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Shoulder Coordination During Full-Can and Empty-Can Rehabilitation Exercises

Xavier Robert-Lachaine, PhD*; Paul Allard, PhD*; Veronique Gobout, MD†; Mickael Begon, PhD*

*Department of Kinesiology, Montreal University, QC, Canada; †Centre Hospitalier Universitaire de Montréal (CHUM), Notre-Dame Hospital, Montreal, QC, Canada

Context: Supraspinatus tear is a common rotator cuff injury. During rehabilitation, debate persists regarding the most appropriate exercises. Whereas shoulder coordination is part of normal arm function, it has been infrequently considered in the context of exercise selection.

Objective: To assess shoulder-motion coordination during 2 common supraspinatus rehabilitation exercises and to characterize load and motion-direction influences on shoulder coordination.

Design: Descriptive laboratory study.

Setting: Motion-analysis laboratory.

Patient or Other Participants: Fifteen asymptomatic right-hand–dominant men (age = 26 ± 4 years, height = 1.77 ± 0.06 m, mass = 74.3 ± 7.7 kg).

Intervention(s): Full-can and empty-can exercises with and without a 2.27-kg load.

Main Outcome Measure(s): We recorded motion with an optoelectronic system. Scapulohumeral rhythm and complete shoulder joint kinematics were calculated to quantify shoulder coordination. The effects of exercise type, load, motion direction, and humerothoracic-elevation angle on the scapulohumeral rhythm and shoulder-joint angles were assessed.

Results: We observed multivariate interactions between exercise type and humerothoracic elevation and between load and humerothoracic elevation. Scapulohumeral rhythm increased by a mean ratio of 0.44 ± 0.22 during the full-can exercise, whereas the addition of load increased mean glenohumeral elevation by 4° ± 1°.

Conclusions: The full-can exercise increased the glenohumeral contribution, as hypothesized, and showed normal shoulder coordination. During the empty-can exercise, the increased scapulothoracic contribution was associated with a compensatory pattern that limits the glenohumeral contribution. Using loads during shoulder rehabilitation seems justified because the scapulohumeral rhythm is similar to that of unloaded arm elevation. Finally, motion direction showed a limited effect during the exercises in healthy individuals.

Key Words: kinematics, shoulder joint, scapulohumeral rhythm, supraspinatus muscle

Key Points

- The full-can exercise increased scapulohumeral rhythm, which was in line with normal shoulder function.
- The empty-can exercise demonstrated increased scapulothoracic contribution, which is associated with a compensation pattern that limits glenohumeral motion.
- Handheld load increased glenohumeral elevation in healthy participants.
- The raising and lowering phases of the exercise resulted in negligible differences in shoulder-joint coordination in healthy individuals.

From 30% to 70% of shoulder pain is attributable to rotator cuff disorders.[1,2] During rotator cuff rehabilitation, progressive exercises are used to recover upper limb function. Shoulder coordination (ie, motion interactions between joints) is often overlooked in rehabilitation protocols but is considered part of normal arm function.[3–5] Shoulder coordination can be quantified with simultaneous observation of complete shoulder kinematics and scapulohumeral rhythm (SHR). The SHR corresponds to the ratio of the glenohumeral (GH) contribution over the scapulothoracic (ST) contribution, where the angular contribution represents the amount of upper extremity elevation that a joint achieves.[6] Patients with rotator cuff tears compensate for the loss of GH motion with more ST motion.[3] Similarly, patients with frozen shoulder or GH osteoarthritis increase their ST upward rotation to achieve upper extremity elevation.[4,7] Fayad et al[4] suggested using SHR as an indicator of the compensation occurring in shoulder coordination. Pathologic shoulder conditions affecting the GH joint seem to diminish the contribution of this joint during upper extremity elevation and create an imbalance in SHR.

In the rotator cuff, the supraspinatus has an important role in GH stabilization and elevation throughout its range of motion.[8] To return shoulder coordination to normal after a supraspinatus injury, exercises should focus on the recovery of GH function. However, the exercises traditionally used in rehabilitation were not originally based on shoulder coordination and often lack an anatomical basis in their design, as shown with shoulder rehabilitation tests.[9] The rehabilitation program is linked closely to the musculoskeletal examination, which typically considers range of motion, pain, and qualitative force.[10] Several clinical exercises have been proposed to strengthen the supraspinatus, but choosing these exercises based on muscle recruitment remains controversial. Whereas electromyography (EMG) is not linearly related to muscle force, authors[11,12] of EMG studies have reported that, by elevating the upper extremity in full internal rotation up to 90° in the scapular plane, the empty-can exercise better engages the supraspinatus. In contrast, some investigators[13,14] have suggested that the full-can exercise, during which the upper extremity is elevated in external rotation up to 90° in the scapular plane, could better activate the supraspinatus muscle. The choice of a proper rehabilitation exercise should not rely solely on muscle recruitment, as no exercise can fully isolate the supraspinatus.[15] Shoulder coordination analysis directly addresses upper extremity functional mechanics and EMG indicates muscular activity. The greater supraspinatus EMG activity observed during the empty-can exercise[11,12] may be related to less effective mechanical leverage, necessitating more supraspinatus activation to achieve upper extremity elevation with internal rotation, and may be detrimental to rehabilitation.[16]

The only motion-analysis study of both exercises was limited to the ST joint, and the authors[8] showed that the empty-can exercise induced less posterior tilt, more internal rotation, and a more rapid increase in upward rotation. These changes were related to a decrease in supraspinatus outlet volume, and the full-can exercise was deemed safer without consideration of GH kinematics. Yet exercises with external loads, such as dumbbells, are clinically accepted during shoulder rehabilitation.[17] Whereas external load is known to affect muscle recruitment, its effect on shoulder coordination is controversial, with researchers reporting no effects,[18] increases in ST upward rotation,[17,19,20] or decreases in ST upward rotation and higher SHR ratios.[21,22] However, for rehabilitation exercises, the effect of external load on shoulder kinematics is usually not assessed directly. Another concern is the influence of the motion direction. Whereas investigators often focus on upper extremity raising,[6,21,22] it remains unclear why scapular dyskinesis is more easily detected on clinical examination during the lowering phase.[23] Some researchers[24–26] have shown similar patterns in the kinematics of the 2 phases. Yet other authors have reported increases in ST upward rotation,[27,28] internal rotation,[29] and posterior tilt[29] for the lowering phase. Based on these findings, we remain uncertain about the effect of motion direction on shoulder coordination.

Therefore, the purpose of our study was to determine the influence of rehabilitation exercises on shoulder coordination and specifically to compare the shoulder kinematics and SHR of the full-can and empty-can exercises. We hypothesized that the contribution of the GH joint would be greater during the full-can exercise because researchers[8] have shown that the empty-can exercise more rapidly increases upward rotation, which should increase the ST contribution. The secondary objectives were to analyze the effects of load and motion direction on shoulder coordination during these exercises.

METHODS

Participants

Fifteen asymptomatic men (age = 26 ± 4 years, height = 1.77 ± 0.06 m, mass = 74.3 ± 7.7 kg) participated. All participants self-reported right-hand dominance, and none had a history of pain, injury, fracture, or instability in any shoulder joint at the time of the experiment. A kinesiologist (physical activity professional X.R.L.) with 5 years of experience in qualitative and quantitative analysis of shoulder biomechanics screened for the exclusion criteria: humerothoracic (HT) range-of-motion limitations in flexion and abduction (>160°), shoulder pain or visible scapular dyskinesis during repeated active raising and lowering of the upper extremity in flexion, or abduction planes in line with the test described by McClure et al[30] and Tate et al.[31] All participants provided written informed consent, and the study was approved by the Université de Montréal Ethics Committee.

Participant Preparation

We explained the experimental protocol to the participants. Next, they performed a 3-minute warm-up consisting of 3 sets of 5 upper extremity elevations in the frontal, scapular, and sagittal planes of elevation without load to familiarize themselves with the protocol. They were instructed to maintain the trunk in a stable, upright posture, and they received feedback about the plane of elevation. We told them to maintain a controlled, steady pace of approximately 2 seconds to raise and lower the limb.

Participant setup included 27 reflective markers placed over the pelvis (n = 4), trunk (n = 6), clavicle (n = 4), scapula (n = 4), upper arm (n = 5), and lower arm (n = 4); markers were positioned to reduce soft tissue artefact (Figure 1). We placed 4 or 5 markers on each segment instead of the minimum 3 markers because the increased number of markers decreased the mean absolute relative distance in the estimation of segment orientation.[32]

Data Collection

Marker trajectories were tracked by an 8-camera system (model 512; Vicon Motion Systems Ltd, Oxford, United Kingdom) at 60 Hz. Each participant stood barefoot in the standardized position: the upper extremity was by his side, his heels were aligned and spaced approximately 0.18 m apart, and the midlines of the feet were pointing outward 7°. His dominant extremity was tested. We recorded a static position; the participants stood with the upper extremity relaxed along the side of the body and without tension in the shoulder girdle. Specific movements for the sternoclavicular (SC), acromioclavicular (AC), and GH joints and elbow axis, including shoulder roll, shrug, upper extremity elevation in many planes, circumduction, and elbow flexion, were performed to allow us to functionally locate joint centers.[33] The participants were instructed to elevate their upper extremities following a vertical pole with a diameter of 5 cm that guided the elevation in the *scapular plane*, defined as 40° anterior to the frontal plane. The full-can exercise was carried out with the extremity in external rotation with the thumb pointing upward toward the ceiling. During the empty-can exercise, they maintained the extremity in internal rotation with the thumbs pointing downward toward the floor. Two sets of 5 repetitions each of full-can and empty-can elevations in the scapular plane were carried out in random order. The exercises were performed without load and then repeated with a 2.27-kg dumbbell to avoid inducing fatigue before

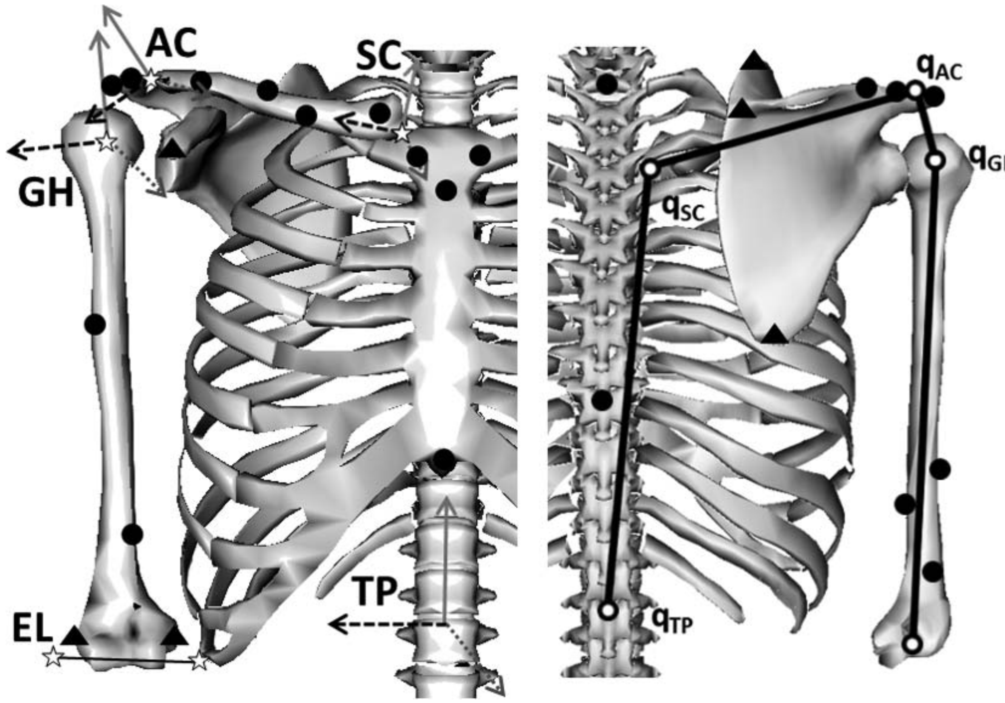

Figure 1. Schematic representation of degrees of freedom (q) of the thoracopelvic (TP), sternoclavicular (SC), acromioclavicular (AC), and glenohumeral (GH) joints in the chain model with the technical (•) and anatomical (▲) marker placement; the functional joint centers (☆); and the elbow-flexion axis (EL). The x, y, and z axes of the coordinate systems are represented by the dotted grey, plain grey, and dashed black arrows, respectively.

the unloaded condition. The dumbbell mass corresponds to the external load commonly used in the last phase of rehabilitation protocols.[34,35] Given the relatively low load for healthy men and the few repetitions and sets, a 30-second rest between sets was deemed sufficient to avoid fatigue effects.[8,36] Each participant was instructed to reach his head's height to obtain at least 90° of HT elevation and then to lower his extremity to the initial position. Angles greater than 90° were not analyzed because of the difficulty of reaching these in the empty-can condition. Furthermore, the first and last repetitions of each condition were excluded from the analysis.[8] We also excluded the 0° to 15° range from the analysis because of gimbal lock occurrences. A gimbal lock occurs when 2 axes of rotation are driven into a parallel configuration, making it impossible to measure all 3 rotations.

Kinematics Reconstruction

The joint kinematics reconstruction was achieved in accordance with the kinematic chain defined in the Jackson et al[37] model to improve joint kinematics based on ball-and-socket joints and marker redundancy (Figure 1). A kinematic chain imposes constraints on the motions at joints with 3 degrees of freedom and no translation, which has been shown to overcome the problem of apparent joint dislocation.[38] From the static position, a reference posture was computed by adjusting the elbow axis parallel to the scapular spine and the longitudinal axis of the humerus parallel to that of the thorax with a GH joint correction (joint angle = 0°). The forearm markers were used in the reconstruction to help estimate upper extremity axial rotation, similar to the lower limb kinetic chain model.[38] The center of rotation of the shoulder joints and the axis of rotation of the elbow were obtained using a functional approach to personalize the model.[33] Additional markers were placed on anatomical landmarks of the SC and AC joints, trigonum spinae, angulus inferior scapulae, and humeral epicondyles. They were used in a static position to define anatomical systems of coordinates according to the International Society of Biomechanics recommendations.[39] The Cardan angle sequence for the SC (retraction, elevation, and posterior rotation) and AC (internal rotation, upward rotation, posterior tilt) joints and the Euler angle sequence for the GH joint (plane of elevation, elevation, internal rotation) were used as recommended.[39] Notable differences are that we placed the origins of the SC and AC joints at the functionally determined centers instead of the palpated landmarks and that we used the functional axis of rotation of the elbow rather than the axis between the epicondyles.

Calculation of SHR

Instead of relying on only the isolated ST upward-rotation and GH-elevation angles, we used a new method of joint contribution to upper extremity elevation for SHR calculation.[6] Given that the reference posture represents no contribution to upper extremity elevation, joints were reset successively to the reference configuration to calculate the amount of limb elevation with respect to the thorax achieved by each joint contribution. Next, we calculated the SHR as a ratio of the GH contribution angle to the ST contribution angle. This approach reduces intersubject variability, which is known to be a concern.[6]

Table 1. Intrarater Within-Day Reliability With Intraclass Correlation Coefficients (SEM) of Scapulohumeral Rhythm and Shoulder Kinematics During the Full-Can Exercise Without Load

		Humerothoracic-Joint Elevation					
		Raising			Lowering		
Variable	Kinematics	30°	60°	90°	90°	60°	30°
Scapulohumeral rhythm		0.93 (0.2)	0.94 (0.1)	0.95 (0.2)	0.98 (0.1)	0.96 (0.2)	0.93 (0.2)
Sternoclavicular joint							
	Retraction	0.95 (1.1)	0.95 (1.3)	0.95 (1.2)	0.94 (1.2)	0.96 (0.9)	0.94 (1.1)
	Elevation	0.92 (0.6)	0.93 (0.5)	0.92 (0.8)	0.92 (1.0)	0.95 (0.7)	0.93 (0.7)
	Posterior rotation	0.97 (1.9)	0.96 (2.3)	0.94 (3.0)	0.94 (3.3)	0.97 (2.0)	0.97 (2.1)
Acromioclavicular joint							
	Internal rotation	0.96 (0.6)	0.95 (0.8)	0.97 (0.8)	0.96 (1.2)	0.92 (1.4)	0.95 (0.9)
	Upward rotation	0.99 (1.1)	0.98 (1.4)	0.94 (2.2)	0.93 (1.8)	0.98 (1.6)	0.97 (1.7)
	Posterior tilt	0.95 (1.1)	0.94 (1.0)	0.95 (1.2)	0.95 (1.1)	0.96 (1.5)	0.94 (1.4)
Glenohumeral joint							
	Plane of elevation	0.96 (2.9)	0.97 (2.8)	0.96 (2.6)	0.95 (2.8)	0.96 (2.8)	0.95 (2.5)
	Elevation	0.95 (0.6)	0.96 (0.7)	0.95 (1.0)	0.97 (0.9)	0.96 (1.1)	0.95 (1.1)
	External rotation	0.98 (1.7)	0.96 (1.9)	0.99 (1.4)	0.99 (1.2)	0.99 (1.6)	0.98 (1.8)

Reliability

Intrarater reliability of the measures was assessed with intraclass correlation coefficients (3,1) and the SEM. We calculated the SEM as the square root of the mean square error term from the 2-way analysis of variance. The tests were conducted on each dependent variable across 1 repetition from the first and second sets of trials (within day, trial to trial). The tests were repeated at 30°, 60°, and 90° of HT elevation for both the raising and lowering phases.

Statistical Analysis

A 4-way repeated-measures multivariate analysis of variance was performed to compare the SHR ratio and the 9 joint angles from the SC, AC, and GH shoulder joints. The 4 factors were exercise type (full can, empty can), load (0 kg, 2.27 kg), motion direction (raising, lowering), and HT-elevation angle (30°, 60°, 90°). Normality was verified with Lilliefors tests to justify the use of parametric statistics. Multivariate differences for all analyses were determined by the Wilks Λ test. We set the α level a priori $\leq$ .05. The univariate tests were observed for each dependent variable when multivariate interactions were found. Sphericity was assessed with the Mauchly test, and when not met, the Huynh-Feldt correction was used. The interactions of interest were limited to HT-elevation angle with the other 3 factors to contrast their dynamic effect. When we observed a univariate interaction, we tested post hoc simple main effects with the Bonferroni adjustment for the pairwise comparisons to determine where the differences occurred. We used SPSS (version 21.0; IBM Corporation, Armonk, NY) for all statistical analyses.

RESULTS

The reliability analysis showed excellent intraclass correlation coefficient values for all dependent variables, with a range of 0.92 to 0.99 (Table 1). The SEM of the SHR varied from 0.1 to 0.2. The SEM values were generally less than 2° for shoulder kinematics, with a maximum of 3.3° in SC anterior rotation reached at 90° of the lowering phase.

The multivariate analysis revealed an interaction between exercise type and HT elevation ($F_{20,34} = 9.639$, $P < .001$), between load and HT elevation ($F_{20,34} = 2.764$, $P = .004$), and between motion direction and HT elevation ($F_{20,34} = 4.686$, $P < .001$; Table 2).

Scapulohumeral Rhythm

A univariate interaction was present between exercise type and HT elevation for the SHR ($F_{2,28} = 5.377$, $P = .02$), with a simple main effect for exercise type observed at 60° ($P = .01$) and 90° ($P = .006$). From 20° to 90°, the mean ratio was 0.44 $\pm$ 0.22 higher for the full-can exercise than for the empty-can exercise (Figure 2). This difference was more noticeable during upper extremity raising. During limb lowering, exercises demonstrated a cross-interaction, with SHR lower at 30° but higher at 60° and 90° for the full-can exercise. The addition of load increased the mean ratio of the SHR, especially at 30° by 0.37 $\pm$ 0.24. We observed a univariate interaction between motion direction and HT elevation ($F_{2,28} = 5.312$, $P = .03$).

Sternoclavicular Joint

We noted a univariate interaction between exercise type and HT elevation for SC retraction ($F_{2,28} = 28.603$, $P <$ .001), elevation ($F_{2,28} = 29.492$, $P < .001$), and posterior rotation ($F_{2,28} = 6.763$, $P = .004$). Post hoc tests showed differences between exercises at 30° ($P = .03$) and 90° ($P =$ .05) for SC retraction (cross-interaction), at the 3 levels of HT elevation ($P \leq .001$) for SC elevation, and at 60° ($P =$ .007) and 90° ($P < .001$) for SC posterior rotation. The empty-can exercise increased SC elevation by 3° compared with the full-can exercise (Figures 3 and 4). A univariate cross-interaction between load and HT elevation was present for SC elevation ($F_{2,28} = 10.438$, $P = .002$), where it increased more rapidly with load.

Acromioclavicular Joint

We observed a univariate interaction between exercise type and HT elevation for AC internal rotation ($F_{2,28} =$ 15.080, $P < .001$) and upward rotation ($F_{2,28} = 13.593$, $P <$ .001). Mean AC upward rotation was 4° $\pm$ 2° higher during the empty-can exercise than during the full-can exercise (Figures 3 and 4). We demonstrated simple main effects between exercises at 30° ($P < .001$) and 60° ($P < .001$) for AC internal rotation and at 60° ($P < .001$) and 90° ($P <$

Table 2. Statistical Results of the Multivariate Analysis of Variance

Interaction	Kinematics	Humerothoracic Joint: Elevation × Exercise Type: P	Power	Partial η^2	Elevation × Load: P	Power	Partial η^2	Elevation × Motion Direction: P	Power	Partial η^2
Multivariate		<.001[a]	1.000[a]	0.850[a]	.004[a]	0.983[a]	0.619[a]	<.001[a]	1.000[a]	0.734[a]
Univariate										
Scapulohumeral rhythm		.02[a]	0.716[a]	0.251[a]	.31	0.212	0.086	.03[a]	0.631[a]	0.290[a]
Sternoclavicular joint										
	Retraction	<.001[a]	0.999[a]	0.688[a]	.12	0.362	0.166	.25	0.240	0.100
	Elevation	<.001[a]	1.000[a]	0.694[a]	.002[a]	0.938[a]	0.445[a]	.15	0.378	0.134
	Posterior rotation	.004[a]	0.884[a]	0.342[a]	.36	0.172	0.071	.24	0.289	0.103
Acromioclavicular joint										
	Internal rotation	.001[a]	0.968[a]	0.537[a]	.28	0.218	0.092	.01[a]	0.786[a]	0.334[a]
	Upward rotation	<.001[a]	0.995[a]	0.511[a]	.02[a]	0.721[a]	0.258[a]	.27	0.271	0.096
	Posterior tilt	.40	0.152	0.061	.045[a]	0.563[a]	0.246[a]	.35	0.222	0.078
Glenohumeral joint										
	Plane of elevation	.80	0.059	0.006	.04[a]	0.589[a]	0.275[a]	.057	0.515	0.230
	Elevation	<.001[a]	0.985[a]	0.464[a]	<.001[a]	0.995[a]	0.588[a]	.07	0.528	0.186
	External rotation	<.001[a]	1.000[a]	0.698[a]	.48	0.121	0.045	.047[a]	0.593[a]	0.209[a]

[a] Indicates difference.

.001) for AC upward rotation. We found a univariate interaction between HT elevation and load for AC upward rotation ($F_{2,28} = 4.527$, $P = .02$) and posterior tilt ($F_{2,28} = 4.248$, $P = .045$), with simple main effects at 60° ($P = .04$) and 90° ($P = .02$) for AC upward rotation. During the exercises, the handheld load induced a mean increase of 3° ± 2° on AC upward rotation and a mean maximum difference of 3° ± 2° on AC posterior tilt. A univariate interaction between motion direction and HT elevation was present for AC internal rotation ($F_{2,28} = 6.522$, $P = .01$), with simple main effects at the 3 levels of HT elevation ($P < .05$).

Glenohumeral Joint

A univariate interaction between exercise type and HT elevation was observed for GH elevation ($F_{2,28} = 11.270$, $P < .001$) and GH external rotation ($F_{2,28} = 30.007$, $P < .001$). The mean GH elevation was 3° ± 1° higher during the full-can exercise than during the empty-can exercise, with a maximum difference of 6° ± 1° at 90° of HT elevation (Figures 3 and 4). We noted simple main effects between exercises at 60° ($P = .004$) and 90° ($P < .001$) for GH elevation. The difference in GH external rotation corresponded to the different instructions we gave participants about upper extremity rotation in the empty-can and full-can exercises. We found a univariate interaction between HT elevation and load for GH elevation ($F_{2,28} = 18.569$, $P < .001$), with simple main effects at 30° ($P = .005$) and 60° ($P = .03$). The addition of load during the exercises resulted in a mean increase of 4° ± 1° in GH elevation.

DISCUSSION

Our objective was to assess shoulder coordination during common supraspinatus rehabilitation exercises. We used SHR and shoulder-joint kinematics to assess shoulder coordination during the empty-can and full-can exercises. The interaction between exercise type and the angle of HT elevation for SHR and 7 of the 9 joint angles highlighted the altered coordination.

Exercise Type

Rotator cuff muscle forces maintain the humeral head within the glenoid fossa and prevent excessive GH translation.[40] The SHR reflects the balance between the

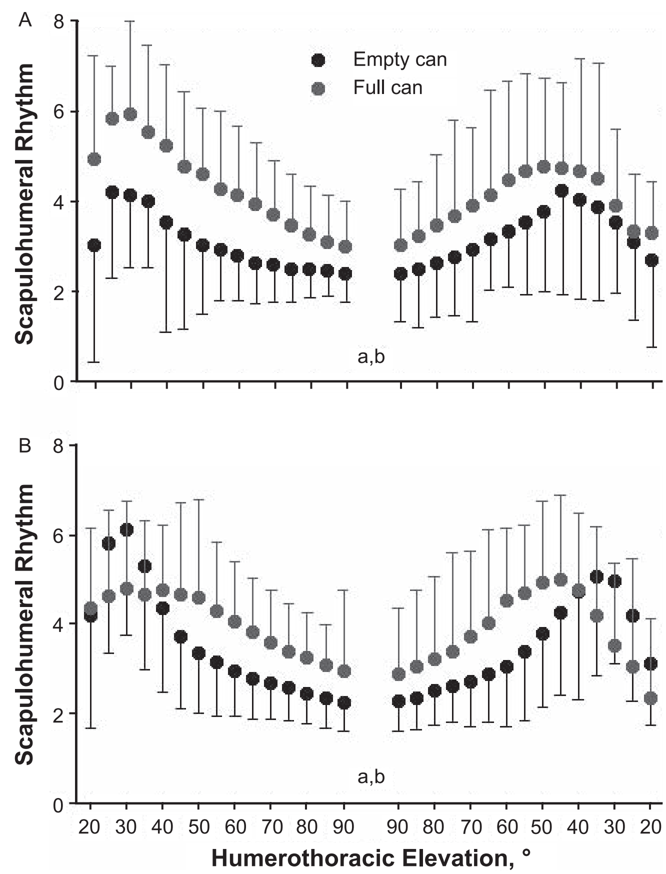

Figure 2. Scapulohumeral rhythm ratio (mean ± standard deviation) at each 5° increment of humerothoracic elevation between 20° and 90° in the scapular plane for the raising and lowering phases with, A, 0 kg, and B, 2.27 kg. [a] Indicates univariate interaction between humerothoracic elevation and exercise type. [b] Indicates univariate interaction between humerothoracic elevation and motion direction.

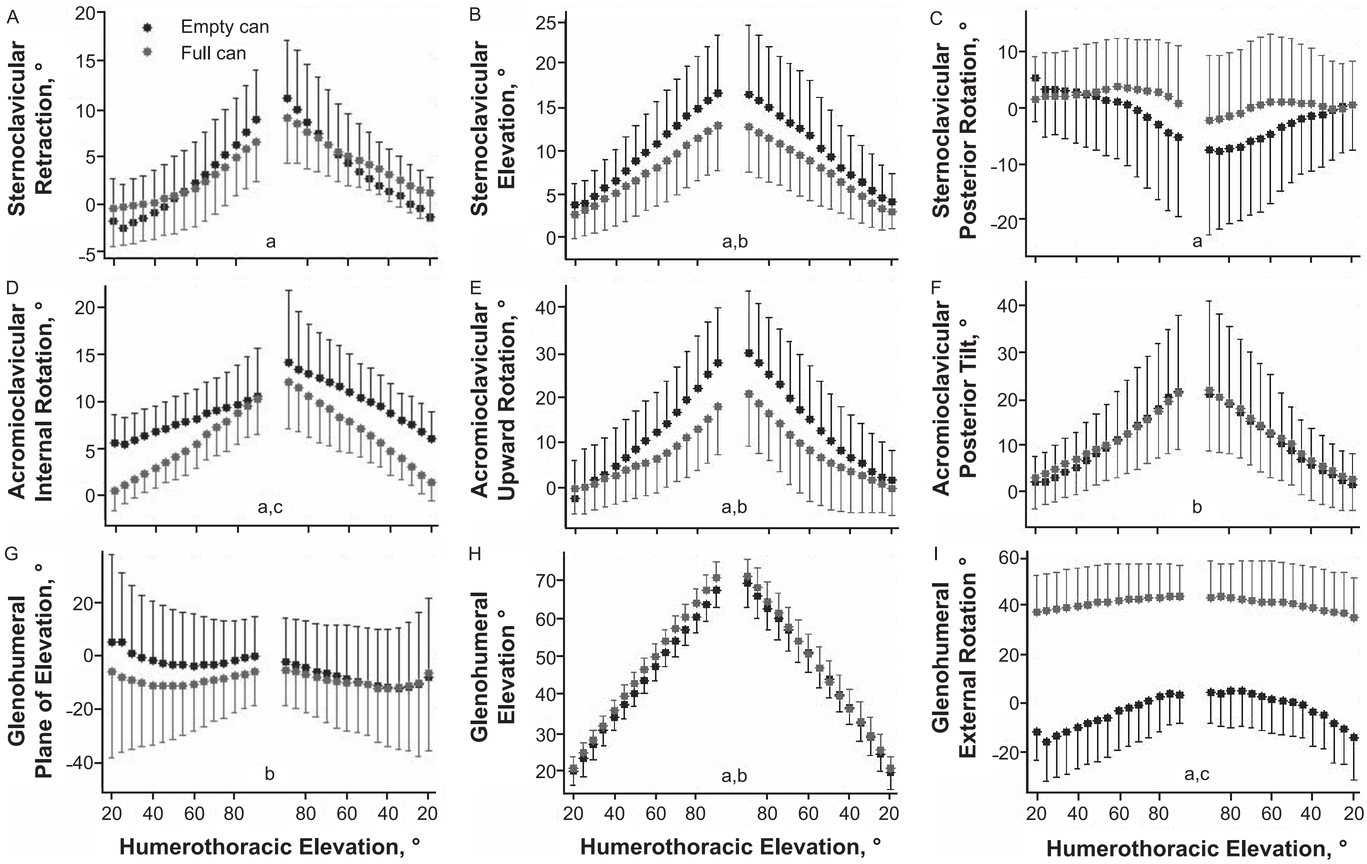

Figure 3. Shoulder kinematics (mean ± standard deviation) at the, A–C, sternoclavicular, D–F, acromioclavicular, and G–I, glenohumeral joints for each 5° increment of humerothoracic elevation between 20° and 90° in the scapular plane for the raising and lowering phases without load. [a] Indicates univariate interaction between humerothoracic elevation and exercise type. [b] Indicates univariate interaction between humerothoracic elevation and load. [c] Indicates univariate interaction between humerothoracic elevation and motion direction.

GH and ST motions during upper extremity elevation. Pathologic rotator cuff conditions change shoulder coordination, generally reducing the SHR.[3,4,7] To regain normal shoulder function after supraspinatus injury, GH motion should be emphasized during exercises. A greater GH contribution, such as in the full-can exercise, may reflect adequate supraspinatus use with GH stabilization to achieve upper extremity elevation. In contrast, an excess of ST motion could jeopardize shoulder stability, as the supraspinatus is activated improperly during upper extremity elevation.

In the only previous investigation of kinematics during these exercises, Thigpen et al[8] observed more ST posterior tilt and ST internal rotation during the full-can exercise. In our study, AC internal rotation and SC posterior rotation were higher during the full-can exercise, which is similar to the findings of Thigpen et al.[8] The full-can exercise increased the SHR as hypothesized. It also allowed more GH contribution, especially at 60° and 90° of upper extremity elevation, as indicated by a greater GH-elevation angle; GH elevation is the most influential rotation of the GH contribution. This range corresponded to the functional range of motion in need of improvement.[41] However, the empty-can exercise increased the ST contribution, as reflected by greater SC elevation and AC upward rotation. This latter coordination is not an aim of shoulder rehabilitation and demonstrates a compensatory pattern that limits GH contribution, as suggested by Fayad et al.[4]

Patients learning proper shoulder coordination potentially could attain a long-term improved functional outcome. A 6-week exercise program in participants with anterior shoulder posture leads to an increased GH contribution to upper extremity elevation and SHR.[42] This latter study showed that shoulder coordination can be monitored through intentional exercise. Maintaining adequate GH and ST contributions to upper extremity elevation is essential because pathologic GH conditions are often associated with overuse of the ST joint.[3,4,7] The scapula gives the shoulder stability and must rotate to allow continued arm elevation with proper GH alignment. The full-can exercise appears more suitable for a supraspinatus rehabilitation program because it solicits the GH contribution during upper extremity elevation and consequently increases the SHR. This recommendation agrees with observations of other authors who suggested the empty-can exercise is prone to causing subacromial impingement[8,13] because the combination of upper extremity elevation and humeral internal rotation decreases the size of the subacromial space.[43] Nevertheless, the timing of the full-can exercise should be considered, as open chain exercises with the elbow fully extended increase the torque on the shoulder[44] and seem more appropriate for the last phases of rehabilitation.

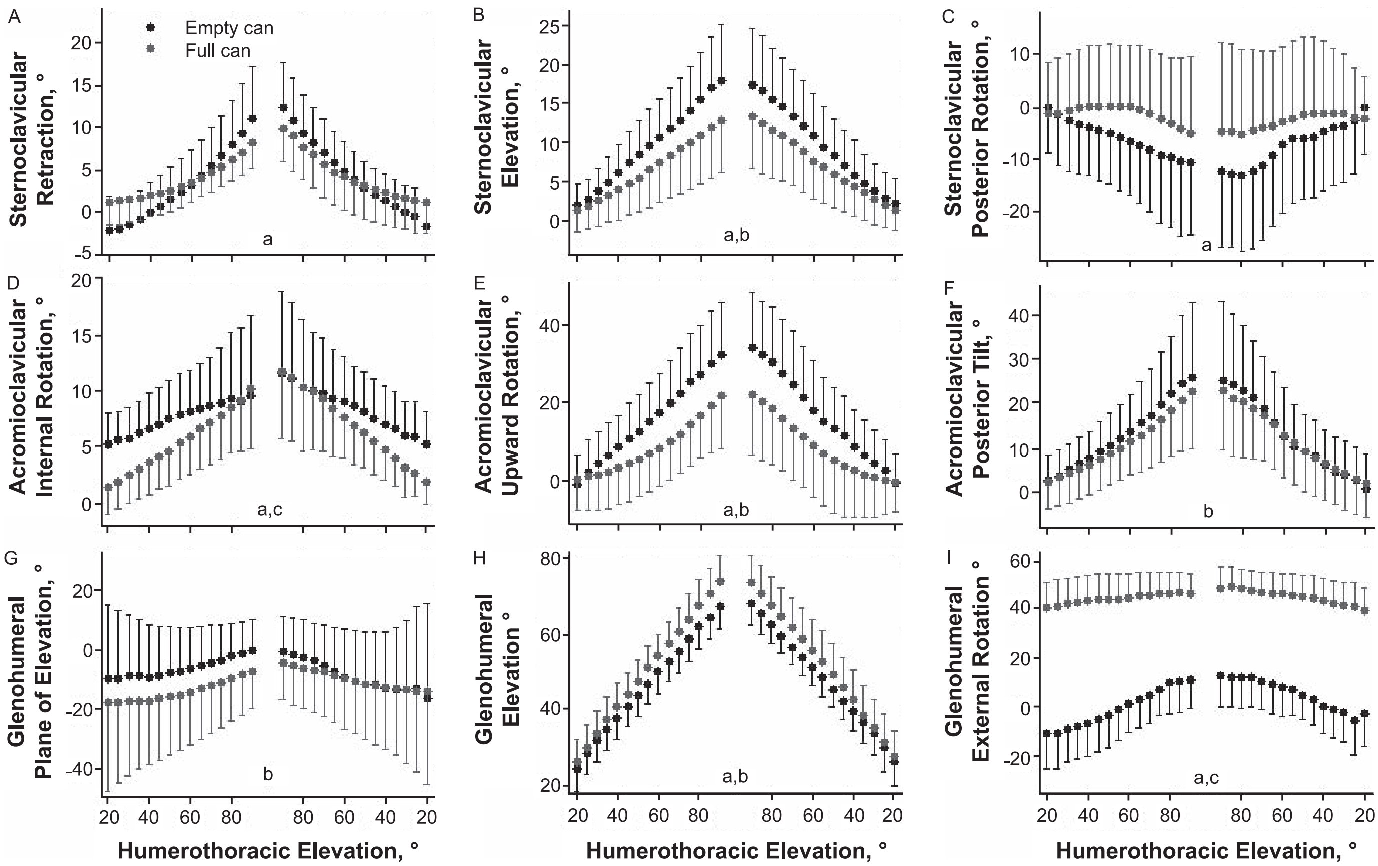

Figure 4. Shoulder kinematics (mean ± standard deviation) at the A–C, sternoclavicular, D–F, acromioclavicular, and G–I, glenohumeral joints for each 5° increment of humerothoracic elevation between 20° and 90° in the scapular plane for the raising and lowering phases with a handheld 2.27-kg load. [a] Indicates univariate interaction between humerothoracic elevation and exercise type. [b] Indicates univariate interaction between humerothoracic elevation and load. [c] Indicates univariate interaction between humerothoracic elevation and motion direction.

Humeral internal rotation increases SC retraction and AC internal rotation at the onset of the movement and could be related to posterior capsule tension.[45] The subsequent upper extremity elevation requires more SC elevation and AC upward rotation and less GH elevation to allow sufficient subacromial space for the movement to continue. External rotation is crucial for clearance of the greater tuberosity as it passes under the coracoacromial arch and for relaxation of the capsular ligaments to allow GH elevation.[45] At 90° of upper extremity abduction with internal rotation, magnetic resonance imaging has shown that the minimal acromiohumeral distance passes through the supraspinatus precisely where most rotator cuff tears occur, suggesting mechanical impingement in this position.[46] This position creates a superiorly directed shear force,[47] causing superior translation of the humeral head, because the rotator cuff does not adequately compress the humerus within the glenoid fossa to counteract the deltoid superior action force.[13]

Load

The full-can and empty-can exercises were executed with a handheld 2.27-kg load and without load to measure the effect of external load on shoulder coordination in asymptomatic men. Given that load did not affect SHR and increased GH elevation in healthy individuals, exercises with load could improve both muscle strength and shoulder coordination. The addition of load led to 3° more AC upward rotation and 4° more GH elevation. These results suggest that patients aiming to regain normal shoulder coordination should not compensate with the ST joint during loaded exercises. The SHR did not show an interaction between load and HT elevation, which agrees with reports in previous studies[18,19] but contrasts with recent findings of higher SHR with load[17,21]; however, we observed an increase in SHR with load from 4.2 to 4.6 at 30° only. The effect of load on shoulder coordination remains to be tested on symptomatic participants. Loading should be progressive during rehabilitation to strengthen the affected structure and avoid overstrain while shoulder coordination is addressed.

Motion Direction

Based on our findings, motion direction in healthy participants did not clinically affect shoulder coordination during full-can and empty-can exercises. Few kinematic differences were observed according to motion direction, which is consistent with recent results.[24–26] Yet researchers have identified kinematic differences, mainly increasing ST upward rotation during upper extremity lowering.[27–29] In our study, GH elevation and the SHR decreased slightly during the lowering phase, but the values remained within the SEM. Given that pathologic shoulder conditions can alter shoulder coordination,[3,4,7] developing such symmetry in motion direction during rehabilitation remains relevant.

Observed differences in motion direction may help us to identify pathologic conditions and later recovery, when raising and lowering coordination are similar.

Attention must be given to the smaller arm-elevation angles of the lowering phase, where SHR decreased rapidly, especially with load. Participants may have inhibited their muscular activation and let the scapula descend by itself. Whereas not problematic for healthy individuals, rehabilitating patients should be instructed to control the scapula until the very end of the lowering phase to maintain stability while the supraspinatus is eccentrically active.

We studied a homogeneous population of healthy men. Therefore, the results may not be directly generalizable to women or symptomatic populations. A patient can react differently to conditions than a healthy individual because patients present high intersubject variability. Clinical application should be individualized, and previous findings can serve as guidelines. Although the use of technical markers (4 to 5 markers per segment), the kinematic chain, and functional joint centers is intended to permit accurate measurement of joint kinematics, soft tissue artefact remains a concern with noninvasive approaches. Some rotations should be interpreted cautiously due to the use of skin markers, such as when SC posterior rotation reaches a maximum SEM of 3.3°.

CONCLUSIONS

When open chain exercises are introduced in the rehabilitation process, the full-can exercise must be emphasized to ensure functional shoulder recovery. Indeed, the full-can exercise increased the SHR in line with normal shoulder coordination. In contrast, the empty-can exercise showed an increased ST contribution, which is associated with a compensatory pattern that limits GH motion. Handheld load increased the GH elevation in healthy participants, suggesting that patients should not compensate with the ST joint during loaded exercises to achieve normal coordination. Differences between the raising and lowering phases of the exercise, which are absent in healthy individuals, could serve to identify pathologic conditions or to guide the rehabilitation process.

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Address correspondence to Xavier Robert-Lachaine, PhD, Department of Kinesiology, Montreal University, 1700 Jacques Tétreault, Laval, QC H7N 0B6, Canada. Address e-mail to xavier.robert-lachaine@umontreal.ca.