated the assumption of sphericity for the effects of both shoulder elevation ($P = .043$) and elbow position ($P < .001$). Therefore, the Greenhouse-Geisser correction for degrees of freedom was applied for both effects. Scapular PT was affected by shoulder elevation ($F_{1.47,22.01} = 17.55$, $P < .001$). Pairwise comparisons showed that the scapula exhibited less PT in the elevated condition than in either the self-selected ($P < .001$) or at-side condition ($P = .001$). No difference was noted in PT between the self-selected and at-side conditions ($P = .210$). Posterior tilt was affected by elbow position ($F_{1.12,16.78} = 4.69$, $P = .042$), demonstrating a linear increase with elbow extension, as indicated by polynomial contrast ($P = .046$).

Upward Rotation

An interaction effect was found between shoulder elevation and elbow position on scapular UR ($F_{28,420} = 5.9$, $P < .001$; Figure 5). Simple effects analyses revealed an effect of shoulder elevation at each level of elbow position ($P < .001$ for all analyses).

External Rotation

No shoulder elevation by elbow position interaction was seen for scapular ER ($F_{28,420} = 1.26$, $P = .30$; Figure 6). The Mauchly test revealed that the data for scapular ER violated the assumption of sphericity for the effects of both shoulder elevation ($P = .01$) and elbow position ($P < .001$). Therefore, the Greenhouse-Geisser correction for degrees of freedom was applied for both main effects. A main effect of shoulder elevation was noted for ER ($F_{1.36,20.41} = 5.97$, $P = .016$). Pairwise comparisons showed that ER was greater in the self-selected and at-side conditions as compared with that in the elevated condition ($P = .001$ and $P = .046$, respectively). No difference was seen between ERs in self-selected and at-side positions ($P = 1.0$). The ANOVA also revealed an effect of elbow position on ER ($F_{1.22,18.25} = 134.73$, $P < .001$). The polynomial contrast revealed a linear decrease in ER with elbow extension ($P < .001$).

DISCUSSION

Many variants of the push-up exercise are commonly prescribed in the clinical setting to correct faulty scapular control due to shoulder conditions. Frequently, this practice is supported in the literature by the high serratus anterior activation relative to that of the upper trapezius. However, very little is known about the kinematic pattern of the

Table. **Scapular Posterior Tilt, Upward Rotation, and External Rotation at 10° Increments Across the Elbow Extension Range of Motion[a] (Mean ±SEM)**

Position	Elbow Flexion, °							
	105	95	85	75	65	55	45	35
Posterior tilt								
Elevated								
Mean	−19.72	−19.22	−18.96	−18.59	−18.24	−17.71	−17.28	−16.68
SEM	2.12	2.15	2.18	2.29	2.30	2.36	2.40	2.43
Self-selected								
Mean	−17.08	−16.41	−16.10	−15.74	−15.59	−15.20	−14.99	−14.71
SEM	2.22	2.11	2.15	2.15	2.21	2.25	2.26	2.30
At side								
Mean	−16.19	−15.40	−14.84	−14.53	−14.22	−14.03	−13.64	−13.20
SEM	2.41	2.43	2.45	2.47	2.47	2.45	2.53	2.57
Upward rotation								
Elevated								
Mean	21.58	21.04	20.20	19.04	18.12	16.91	15.47	13.71
SEM	2.87	2.74	2.67	2.64	2.65	2.67	2.71	2.77
Self-selected								
Mean	19.88	19.52	19.11	18.50	17.69	16.70	15.31	14.05
SEM	3.09	2.95	2.85	2.86	2.80	2.71	2.75	2.79
At side								
Mean	18.92	19.87	19.90	19.46	18.93	17.77	16.27	14.40
SEM	2.56	2.53	2.52	2.55	2.61	2.70	2.83	2.91
External rotation								
Elevated								
Mean	−46.27	−48.62	−50.81	−53.05	−55.17	−57.47	−60.05	−62.56
SEM	3.13	3.12	3.00	2.98	2.95	2.89	2.90	2.79
Self-selected								
Mean	−44.50	−46.91	−48.87	−51.00	−52.93	−55.03	−57.29	−59.54
SEM	3.16	3.19	3.11	3.09	3.14	3.16	3.10	3.07
At side								
Mean	−44.17	−46.53	−48.64	−50.68	−52.56	−54.67	−56.99	−59.19
SEM	3.05	3.09	3.12	3.17	3.15	3.15	3.04	2.99

[a] Negative numbers indicate movement in the opposite direction.

scapula during these exercise variants. Our purpose was to examine the effect of shoulder-elevation condition (self-selected versus at side versus elevated) on scapular kinematic patterns (PT, UR, and ER) across elbow-extension ROM during the concentric portion of a traditional push-up. We hypothesized that increasing shoulder elevation would result in increased UR, PT, and ER, a common pattern reported in the literature for scapular

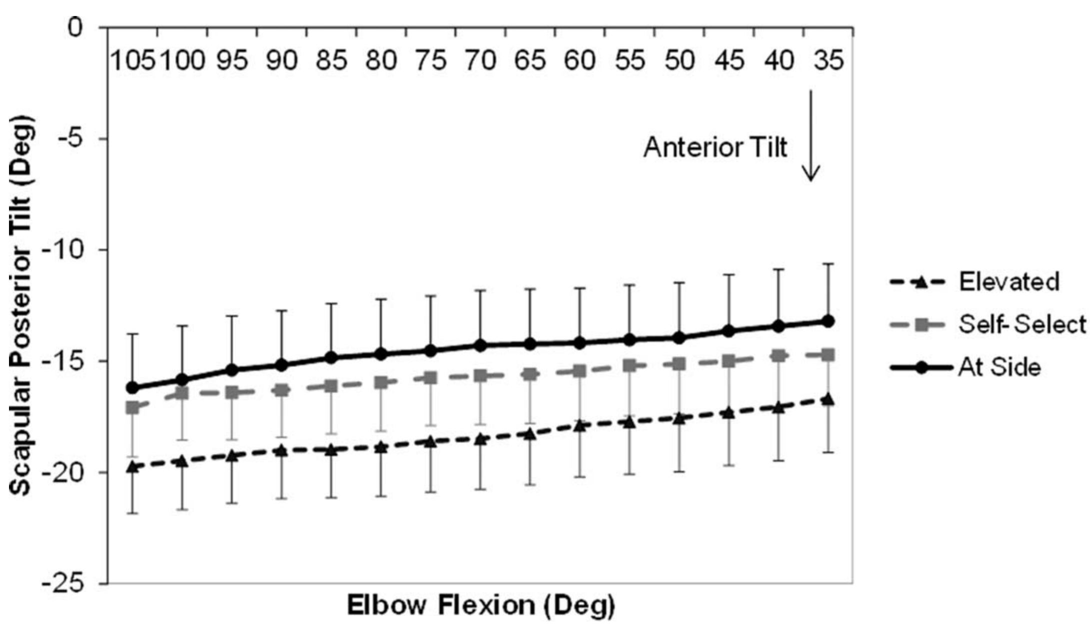

Figure 4. Effect of altering the shoulder-elevation angle on scapular posterior tilt across the range of motion of elbow extension (mean ± SEM).

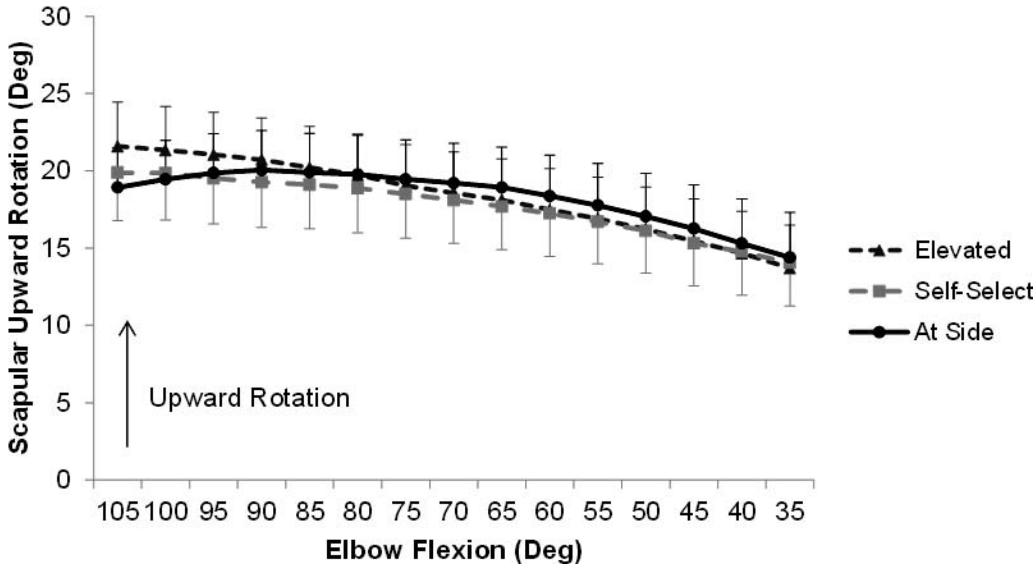

Figure 5. Effect of altering the shoulder-elevation angle on scapular upward rotation across the range of motion of elbow extension (mean ± SEM).

rotations with increased arm elevation.[2] However, this hypothesis was not supported by the current data. We found greater PT in both the self-selected and at-side positions compared with that in the elevated position across elbow-extension ROM. Our participants also showed greater PT in the at-side condition compared with the self-selected condition, but this difference was not significant. Further, we found an interaction of shoulder elevation by elbow position on UR, indicating greater UR in the beginning of the ROM of elbow extension in the elevated position compared with that in the self-selected and at-side positions and greater UR in the middle ROM of elbow extension in the at-side position compared with that in the self-selected and elevated positions. Finally, we observed greater ER in the self-selected and at-side positions than in the elevated position. Actually, in no condition did the scapula ever achieve an externally rotated or posteriorly tilted position, but the positions were expressed with respect to the degree of ER and PT, respectively, in order to conform to accepted biomechanical conventions of scapular rotations.

In the only other investigation of scapular kinematics during a variation of the push-up exercise, Lunden et al[19] reported some similarities in scapular kinematics during a wall push-up plus to the data presented here. At the beginning of the concentric phase of the wall push-up, as well as in all conditions of the traditional push-up in our study, the scapula was in a position of anterior tilt, UR, and internal rotation. During the exercise in the present study, and the push-up phase in Lunden et al,[19] the data from both studies indicate an overall decrease in ER across the ROM. Although our data indicated a different pattern of UR in the

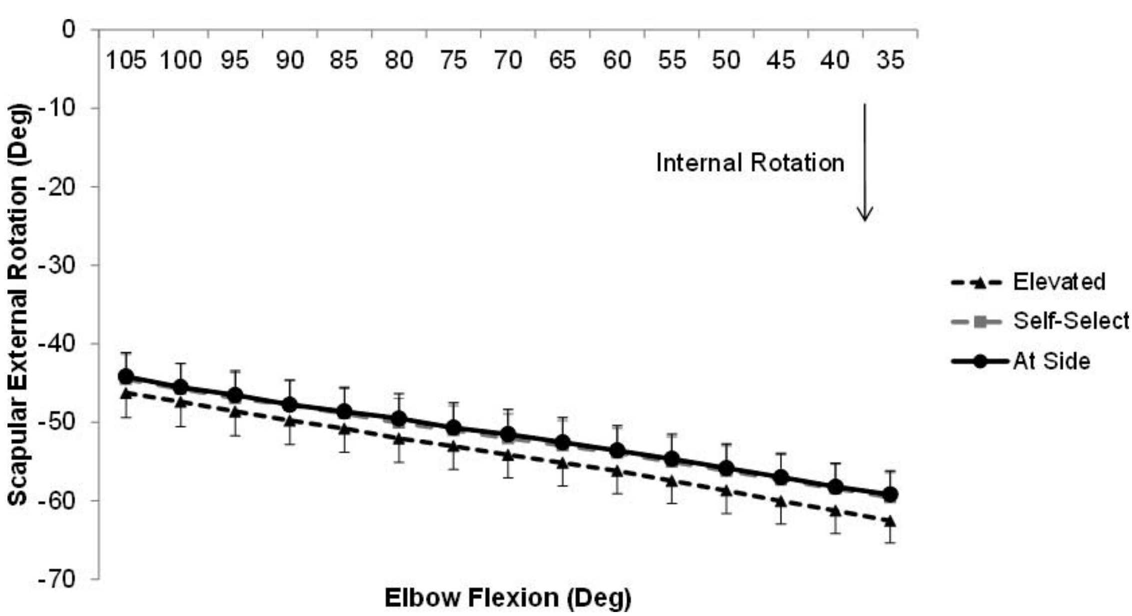

Figure 6. Effect of altering the shoulder-elevation angle on scapular external rotation across the range of motion of elbow extension (mean ± SEM).

at-side condition than in the other 2 conditions, the main pattern across the ROM was for the scapula to decrease UR.

Some differences exist, however, between our data and those of Lunden et al.[19] Compared with their data, the present data indicated that the scapula may exhibit less PT (~15°), less ER (~10°), and similar UR in a traditional push-up compared with a wall push-up. Our observation of less PT is somewhat surprising, given the higher upper trapezius/serratus anterior ratio reported in the literature in the wall push-up than in the traditional push-up.[13] Also, Lunden et al[19] noted no change in PT during the concentric phase of the wall push-up, whereas we observed increased PT in the traditional push-up. These differences may be a function of the greater weight-bearing demand in the traditional push-up and the resulting activation levels of the scapular-stabilizing musculature, as well as the fact that Lunden et al[19] studied static positions within the ROM, whereas we tracked scapular rotations across the ROM during a dynamic movement. Because it is difficult to compare data directly across multiple studies, future authors should examine both scapular kinematics and muscle-activation patterns in these 2 exercises, using similar experimental setups, to resolve this apparent contradiction. Given that the percentage of the body mass supported by the upper extremity decreases with elbow extension in the traditional push-up[17] and probably to a greater degree than in the wall push-up because of the large difference in torque about the center of rotation (feet) exerted by the center of mass, the ability of the serratus anterior to cause PT in the presence of high upper trapezius activation[12] may improve as the elbow extends. This speculation should be explored in the future.

In the present study, we observed less PT with the shoulder in the elevated position than in the self-selected or at-side positions. This result may be due to differential upper trapezius and serratus anterior activation patterns with shoulder elevation under load. Decker et al[9] reported similar serratus anterior activity during the traditional and modified push-up–plus exercises, although they noted greater force output in the traditional variant. The modified push-up is characterized by less arm elevation and weight-bearing demand than the traditional push-up.[17] Therefore, similar serratus anterior activation coupled with greater weight-bearing demand in the traditional push-up and greater shoulder elevation may result in upper trapezius activation in the elevated condition for which the serratus anterior cannot compensate. Because of the role of the serratus anterior in PT, UR, and ER, this possible imbalance between the upper trapezius and serratus anterior would lead to a relatively high upper trapezius-serratus anterior ratio and may at least partially explain a lower degree of PT in the elevated position. It is also possible that the pectoralis minor undergoes a greater degree of passive lengthening in the elevated condition compared with the self-selected and at-side conditions, and combined with its own activation, results in less PT.[26]

The ER was greater in the self-selected and at-side conditions compared with the elevated condition. As with PT, the greater ER in the self-selected and at-side conditions may also be explained by the upper trapezius-serratus anterior ratio and pectoralis minor length and activation. In the elevated position, the upper trapezius may have been more activated than in the other conditions,[2] resulting in superior scapular translation[13] and subsequent pectoralis minor lengthening,[26] leading to greater scapular internal rotation. These possible effects should be explored in the future. The linear decrease in ER with elbow extension across all conditions was an expected result, given the natural protraction that happens in the movement. This effect was not different across elevation conditions.

Upward rotation showed a different pattern in the at-side condition than in the self-selected and elevated conditions. The scapula began the push-up motion in a more downwardly rotated position in the at-side position than the other 2 positions and quickly became more upwardly rotated as the elbow began extending. After this initial increase in UR in the at-side condition, it followed a pattern similar to that of the other conditions throughout the remainder of the ROM. This is consistent with the data regarding humeral elevation in the scapular plane.[27] Although in the at-side condition, the shoulder remained well below the elevation angles of the other 2 conditions across the ROM, the scapula upwardly rotated early in the concentric phase, catching up with that in the other conditions, and possibly indicating a sharp rise in serratus anterior activation in an attempt to stabilize the scapula, allowing for humeral elevation. However, given the paucity of electromyographic (EMG) data in the literature related to elevation angles in the push-up exercise and its variants, as well as the absence of EMG measurements in this study, these proposed mechanisms remain speculative and should be studied in the future.

In rehabilitating patients with shoulder dysfunction, the objective is to select exercises that maximize serratus anterior activation and minimize upper trapezius activation, while placing the scapula in a position that alleviates stress on subacromial structures.[28] To date, much of the research in the literature on variants of the push-up and other open and closed kinematic chain exercises used in the rehabilitation setting has focused on muscle activation of the rotator cuff and scapular-stabilizing muscles. These authors have reported the prominent role of serratus anterior activation in the push-up and push-up–plus exercises, greater rotator cuff muscle activation with greater weight-bearing in closed chain exercises,[29] lower upper trapezius-serratus anterior ratios in stable exercises as compared with exercises performed on unstable surfaces, the relationship between shoulder elevation and serratus anterior activation during closed chain exercises,[9] and a greater upper trapezius-serratus anterior ratio in the wall push-up compared with the traditional push-up, among other findings. However, very little work has been done examining the scapular kinematics associated with these exercises. The current data indicate that shoulder-elevation angle has an effect on PT and ER, and that, when performing a traditional push-up in a position of elevation above 60°, the scapula may impinge subacromial structures. Coupled with the inconsistent pattern of UR across elevation positions, these results suggest that performing a traditional push-up with the shoulders elevated may be disadvantageous for a patient attempting to strengthen the shoulder musculature while avoiding further stress to the subacromial structures. In addition, asymptomatic individuals may also benefit from avoiding positions of shoulder elevation when performing a traditional push-up and similar exercises.

Our study had several limitations. First, elbow flexion was reported for only the ROM between 105° and 35° during the concentric phase. It would have been desirable to examine scapular kinematics over the entire elbow-flexion ROM during the push-up, and that was our original intention. However, elbow ROM during the push-up varied considerably among participants in our sample, although all had full shoulder and elbow ROM. This variability may have been due to differences in carrying angle or muscle lengths during movement execution. Also, elbow ROM varied across shoulder position conditions, with the smallest ROM observed in the elevated condition. In order that the discussion of the results could be easily referenced to actual elbow-joint angles, and therefore points within the ROM, we chose to analyze those data with respect to the smallest common ROM (105°–35°). Yet even with this limited ROM, we believe that we are still able to observe the pattern of scapular movement over a large proportion of the movement and make appropriate conclusions.

Second, we did not collect EMG data, which limits our ability to definitively conclude why we observed these scapular kinematic patterns. Although many authors have investigated the activation patterns of several rotator cuff and scapular muscles during shoulder elevation and push-up variants, very little is known about the behavior of these muscles over the ROM during push-up exercises. This information must be ascertained before more concrete conclusions can be drawn about the relative appropriateness of the push-up variants examined in the present study.

Third, the participants in this study were all healthy individuals, with full shoulder and elbow ROM and without any injury to the upper extremity and spine. Extrapolation of the current data to patient groups must be done with caution, as scapular kinematic patterns are known to be altered in patients with shoulder conditions.

CONCLUSION

Performing the traditional push-up in a position of shoulder elevation may place the scapula in a position resulting in decreased subacromial space volume, possibly contributing to symptoms of impingement, and further damage for those with symptoms. For the rehabilitation setting, as well as for asymptomatic individuals, we recommend prescribing traditional push-ups with the arms in a self-selected position or at the side, rather than elevated above 60°. Clinicians should be cognizant that the self-selected position for some individuals may exceed 60°, as we observed, and may advise those individuals to assume a less-elevated position. The participants in this study were without upper extremity dysfunction, so the results should be applied to injured populations with caution. These results should be confirmed in participants with shoulder injuries.

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