Title	The effect of trunk rotation during shoulder exercises on the activity of the scapular muscle and scapular kinematics
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Title: The effect of trunk rotation during shoulder exercises on the activity of the scapular muscle and scapular kinematics

Running title: Trunk rotation during shoulder exercises

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Abstract

Background: In patients with shoulder pathology, kinetic chain exercises including hip or trunk movement are recommended. However, the actual muscle activation and scapular kinematics of these exercises are not known. The purpose of this study was to examine the effect of trunk rotation on shoulder exercises that are devised to improve scapular function.

Methods: Thirteen healthy young men participated in this study. Scaption, external rotation in the 1st and 2nd position, and prone scapular retraction at 45°, 90°, and 145° of shoulder abduction were performed with and without trunk rotation. Electromyography was used to assess the scapular muscle activity of the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT) and serratus anterior (SA), and electromagnetic motion capture was used to assess scapular motion. The muscle activity ratio, which is the activity of the UT to the MT, LT, and SA were calculated. These data were compared between two conditions (with and without trunk rotation) for each exercise.

Results: Adding trunk rotation to scaption, the 1st and the 2nd external rotation significantly increased scapular external rotation and/or posterior tilt, and all three exercises increased LT activation. Additionally, trunk rotation with scapular retraction at 90° and 145° of shoulder abduction significantly decreased the UT/LT ratio.

Conclusions: Our findings suggest that shoulder exercises with trunk rotation in this study may be effective in patients who have difficulty in enhancing LT activity and suppressing excessive activation of the UT, and/or in cases where a decreased scapular external rotation and/or posterior tilt is observed.

Level of evidence: Basic Science, Kinesiology Study

Key words: shoulder exercise; kinetic chain; trunk rotation; rehabilitation; scapular kinematics; muscle activation ratio

Introduction

Appropriate movement of the scapula is crucial for preventing shoulder injuries caused by accumulated minimal stress on the soft tissues surrounding the glenohumeral joint.[3, 5-8, 13, 20-23, 25, 26, 34] Inadequate scapular movements and positions are known to be a commen cause of shoulder dysfunction or pain, and recovery of scapular control plays a key role in shoulder rehabilitation.[3, 13, 21, 25, 26, 34] A previous review examining the scapular kinematics during shoulder elevation indicated that many studies found decreased upward rotation, posterior tilt, and increased internal rotation of the scapula during shoulder elevation.[26] Therefore, exercises in which the scapula moves into upward rotation, external rotation (ER), or posterior tilt are very important.[24, 30, 32]

Proper scapular motion during arm elevation is achieved by force couples provided by the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA).[5-7, 14, 16, 22, 23, 25, 36] UT and SA act in scapular upward rotation, UT in scapular elevation, and SA in scapular protraction.[16] The MT and LT resist the SA during scapular protraction, and the LT resists the UT during scapular elevation; as a result, the MT and LT maintain the position of scapula and build an axis of scapular upward rotation.[16] In addition, LT activity increases at ≥90° of arm elevation and is important for scapular posterior tilt.

A failure in cooperative activation of scapular muscles, including hyperactivity of the upper trapezius (UT) in combination with poor activity of the middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA), leads to inadequate scapular motion and shoulder pathologies.[5-7, 25, 36] Therefore, the relative activity of the UT with respect to the MT, LT, and

SA; i.e., the muscle activation ratios of the UT/LT, UT/MT, and UT/SA; are of particular importance.[5, 25, 36]

Previous studies investigating the role of the scapula in shoulder pathology have focused on scapular muscle activation during shoulder rehabilitation exercises; many have evaluated activation using electromyography (EMG).[5, 22, 23, 32] However, scapular kinematics during such exercises are not well known. Oyama et al.[32] investigated scapular kinematics and muscle activity during six scapular retraction exercises. They reported that scapular retraction with the shoulder ER at 90° abduction, and with shoulder ER at 45° abduction increased in scapular ER, upward rotation, and posterior tilt.[32] By knowing the scapular kinematics during exercises from these biomechanical studies, clinicians can obtain valuable information needed for selecting proper exercises for patients with shoulder pathologies.[32, 35]

Recently, kinetic chain exercises including the hip and trunk extension or diagonal movement pattern in scapular retraction exercises are drawing attention because such exercises activate the scapular muscles, in particular the LT.[22, 23, 27] Nagai et al. examined the effect of trunk rotation added to shoulder flexion exercise in the sitting position, and reported that scapular kinematics and muscle activity were changed with trunk rotation.[31]

They reported that the ipsilaterally rotated trunk position during humeral elevation increased scapular ER and upward rotation, while a contralaterally rotated trunk position caused higher UT and SA activity and lower LT activity. In view of their research, shoulder exercises with ipsilateral trunk rotation may induce desirable scapular motion and muscle activation. However, to the best of our knowledge, no study has examined scapular movement along with the muscle activity and muscle activation ratio during various shoulder exercises with trunk rotation.

The aim of this study was to compare the scapular kinematics and muscle activity during various shoulder exercises with and without trunk rotation.

Materials and Methods

This is a cross sectional basic science kinesiology study comparing scapular kinematics and muscle activity during various shoulder exercises with and without trunk rotation.

Participants

Thirteen healthy young men (mean age, 21.5 ± 1.5 years; mean height, 172.5 ± 8.2 cm; and mean weight, 65.2 ± 7.4 kg) with no history of shoulder pathology or any complaint participated in this study. All subjects were right-handed, and the dominant shoulder was tested. The study protocol well was explained, and all subjects were fully consented with the study.

Instrumentation

Three-dimensional kinematic data was obtained from the thorax, humerus, and scapular using an electromagnetic motion capture system (Liberty, Pohlemus, Colchester, Vermont, USA) operating at a sampling rate of 120 Hz. Its System Electronics Unit generates and senses the electromagnetic fields and computes the location and orientation of each sensor. A global coordinate system was established from a transmitter fixed on a board. Electromagnetic sensors were attached on the skin overlying the sternum, acromion, midpoint of the humerus (via a molded thermoplastic cuff), and the styloid process of ulna of the dominant arm. Next, in order to establish the anatomically based local coordinate systems (LCSs), the bony landmarks of the subjects were palpated and established using the Liberty sensor stylus with an embedded electromagnetic sensor while they stood with their arms hanging at their side. Each LCS was defined according to the recommendations of the International Society of Biomechanics (ISB) [37]. The C7 spinous process, sternal notch, xiphoid process, and T8 spinous process were used to define the LCS of the thorax; the acromial angle, trigonum scapulae, and inferior angle were used to define the LCS of the scapula; the midpoint of the thermoplastic cuff on the humerus and the medial/lateral epicondyles were used to define the LCS of the humerus; and the medial/lateral epicondyles and ulnar styloid were used to define the LCS of the forearm. Previous studies have shown that 3-dimensional scapular kinematics can be assessed using this method with high accuracy in humeral elevation angle less than 120°.[18, 28]

EMG activities were collected with a sampling rate of 1,500 Hz by using the Telemyo DTS Telemetry system (Noraxon Inc., Scottsdale, AZ, USA). EMG activities and kinematic data obtained from the electromagnetic sensor were synchronized using a manual trigger. Four muscles (UT, MT, LT, and SA) that play key roles in scapular control were chosen for analysis. After the electrode sites were shaved and cleaned with scrubbing gel and alcohol, electrodes with 2-cm center-to-center inter-electrode distance were applied to the skin overlying each muscle of the dominant arm according to the SENIAM recommendations[14] and a previous study.[2] We chose these four muscles because these muscles are involved in scapular control. [5, 7, 22, 23, 32, 33]

The UT electrode was placed at 50% on the line from the acromion to the spine on vertebra C7; the MT electrode was placed at 50% between the medial border of the scapula and the spine at the level of T3; the LT electrode was placed at 2/3 on the line from the trigonum spinea to the 8th thoracic vertebra; and the SA electrode was placed over the 7th rib on the anterior axillary line.

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Procedures

Each subject performed a series of six exercises with or without trunk rotation in a random order to avoid systematic influences of fatigue and learning effects. The exercises are presented in Figs. 1 and 2. We examined functional shoulder exercises performed in the standing position with and without hip and trunk rotation, and scapular retraction exercises were performed in the prone position, which is a common MT/LT exercise, with and without trunk rotation. Each exercise was chosen for the following reasons. Scaption was chosen because it is a basic arm elevation exercise. We chose the 1st ER because LT was activated without excessive UT activity.[5, 31] Further, the 2nd ER was chosen because this exercise involves an action similar to the late-cocking phase of the throwing motion.[12] Retraction exercises at 45, 90, and 145 were chosen because these exercises increased scapular ER, upward rotation, posterior tilt, and LT activation.[30]

With the dominant arm, subjects performed exercises initiating at the start position to the end position, i.e., up to the end range of motion. All exercises were performed in three phases—a concentric phase for 2 seconds, isometric phase for 1 second, and eccentric phase for 2 seconds—with time controlled by a metronome. For exercises with trunk and hip rotation, subjects were instructed to ipsilaterally and maximally rotate their trunk and hip for exercises performed in the upright position (i.e., scaption, the 1st ER, and the 2nd ER) simultaneously with upper limb motion. Subjects were instructed to rotate their trunk without moving their pelvis for exercises performed in the prone position (i.e., retraction at 45° [retraction 45], retraction at 90° [retraction 90], and retraction at 145° [retraction 145]) simultaneously with upper limb motion. For exercises performed in the prone position, only the trunk was rotated without including hip rotation in order to perform a stable movement. All subjects completed five trials of each exercise.

Data reduction

Rotations of the distal coordinate system (humerus and scapula) were described with respect to the proximal coordinate system (thorax) using Euler angles in accordance with ISB's recommendations (Fig. 3).[37] The scapular angles (upward/downward rotation, external/internal rotation, and posterior/anterior tilting) and humeral elevation angles in scaption and external rotation during the 1st ER and 2nd ER were measured using custom Matlab code (Mathworks, Natick, MA, USA). Kinematic data were smoothed using a Butterworth low-pass digital filter (fourth order) at an estimated cutoff frequency of 4 Hz.

The original raw EMG signal was band-pass filtered at 20–500 Hz. The root-mean-squares (RMS) of the raw data were determined, and 3-s maximal voluntary contractions (MVC) were calculated for each muscle. The MVC EMG activity was recorded for the UT, MT, LT, and SA while the subject performed MVC against manual resistance, as previously described for manual muscle testing.[19] EMG data from the MVC were used to normalize the EMG amplitude (% MVC) during the testing protocol. The average RMS EMG amplitude of the each muscle was normalized to each of the MVCs. For the analytical EMG data, the EMG and kinematic data were synchronized using Matlab. The middle three of five trials were used for analysis. The three data sets were averaged. Then the mean EMG data during the concentric phase of each exercise and the amount of change in the scapular angle from start to end position for each task were analyzed.

Since the aim of this study was to investigate the muscle balance among the scapular muscles during these exercises, the relative activity of the UT with respect to the MT, LT, and SA was determined. The muscle activity ratios were calculated by dividing normalized EMG values of the UT by normalized EMG values of the LT, MT and SA, and was expressed as the ratios of UT/LT, UT/MT, and UT/SA.[5] Values <1 reflected that the MT, LT, or SA muscles were more activated compared to the UT.

Statistics

SPSS for Windows, version 14.0 software (SPSS, Chicago, IL, USA) was used for the data analysis. We compared the kinematic and EMG data collected during each exercise and the calculated muscle activity ratio between the two conditions (with and without trunk rotation) by using the Wilcoxon signed-rank test. The level of statistical significance was set at $p < 0.05$. Results are presented as mean ± standard deviation.

Results

Scaption

The results of the kinematic and EMG data and the muscle activity ratio for scaption are shown in Table 1. With trunk rotation, the angle of scapular ER and posterior tilt significantly increased, the EMG activity of the MT and LT significantly increased, and the UT/MT and UT/LT ratios significantly decreased.

1st ER

The results of the kinematic and EMG data and the muscle activity ratio for the 1st ER are shown in Table 2. With trunk rotation, the angle of scapular posterior tilt significantly increased, the EMG activity of the LT and SA significantly increased, and the UT/LT and UT/SA ratios significantly decreased.

2nd ER

The results of the kinematic and EMG data and the muscle activity ratio for the 2nd ER are shown in Table 3. With trunk rotation, the angle of scapular ER significantly increased, the EMG activity of the UT, MT, and LT significantly increased, the UT/MT ratio significantly decreased, and the UT/SA ratio significantly increased.

Retraction 45

The results of the kinematic and EMG data and the muscle activity ratio for retraction 45 are shown in Table 4. With trunk rotation, the scapular kinematics, EMG activity of any muscle, and the muscle activity ratio were not changed.

Retraction 90

The results of the kinematic and EMG data and the muscle activity ratio for retraction 90 are shown in Table 5. With trunk rotation, the angle of scapular upward rotation significantly decreased, but the scapular posterior tilting and ER were not changed. Additionally, with trunk rotation, the EMG activity of the UT significantly decreased, and the UT/MT, UT/LT, and UT/SA ratios significantly decreased.

Retraction 145

The results of the kinematic and EMG data and the muscle activity ratio for retraction 145 are shown in Table 6. With trunk rotation, the angle of scapular upward rotation significantly decreased, but the scapular posterior tilting and ER were not changed. Additionally, with trunk rotation, the EMG activity of the UT and SA significantly decreased, the UT/MT and UT/LT ratios significantly decreased, but the UT/SA ratio significantly increased.

Discussion

This study examined the effects of hip and trunk rotation on the scapular kinematics and the muscle activity during a series of six exercises. To the best of our knowledge, no study has examined scapular movement along with muscle activity and the muscle activation ratio during various shoulder exercises with trunk rotation.

In prior studies examining scapular muscle activity during shoulder exercises including hip and trunk movement, knee push up plus with contralateral leg extended and scapular retraction in a lunge position with contralateral leg forward increase LT activation.[23, 27] It is also known that scapular retraction exercises with hip and trunk ipsilateral rotation increase LT activity.[22] In the current study, three exercises performed in the upright position (scaption, the 1st ER, and the 2nd ER) with maximum ipsilateral hip and trunk rotation increased LT activation and scapular ER and/or posterior tilt. Exercises performed in the prone position (retraction 45, 90, and 145) with maximum ipsilateral trunk rotation did not change LT activity but decreased UT activity and the UT/LT ratio. Each exercise is discussed below.

Elevation of the arm - Scaption

Scaption is a motion that frequently causes pain in the shoulder. To prevent impingement and stress to the subacromial tissues, proper scapular motion; i.e., sufficient scapular upward rotation, ER, and posterior tilt; is essential during arm elevation.[13, 24] One factor preventing proper scapular motion is excess activation of the UT, accompanied by decreased activation of the LT, MT, and SA. [5-7, 25, 36]

In scaption with trunk rotation, the angle of scapular ER and posterior tilt were significantly increased, and the EMG activities of the MT and LT were significantly increased. In elevation of the arm, thoracic ipsilateral rotation and scapular ER have a positive correlation.[9] Besides, ipsilaterally rotated trunk position during humeral elevation promoted scapular ER.[31] In our study, ipsilateral trunk rotation increased scapular ER, which is consistent with these previous studies.[9, 31] Kibler et al.[22] have proposed that scapular retraction exercise with ipsilateral trunk rotation highly activates the LT. It is possible that ipsilateral trunk rotation increased the LT activation, which caused scapular ER and posterior tilt.

Clinically, muscle activity below 20% is considered low, activity between 20–40% is moderate, activity between 40–60% is high, and activity greater than 60% is very high.[11] In scaption with trunk rotation, the LT activity reached 25.7 ± 14.4%, which is considered moderate. Moreover, the UT/MT and UT/LT ratios decreased, because trunk rotation increased the MT and LT but did not change the UT activation. These results suggest that scaption with trunk rotation is more effective than normal scaption for stimulating the LT without excessive activation of the UT. Furthermore, considering the specific adaptation to the imposed demands principle, it is important to induce the desirable motion of the scapula and muscle in a practical motion such as scaption by adding trunk rotation. Therefore, patients with shoulder pathology with decreased scapular ER, posterior tilt, and decreased LT activation during elevation of the arm may benefit from this type of exercise.

Shoulder external rotation - 1st ER and 2nd ER

The 1st ER is typically performed for strengthening the infraspinatus[1, 8] however, in this study, we focused on the scapular kinematics and the scapular muscle activity. Cools et al.[5] recommended the 1st ER for strengthening the scapular muscles due to their low UT/LT and UT/MT ratios. In the 1st ER with trunk rotation, the angle of scapular ER was not changed, but the EMG activity of the LT significantly increased and the UT/LT ratio was significantly decreased. Although LT activity is low during the 1st ER with trunk rotation (12.5% ± 8.7%), the extremely low UT/LT ratio of this exercise may be beneficial for retraining neuromuscular control of scapular muscles, especially in the initial stage of rehabilitation. Therefore, the 1st ER with trunk rotation may enhance LT activity especially as an initial therapeutic exercise in patients with excessive UT activation.

The 2nd ER is an action similar to the late-cocking phase of the throwing motion,[12] so this exercise is important for overhead-throwing athletes. Previous studies have proposed the concept of internal impingement of the posterior cuff, which is a pathologic contact in the 2nd ER position between the greater tuberosity and the posterosuperior glenoid rim, often observed in overhead athletes with shoulder pain.[10, 17] Mihata et al.[29] reported that increased scapular internal rotation significantly increased glenohumeral contact pressure and the area of impingement during a simulated throwing motion. In the 2nd ER with trunk rotation, the angle of scapular ER significantly increased, and the EMG activity of the UT, MT, and LT significantly increased. Therefore, the 2nd ER with trunk rotation may be beneficial to overhead-throwing athletes who have shoulder pain due to decreased trapezius muscle activation and scapular ER at the late-cocking phase.

Scapular retraction - retraction 45, retraction 90, and retraction 145

Scapular retraction exercises in various positions have been widely used to strengthen the scapular retractor muscles, particularly the MT and LT.[3, 32] With regards to scapular kinematics, Oyama et al.[32] showed that the general pattern of scapular kinematics observed during most retraction exercises were scapular ER, upward rotation, and posterior tilt. In the present study, no difference in the scapular kinematics was observed in retraction exercises with and without trunk rotation. We assume this is because significant scapular ER already occurs during retraction exercises without trunk rotation, with no additional scapular movement occurring with trunk rotation.

In retraction 90 and retraction 145 with trunk rotation, the EMG activity of the UT significantly decreased, and the UT/MT and UT/LT ratios significantly decreased. However, in retraction 45 with trunk rotation, no change in the EMG activity was observed. We speculate that because the UT activity was low in retraction 45 without trunk rotation (11.1 ± 10.6%), further reduction of the UT did not occur in retraction 45 with trunk rotation.

Trunk rotation further decreases the UT/MT and UT/LT ratios, and these findings suggest that adding trunk rotation to retraction 90 may be more beneficial for trapezius muscle balance rehabilitation. Retraction 90 with trunk rotation in this study was performed in a position similar to the 2nd ER and emphasizes more scapular ER. Considering this, retraction 90 with trunk rotation may be useful especially in overhead-throwing athletes with shoulder pain due to decreased scapular ER at the late-cocking phase.

Retraction 145 is used for manual muscle testing of the LT[19] but the UT is highly activated simultaneously with the LT.[5, 32] However, retraction 145 with trunk rotation showed decreased UT activation and a decreased UT/LT ratio. In addition, the LT activation in retraction 145 with trunk rotation increased to 60.2 ± 29.9%, which is very high activity. Therefore, retraction 145 with trunk rotation may be adequate for strengthening the LT without excessive UT activation for patients whose primary problem is LT weakness.

Limitations

Some limitations of this study needs to be considered. First, kinematic data of the scapula are reliable in humeral elevation angles less than 120°,[18] but scaption and retraction 145 are exercises at humeral elevation greater than 120°. Thus, scapular angle values for these exercises should be interpreted cautiously. Nevertheless, our purpose of this study was to compare the data with and without trunk rotation in the same exercise, so the error, which could occur due to high shoulder elevation angle, may be discounted.

Second, since we determined the muscle activation during movements, conduction velocity may affect the amplitude and frequency characteristics of the EMG signal. The EMG date may be influenced by the change of the skin condition and the artifact caused from the movements. [4] We should also consider crosstalk, which reflects the activity of the adjacent muscles.[4]

Third, we evaluated four scapular muscles using surface EMG, but other deeper muscles such as the levator scapulae, rhomboids, and the pectoralis minor were not evaluated in this study.[5] The limited number of muscles tested in this study did not allow for accurate analysis of the relationship between the scapular muscle activation and the scapular kinematics.

Fourth, hip and trunk rotation angle were not evaluated in this study. We directed the subjects to rotate their trunk or trunk and hip maximally, but there might be an appropriate amount or threshold of hip and trunk rotation angle required to optimize scapular function. In addition, though adding trunk and hip rotation to shoulder exercises increased muscle activation or scapular movement, it is not possible to differentiate the effects of hip and trunk movement on the change in scapular movement and scapular muscle activation from our study. In order to know this, further study is needed.

Lastly, when prescribing these exercises in rehabilitation programs for patients with shoulder pathology, clinicians should consider whether our results apply, because patients may produce different results. Likewise, when adding external loads in these exercises, it may or may not show similar results to this research. Future investigations should perform evaluations with shoulder patients or with external loads.

Conclusion

We investigated the effect of ipsilateral trunk rotation during shoulder exercises on the scapula. Scaption, the 1st ER, and the 2nd ER with trunk rotation significantly increased scapular ER or posterior tilt and LT activation. Retraction 90 and retraction 145 with trunk rotation significantly decreased UT activation and decreased the UT/MT and UT/LT ratios.

Our findings suggest that the shoulder exercises with trunk rotation used in this study may be effective in patients who have decreased activity of the LT and excessive activation of the UT or in cases where a decreased scapular external rotation or posterior tilt is observed.

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Table 1

Scapular angle, muscle activation, and the muscle activity ratio during scaption.

mean ± standard deviation; *, p <0.05; **, p <0.01

		Without rotation	With rotation
Scapular angle (°)	External rotation	1.9 ± 13.4	15.5 ± 11.9**
	Upward rotation	38.4 ± 10.7	35.4 ± 10.3
	Posterior tilt	17.2 ± 9.7	20.5 ± 7.2*
Muscle activation (% maximal voluntary contractions)	UT	16.1 ± 7.7	17.1 ± 7.5
	MT	6.4 ± 5.0	8.8 ± 5.1*
	LT	15.2 ± 8.3	25.7 ± 14.4**
	SA	25.4 ± 9.7	25.1 ± 13.7
Muscle activity ratio	UT/MT	3.6 ± 2.7	2.4 ± 1.5*
	UT/LT	1.3 ± 0.7	0.8 ± 0.5*
	UT/SA	0.7 ± 0.4	0.9 ± 0.6

Table 2

Scapular angle, muscle activation, and the muscle activity ratio during the 1st external rotation.

mean ± standard deviation; *, $p < 0.05$; **, $p < 0.01$

		Without rotation	With rotation
Scapular angle (°)	External rotation	21.4 ± 8.0	25.6 ± 9.1
	Upward rotation	-2.1 ± 2.8	0 ± 3.2
	Posterior tilt	-3.5 ± 2.9	-0.9 ± 2.1**
Muscle activation (% maximal voluntary contraction)	UT	2.3 ± 1.9	2.2 ± 2.0
	MT	5.7 ± 3.4	7.8 ± 7.3
	LT	8.2 ± 4.9	12.5 ± 8.7**
	SA	0.9 ± 0.4	1.8 ± 0.7**
Muscle activity ratio	UT/MT	0.5 ± 0.3	0.3 ± 0.2
	UT/LT	0.3 ± 0.3	0.2 ± 0.2*
	UT/SA	3.1 ± 3.3	1.4 ± 1.1**

Table 3

Scapular angle, muscle activation, and the muscle activity ratio during the 2nd external rotation.

mean ± standard deviation; *, p <0.05; **, p <0.01

		Without rotation	With rotation
Scapular angle (°)	External rotation	15.2 ± 5.2	20.4 ± 7.3**
	Upward rotation	2.8 ± 4.6	3.6 ± 4.4
	Posterior tilt	15.0 ± 4.8	15.5 ± 6.2
Muscle activation (% maximal voluntary contraction)	UT	8.1 ± 3.6	11.4 ± 5.1**
	MT	8.1 ± 3.8	14.8 ± 7.2**
	LT	19.6 ± 12.0	29.3 ± 18.9**
	SA	23.5 ± 15.4	16.2 ± 9.9**
Muscle activity ratio	UT/MT	1.1 ± 0.6	1.0 ± 0.7*
	UT/LT	0.5 ± 0.3	0.6 ± 0.4
	UT/SA	0.5 ± 0.3	1.5 ± 2.9**

Table 4

Scapular angle, muscle activation, and the muscle activity ratio during retraction 45.

mean ± standard deviation; *, p<0.05; **, p<0.01

		Without rotation	With rotation
Scapular angle (°)	External rotation	22.5 ± 9.0	25.4 ± 8.8
	Upward rotation	-4.0 ± 8.4	-5.6 ± 7.9
	Posterior tilt	0 ± 5.9	-1.2 ± 6.1
Muscle activation (% maximal voluntary contraction)	UT	11.1 ± 10.6	8.3 ± 6.1
	MT	24.9 ± 13.1	28.9 ± 15.9
	LT	35.9 ± 18.6	33.4 ± 17.2
	SA	3.4 ± 6.6	2.0 ± 0.8
Muscle activity ratio	UT/MT	0.5 ± 0.4	0.4 ± 0.2
	UT/LT	0.4 ± 0.3	0.3 ± 0.2
	UT/SA	10. 2 ± 12.1	4.9 ± 4.2*

Table 5

Scapular angle, muscle activation, and the muscle activity ratio during retraction 90.

mean ± standard deviation; *, p <0.05; **, p <0.01

		Without rotation	With rotation
Scapular angle (°)	External rotation	23.2 ± 8.5	24.9 ± 9.8
	Upward rotation	-2.7 ± 7.3	-8.9 ± 12.5*
	Posterior tilt	6.5 ± 8.5	6.7 ± 10.7
Muscle activation (% maximal voluntary contraction)	UT	24.2 ± 12.2	18.2 ± 11.5**
	MT	38.4 ± 17.9	35.3 ± 14.2
	LT	53.5 ± 25.0	52.7 ± 27.0
	SA	4.6 ± 7.5	4.8 ± 6.0
Muscle activity ratio	UT/MT	0.9 ± 0.9	0.6 ± 0.4*
	UT/LT	0.5 ± 0.3	0.4 ± 0.2*
	UT/SA	18.7 ± 17.1	9.3 ± 9.5**

Table 6

Scapular angle, muscle activation, and the muscle activity ratio during retraction 145.

mean ± standard deviation; *, p <0.05; **, p <0.01

		Without rotation	With rotation
Scapular angle (°)	External rotation	32.4 ± 11.5	30.8 ± 8.7
	Upward rotation	6.1 ± 7.0	-2.6 ± 12.0*
	Posterior tilt	23.5 ± 10.3	15.3 ± 10.0
Muscle activation (% maximal voluntary contraction)	UT	30.6 ± 15.9	20.2 ± 7.2*
	MT	25.2 ± 10.6	27.7 ± 17.3
	LT	56.7 ± 28.4	60.2 ± 29.9
	SA	16.9 ± 9.3	8.3 ± 7.1**
Muscle activity ratio	UT/MT	1.5 ± 1.3	1.0 ± 0.6*
	UT/LT	0.7 ± 0.6	0.4 ± 0.2**
	UT/SA	2.5 ± 1.7	4.2 ± 3.0*

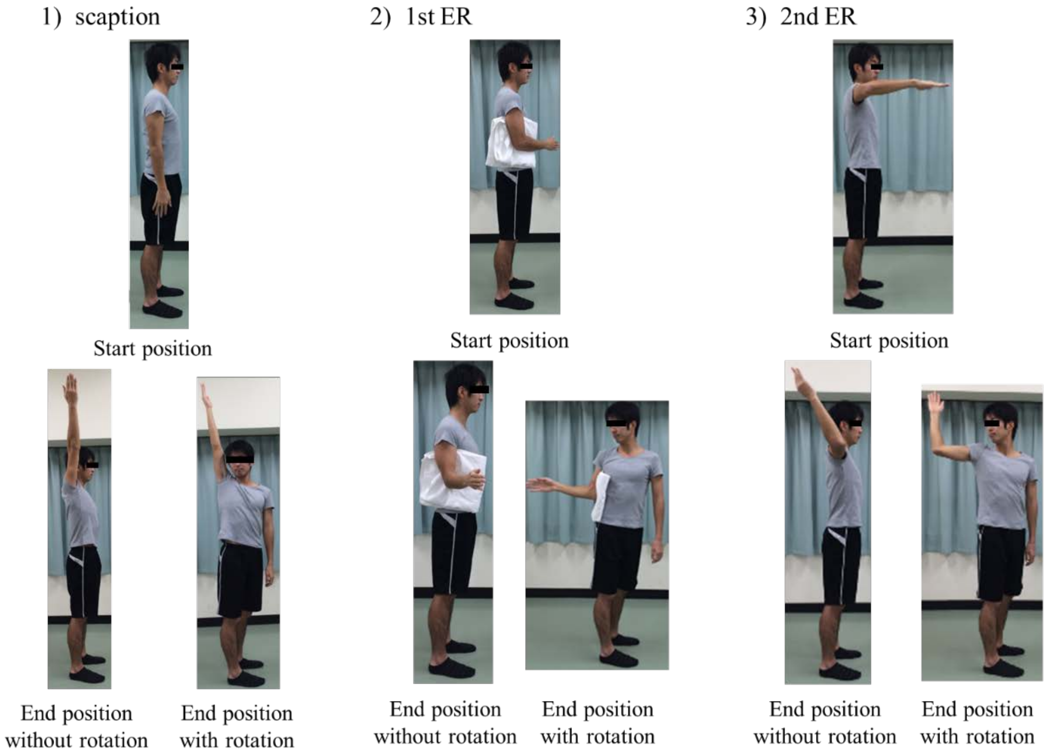

Fig. 1. Exercises performed in the upright position

1) Scaption: Each subject stood with the shoulder in neutral position while performing maximum elevation of the arms in the plane of the scapula (30° anterior of the frontal plane).

2) 1st external rotation (ER): Each subject stood with the shoulder at 45° internal rotation and the elbow at 90° flexion while performing maximum external rotation of the shoulder (a towel was positioned between the trunk and elbow to avoid compensatory movements).

3) 2nd ER: Each subject stood with the shoulder at 90° abduction and the elbow at 90° flexion while performing maximum external rotation of the shoulder.

During trunk rotation, all subjects were instructed to maximally rotate their trunk and hip.

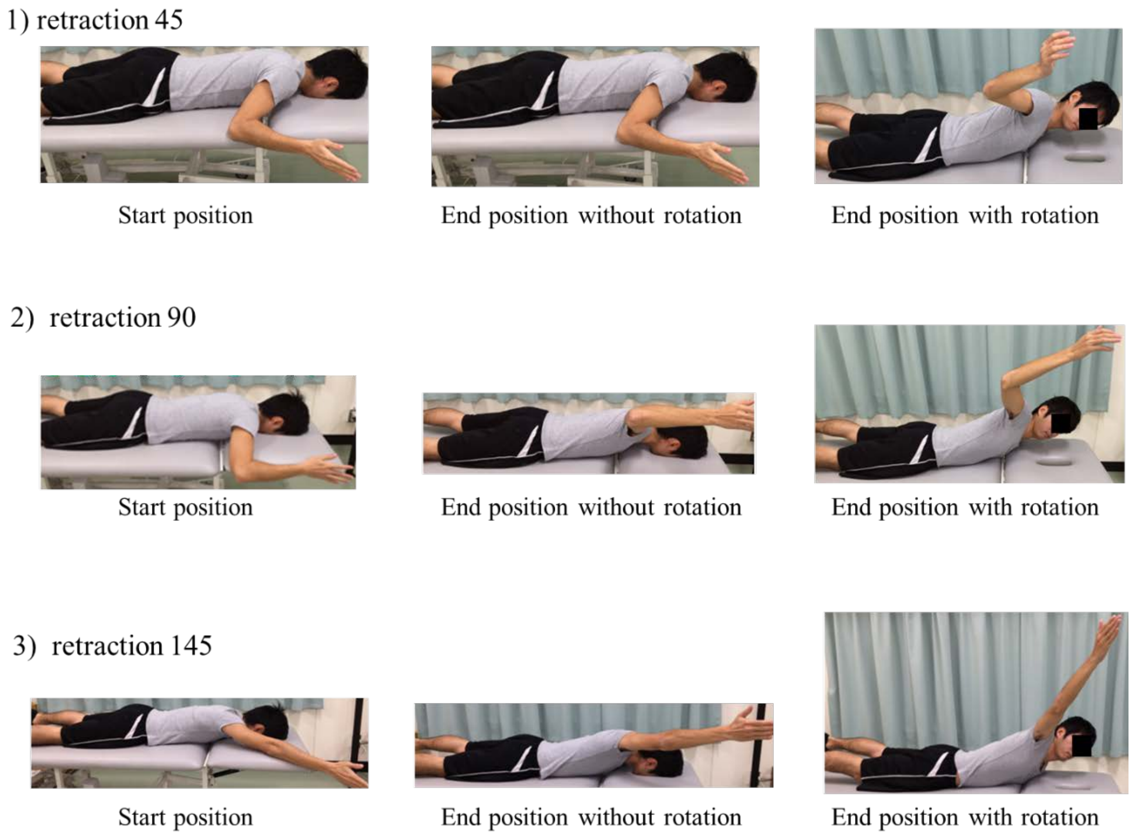

Fig. 2. Exercises performed in the prone position

4) Retraction 45°: Each subject in the prone position with the shoulder at 45° abduction and 90° external rotation with the elbow at 90° flexion performed maximum scapular retraction.

5) Retraction 90°: Each subject in the prone position with the shoulder at 90° abduction and 90° external rotation with the elbow at 90° flexion performed maximum scapular retraction.

6) Retraction 145°: Each subject in the prone position with the shoulder at 145° abduction and his thumb pointing toward the ceiling performed maximum scapular retraction.

During trunk rotation, all subjects were instructed to maximally rotate their trunk without moving their pelvis.

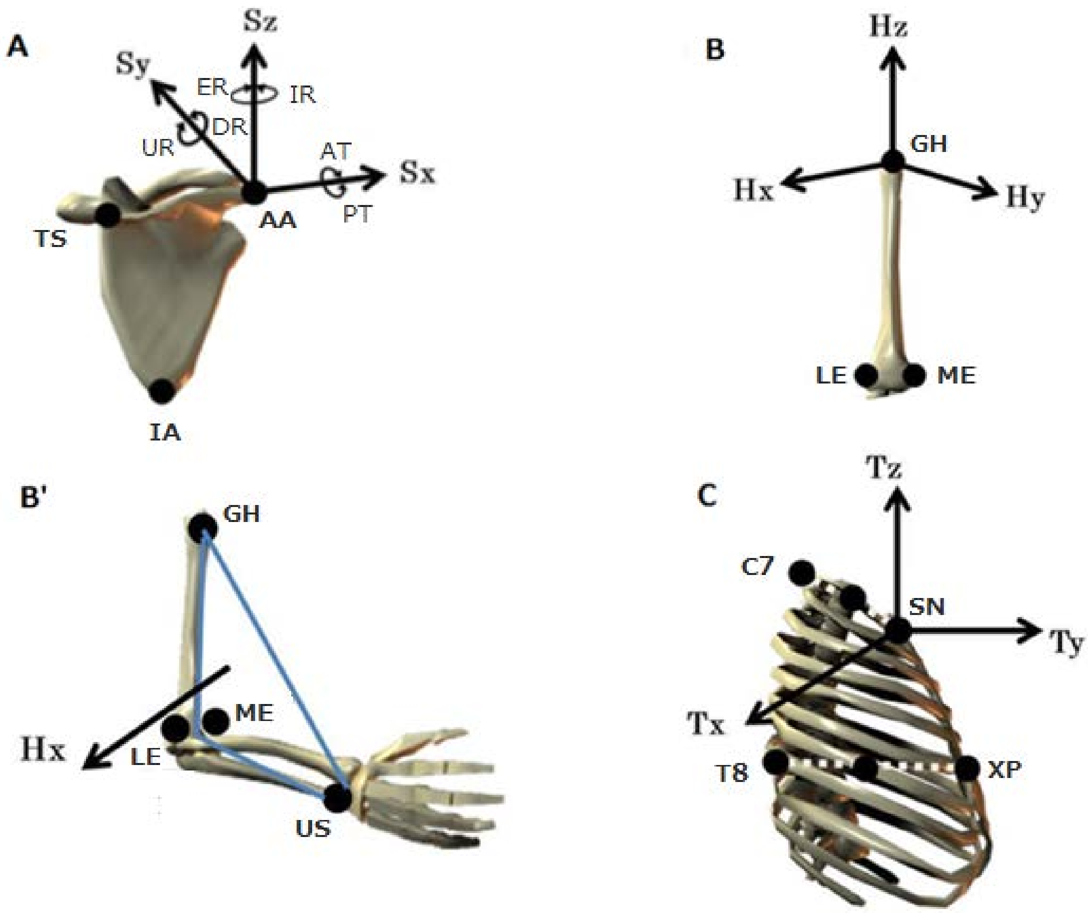

Fig. 3. Anatomic landmarks used for digitization and coordination of axes for each segment.

A) Scapular: AA, acromial angle; TS, trigonum scapulae; IA, inferior angle; UR, upward rotation; DR, downward rotation; ER, external rotation; IR, internal rotation; PT, posterior tilt; AT, anterior tilt. B) Humerus: ME, medial epicondyle; LE, lateral epicondyle. B') Humerus: US, ulnar styloid. C) Thorax: C7, C7 spinous process; T8, T8 spinous process; SN, sternal notch; XP, xiphoid process.