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Influence of thoracic posture on scapulothoracic and glenohumeral motions during eccentric shoulder external rotation

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ABSTRACT

Background: Throwing injuries to the shoulder joint often occur during shoulder external rotation. An appropriate combination of thoracic, scapular, and humeral motion during throwing is important to prevent such injuries, but it is unclear how thoracic posture contributes to shoulder motion during throwing.
Research question: The purpose of this study, therefore, was to clarify the influence of thoracic posture on scapulothoracic and glenohumeral motion during shoulder external rotation.
Methods: Eccentric external rotation at 90° of shoulder abduction in thoracic flexion and extension postures was performed by 15 asymptomatic participants. Three-dimensional scapulothoracic and glenohumeral movements were measured with an electromagnetic tracking device at 75°, 80°, 85°, and maximum shoulder external rotation. The thoracic angle and maximum shoulder external rotation in absolute coordination were measured with a three-dimensional motion capture system.
Results: The results showed that scapular posterior tilting and external rotation in the thoracic extension posture were significantly greater than those in the flexion posture ($p < 0.05$). Glenohumeral horizontal extension was significantly less in the thoracic extension posture than in the flexion posture ($p < 0.05$), whereas maximum shoulder external rotation was significantly greater ($p < 0.01$). Thus, thoracic extension increased scapulothoracic posterior tilting and external rotation and reduced glenohumeral horizontal extension during shoulder external rotation, as well as increasing maximum shoulder external rotation.
Significance: These findings suggest that thoracic extension may contribute to reduction of mechanical demand in the glenohumeral joint during throwing, potentially reducing shoulder injuries.

1. Introduction

Shoulder injuries in baseball pitchers are common, with an incidence of 28% [1]. The shoulder joint is subject to the greatest internal rotation torque during throwing around the moment at maximal shoulder external rotation (MSER) [2]. It has been reported that shoulder horizontal extension combined with external rotation increases glenohumeral contact pressure, potentially causing injuries of the posterosuperior labrum and rotator cuff [3]. This forced external rotation and/or horizontal extension at shoulder abduction is well established as a cause of throwing shoulder injuries [4–6].

Scapular motion and thoracic extension as well as glenohumeral motion contribute to the range of shoulder external rotation during pitching motion [7]. Contributions of scapulothoracic and thoracic movements may affect throwing injuries of the glenohumeral joint. Changes in scapular position reportedly affected the glenohumeral contact pressure, potentially causing painful internal impingement [8]. Studies have also demonstrated that thoracic posture influences scapulothoracic motion and the range of shoulder motion [9–11]. It is assumed that the changes in scapulothoracic motion due to postural changes can affect shoulder motion [10], but the effect of thoracic posture on scapulothoracic and glenohumeral motion during shoulder external rotation in pitching motion remains unclear.

In general, MSER during pitching motion is not generated by concentric contraction of the external rotators, but rather by the eccentric contraction of the shoulder internal rotators [12]. Thoracic,

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scapulothoracic, and glenohumeral motion during eccentric shoulder external rotation may differ from that during concentric shoulder external rotation because the recruitment pattern of muscles around the shoulder can differ between these two types of external rotation. However, to our knowledge, no previous study has established the effect of thoracic posture on scapulothoracic and glenohumeral motion during eccentric shoulder external rotation.

The purpose of the present study was to clarify, in healthy men, the differences between thoracic flexion and extension postures in their effects on scapulothoracic motion during eccentric shoulder external rotation and on the range of shoulder external rotation. It was hypothesized that thoracic extension increases scapulothoracic motion and the range of shoulder external rotation, thereby reducing glenohumeral motion.

2. Materials and methods

2.1. Participants

Fifteen men participated in this study. All were without shoulder pain and none had a history of any of the following conditions: injury or surgery to the upper extremity that affected shoulder motion; spinal injury; any internal disease that affected shoulder motion, such as immunological, metabolic, and neurologic diseases; any other disorders that affected joint motion, such as avascular necrosis and inflammatory arthritis. A further exclusion criterion was having less than 90° of passive shoulder abduction and less than 75° of passive shoulder external rotation in shoulder abduction. The mean (± standard deviation) age, height, and weight of the participants were 28.0 ± 3.3 years, 174.6 ± 5.6 cm, and 66.9 ± 6.3 kg, respectively. All were right-handed.

The study was approved by the local ethics committee (No. 2014-1-795), and all participants gave written informed consent before participating.

2.2. Measurement procedure

Throughout the measurement process, the participant sat on a stool with his knees and hips at 90° and his feet flat on the floor. He placed his right upper arm on an adjustable table (made from wood and polyvinyl chloride pipe), and the height of the table was set so that his right shoulder was positioned in 90° of abduction. A wooden positioner was used to position the shoulder at 75° of external rotation (Fig. 1).

The measurements involved eccentric shoulder external rotation performed in thoracic extension and flexion postures. For the thoracic extension posture, the participant was instructed to keep his eyes looking straight ahead and to stick out his chest, moving his sternum forward as far as possible. For the thoracic flexion posture, he was instructed to keep looking straight ahead and to round his back, moving his sternum backward as far as possible (Fig. 2). No significant differences in thoracic lateral flexion and rotation between thoracic flexion and extension postures were confirmed in a preliminary study. The examiner checked the thoracic flexion or extension and gave feedback to the participant if necessary to enable him to maximize the thoracic positioning. In each position, the participant performed the eccentric shoulder external rotation while holding a plastic bottle containing 500 ml of water, gripping the top of the bottle from the radial side. The participant was instructed to rotate his shoulder externally from the starting position (75° of external rotation) to the end range in 1 s (Fig. 1). Before the measurements were made, the participant was allowed sufficient practice of the task to ensure the appropriate movement speed. The participant then repeated this task five times in each of the thoracic flexion and extension postures.

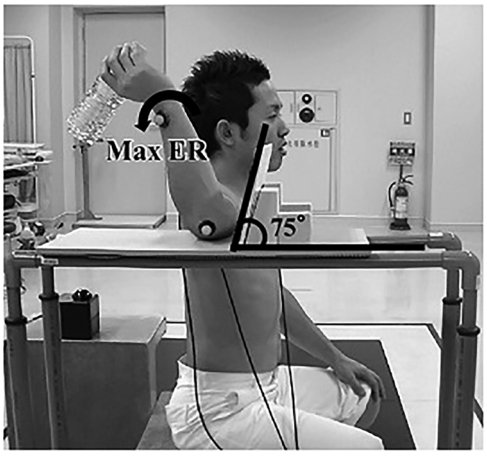

Fig. 1. Experimental view of the MSER motion from shoulder joint abduction at 90° and external rotation of 75°, with elbow joint flexion at 90°. Max ER, maximum external rotation.

2.3. Measurement of the glenohumeral and scapulothoracic joint motion

Kinematic data for the glenohumeral and scapulothoracic joint during the task were collected using an electromagnetic tracking device with six degrees of freedom (3SPACE FASTRAK, Polhemus, Inc., Colchester, VT, USA) and accompanying software (MotionMonitor, Innovative Sports Training, Chicago, IL, USA). The data collection was performed at a sampling rate of 30 Hz. Electromagnetic sensors were rigidly fixed with adhesive tape to the participant's sternum, superior acromion process, and right humerus according to the recommendations of the International Society of Biomechanics (ISB) [13]. A transmitter secured to a wooden table was located within 500 mm of the participant's upper body. According to the manufacturer's user manual, the root mean square error static accuracy is 0.8 mm, within a range of 760 mm from the magnetic source, whereas the angular accuracy is 0.15°, and the root mean square error due to skin motion artifacts is < 5° at a humeral elevation of < 120° [14]. Therefore, data corresponding to shoulder elevation angles of 90° were analyzed in this study.

Coordinate systems for the thorax, scapula, and humerus were defined using a calibrated digitizing stylus attached to a sensor by following ISB recommendations [13]. The three thoracic axes were defined as follows: the superiorly directed axis (Yt-axis) extended from the midpoint between the T8 spinous process (T8) and the xiphoid process to the midpoint between the C7 spinous process (C7) and the incisura jugularis (IJ); the laterally directed axis (Zt-axis), pointing to the right, was perpendicular to the plane defined by IJ, C7, and the midpoint between PX and T8; and the anteriorly directed axis (Xt-axis) was defined by the cross product of the Yt and Zt axes. The humeral axes were defined as follows: the longitudinal axis (Yh-axis) extended from the midpoint between the lateral and medial epicondyles (EL and EM) to the glenohumeral rotation center; the anteriorly directed axis (Xh-axis) was perpendicular to the plane defined by the glenohumeral rotation center, EL, and EM; and the laterally directed axis (Zh-axis) was defined by the cross product of the Xh and Yh axes. The scapular axes were defined as follows: the laterally directed axis (Zs-axis) extended from the trigonum spine (TS) to the acromial angle (AA); the anteriorly directed axis (Xs-axis) was perpendicular to the plane defined by the TS, AA, and inferior angle; and the superiorly directed axis (Ys-axis) was defined as the cross product of the Xs and Zs axes.

Using three-dimensional data recorded for each segment, glenohumeral horizontal extension and scapular external rotation, posterior tilt, and upward rotation were calculated using the Euler angle rotation sequence, as recommended by ISB [13]. The orientation of the scapula was determined by its rotation about its y-axis (internal/external rotation), z-axis (upward/downward rotation), and x-axis (anterior/posterior tilting). Similarly, the orientation of the humerus was determined

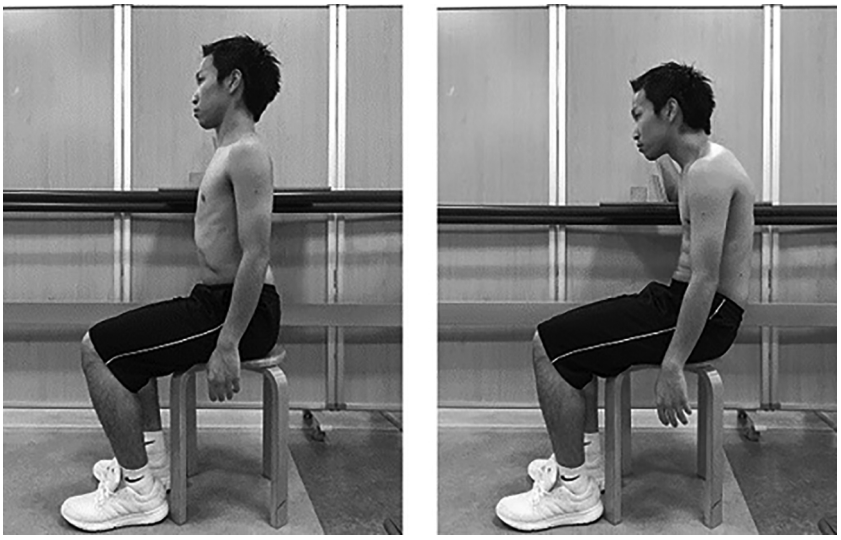

Fig. 2. The thoracic extension and flexion postures. (a) Thoracic extension posture. (b) Thoracic flexion posture.

by its rotation about its y-axis (plane of elevation), z-axis (elevation), and y-axis (axial rotation). However, glenohumeral axial rotation was not determined because it has previously been shown that the measurement error is large when using this method [15]. Instead, shoulder external rotation, including glenohumeral, scapulothoracic, and thoracic motion, was measured via the three-dimensional motion capture system described later.

2.4. Measurement of thoracic extension and shoulder external rotation angle during shoulder external rotation

Thoracic extension and shoulder external rotation relative to an absolute coordinate system were measured by using a three-dimensional motion capture system with eight cameras (MAC 3D, Motion Analysis Corporation, Santa Rosa, USA), recording at 30 Hz. In the absolute coordinate system, the *x*-axis was parallel to the sagittal plane of the participant's body and parallel to the ground, the *y*-axis was perpendicular to the *x*-axis and parallel to the ground, and the *z*-axis was defined by the cross product of the *x*- and *y*-axes. Five reflective markers (diameter, 1.9 cm) were placed with on two segments according to the anatomical positions suggested by a previous study [7]. These reflective markers were attached with adhesive tape to the spinous processes of the 7th cervical vertebra (C7) and 8th thoracic vertebra (Th8), and to the 1st lumber vertebra (L1), elbow, and wrist. Thoracic extension was defined as the angle in the sagittal plane between a line connecting the C7 and Th8 markers and another line connecting the Th8 and L1 markers. Shoulder external rotation was measured as the angle between the *y*-axis and a line connecting the elbow and wrist markers.

A KineAnalyzer (Kissei Comtec Corporation, Matsumoto, Nagano, Japan) was used to process the position data of the markers and to calculate the thoracic extension and shoulder external rotation in the sagittal plane. The kinematic data were filtered using a low-pass finite impulse response filter with a cutoff frequency of 10 Hz.

2.5. Data analysis

MSER in the thoracic flexion and extension positions were analyzed. Thoracic extension, glenohumeral horizontal extension, and scapular posterior tilting, external rotation, and upward rotation were calculated at 75°, 80°, 85°, and MSER. For all calculations, data were averaged over the five trials. Moreover, to determine the magnitude of variance in the calculated values of each parameter between the trials, we calculated root mean square difference (RMSD).

Two-way repeated-measures analysis of variance (ANOVA) was used to determine the effect of thoracic posture and shoulder external rotation position for the thoracic extension, glenohumeral horizontal extension, and scapular posterior tilting, external rotation, and upward rotation. When ANOVA showed a significant main effect, the Bonferroni multiple pairwise comparisons procedure was used as a post hoc test. In addition, a paired *t*-test was used to compare MSER between the thoracic extension and flexion postures. All statistical analyzes were performed with SPSS version 15 statistical software (SPSS, Chicago, IL, USA). The statistical significance was set at 5% in all analyzes.

3. Results

3.1. RMSD

RMSD values for measurements of the thoracic, glenohumeral, and scapulothoracic motions are shown in Table 1. All RMSD values were < 1.08°.

3.2. Effect of thoracic posture

The results of the ANOVA and post hoc test are presented in Table 2. There was a significant main effect of thoracic posture on glenohumeral horizontal extension ($F_{1,\ 42} = 12.8$; $p = 0.006$). Glenohumeral horizontal extension was significantly lower in the thoracic extension posture than in the thoracic flexion posture throughout the shoulder external rotation. There were also significant main effects of thoracic posture for scapular posterior tilting ($F_{1,\ 42} = 12.1$; $p = 0.007$) and external rotation ($F_{1,\ 42} = 14.6$; $p = 0.004$). However, no significant main effect of thoracic posture was observed for scapular upward rotation ($F_{1,\ 42} = 3.4$; $p = 0.097$). Scapular posterior tilting and external rotation were significantly greater in the thoracic extension posture than in the thoracic flexion posture throughout the shoulder external rotation motion.

3.3. Effect of shoulder external rotation

Significant main effects of the shoulder external rotation position were observed for thoracic extension ($F_{3,\ 42} = 10.3$; $p = 0.01$), scapular posterior tilting ($F_{3,\ 42} = 14.6$; $p = 0.002$), and scapular external rotation ($F_{3,\ 42} = 10.0$; $p = 0.02$), but there was no significant main effect for glenohumeral horizontal extension ($F_{3,\ 42} = 0.9$; $p = 0.382$) or scapular upward rotation ($F_{3,\ 42} = 2.3$; $p = 0.153$).

In the thoracic extension posture, the thoracic and scapular

Table 1
Root mean square difference and standard deviation for scapular and thoracic motion in thoracic extension and flexion postures.

			Thoracic extension posture					Thoracic flexion posture				
			TE	SPT	SER	SUR	GHHE	TE	SPT	SER	SUR	GHHE
Angle	ER 75°	RMSD (°)	0.71	0.76	0.98	0.48	0.80	0.64	0.89	0.92	0.46	0.85
		SD	0.39	0.14	0.48	0.09	0.19	0.46	0.01	0.27	0.08	0.37
	ER 80°	RMSD (°)	0.82	0.83	0.88	0.49	0.75	0.74	0.87	0.94	0.58	0.58
		SD	0.34	0.33	0.39	0.06	0.56	0.53	0.23	0.27	0.41	0.42
	ER 85°	RMSD (°)	0.64	0.65	0.89	0.43	0.70	0.79	0.95	1.08	0.45	0.76
		SD	0.50	0.39	0.43	0.06	0.51	0.86	0.26	0.27	0.14	0.44
	MSER	RMSD (°)	0.50	0.81	0.89	0.63	1.04	0.62	0.77	0.94	0.58	0.86
		SD	0.55	0.39	0.37	0.30	0.23	0.56	0.37	0.22	0.26	0.39

Abbreviations: ER, external rotation; MSER, maximum shoulder external rotation; RMSD, Root mean square difference; SD, standard deviation; TE, thoracic extension; SPT, scapula posterior tilting; SER, scapula external rotation; SUR, scapula upward rotation; GHHE, glenohumeral horizontal extension.

positions were almost constant from 75° to 85°. However, at MSER, they changed significantly in the directions of thoracic extension ($p = 0.001$), scapular posterior tilting ($p = 0.001$), and external rotation ($p = 0.001$). Similarly, in the thoracic flexion posture, there were insignificant changes in thoracic and scapular motion from 75° to 85°, followed by significant increases in thoracic extension ($p = 0.001$) and scapular posterior tilting ($p = 0.001$) from 85° to MSER. However, unlike with scapular motion in the thoracic extension posture, no significant change in scapular external rotation in the thoracic flexion posture was observed throughout the range of shoulder external rotation.

3.4. Interaction

No significant interaction between the thoracic posture and shoulder external rotation position was observed for thoracic extension ($p = 0.774$), for scapular posterior tilting ($p = 0.614$), upward rotation ($p = 0.208$), or external rotation ($p = 0.076$), or for glenohumeral horizontal extension ($p = 0.209$).

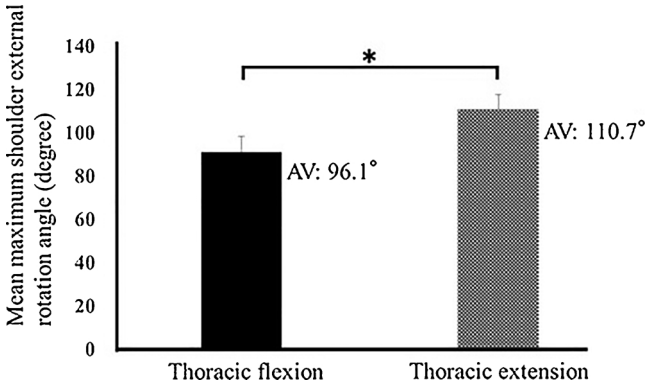

Fig. 3. Differences in mean maximum shoulder external rotation angles between thoracic extension and flexion postures ($n = 15$). Values are presented as mean ± standard deviation. *$p < 0.01$ by paired t test. AV average.

Table 2
Differences in thoracic, scapulothoracic, and glenohumeral motions between the thoracic extension and flexion postures.

	TE[a]		SPT[b]		SER[c]		SUR[d]		GHHE[e]	
	Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion
ER 75° Mean (SD), deg	167.4 (5.2)[f]	151.6 (7.5)	169.6 (8.6)[f]	165.6 (8.1)	−58.6 (32.2)[g]	−50.4 (30.9)	−28.4 (9.6)	−30.9 (10.7)	−14.4 (21.7)[f]	−22.1 (17.3)
ER 80° Mean (SD), deg	167.4 (5.3)[f]	151.9 (7.6)	169.6 (8.9)[f]	165.2 (7.7)	−58.8 (32.1)[g]	−50.3 (31.2)	−28.3 (9.5)	−31.0 (10.6)	−14.1 (21.5)[f]	−22.1 (17.4)
ER 85° Mean (SD), deg	167.5 (5.3)[f]	151.8 (7.6)	169.6 (8.9)[f]	165.1 (7.4)	−59.0 (31.8)[g]	−50.5 (30.9)	−28.5 (9.6)	−30.9 (10.8)	−13.7 (21.5)[f]	−22.1 (17.3)
MSERA Mean (SD), deg	168.8 (5.4)[f,h]	153.3 (8.9)[h]	171.2 (7.1)[f,h]	167.1 (7.0)[h]	−59.9 (31.6)[g,h]	−50.6 (31.1)	−28.6 (9.5)	−31.3 (10.9)	−14.5 (20.4)[f]	−21.6 (17.9)
Main effect: thoracic posture[*]	< 0.01		< 0.01		< 0.01		0.097		< 0.01	
Main effect: shoulder external rotation[**]	0.01		< 0.01		0.02		0.153		0.382	
Thoracic posture × Shoulder external rotation interaction	0.774		0.614		0.076		0.208		0.209	

Abbreviations: ER, external rotation; MSERA, maximum shoulder external rotation in abduction; SD, standard deviation; TE, thoracic extension; SPT, scapula posterior tilting; SER, scapula external rotation; SUR, scapular upward rotation; GHHE, glenohumeral horizontal extension.

[a] Positive and negative values indicate extension and flexionrespectively.
[b] Positive and negative values indicate posterior and anterior tiltingrespectively.
[c] Positive and negative values indicate internal and external rotationrespectively.
[d] Positive and negative values indicate upward rotation and downward rotationrespectively.
[e] Positive and negative values indicate horizontal flexion and extensionrespectively.
[f] Significant larger angle than for thoracic flexion ($p < 0.05$).
[g] Significant smaller angle than for thoracic flexion ($p < 0.05$).
[h] Significant larger angle than for ER75°ER80°, ER85° ($p < 0.05$).
* Two thoracic postures: extension and flexion.
** Four shoulder external rotations: ER75°ER80°, ER85°, and Maximum.

3.5. MSER

Mean MSER for the two postures is shown in Fig. 3. The maximum rotation was significantly greater with the thoracic extension posture than with the thoracic flexion posture ($p = 0.001$).

4. Discussion

As hypothesized, MSER was significantly greater with thoracic extension. This can be explained by thoracic extension leading to scapular posterior tilting, thereby increasing MSER because both movements are in almost the same direction. Actually, our findings demonstrated increase in scapular posterior tilting with thoracic extension.

In this study, scapular posterior tilting increased only at MSER. However, this tilting was significantly larger in the thoracic extension posture than in the thoracic flexion posture throughout the rotation. These findings suggest that thoracic extension itself, rather than the shoulder external rotation, causes the scapular posterior tilting. Previous studies have reported that scapular posterior tilting in an erected trunk position was greater than that in a slouched position throughout arm elevation [10,11]. Although the shoulder motion investigated in those studies differed from that in the present study, the results for the relationship between thoracic posture and scapular posterior tilting were consistent.

The increase in scapular posterior tilting with thoracic extension may have resulted from changes in scapular muscle activation and the configuration of the thorax. A previous study reported that the lower trapezius is a primary agonist muscle for scapular posterior tilting [16]. If activation of the lower trapezius is increased by thoracic extension, scapular posterior tilting can increase. However, another study demonstrated that activation of the lower trapezius during shoulder elevation was greater in a slouched than in an erect sitting posture [17], although the investigated shoulder motion differed from that in the present study.

The configuration of the thorax can also be affected by thoracic extension. Thoracic extension leads to backward rotation of the ribs on the costovertebral joints [18]. This may have caused posterior tilting of the dorsal surface of the thorax, on which the scapula is located, relative to the sternum (where the thoracic sensor was attached in the present study).

In this study, pattern of changes in scapular external rotation with thoracic extension was similar with that in scapular posterior tilting. Moreover, this finding suggests that thoracic extension affects scapular external rotation concomitantly with shoulder external rotation. A previous study demonstrated an increase in scapular external rotation with thoracic extension during humeral elevation as well [11]. However, glenohumeral horizontal extension significantly decreased with thoracic extension. This can be attributed to an increase in scapular external rotation with thoracic extension. Because the upper arm was maintained in a constant position on the table, increased scapular external rotation would result in a relative decrease in glenohumeral horizontal extension.

This study had several limitations. First, the measurement process was unable to directly measure glenohumeral external rotation, so the contribution of glenohumeral external rotation to MSER, as well as the change in glenohumeral external rotation with thoracic extension, remain unclear. However, the glenohumeral external rotation could be estimated by subtracting the scapular posterior tilting angle from the shoulder external rotation angle. Second, because all participants in the present study were men, it is unknown whether similar results would apply to women. However, our findings are comparable to those from previous studies regarding the throwing injury on which the present study focused, in which most participants were men [1,5,7]. Finally, measurements in this study were not performed during a real pitching motion, including thoracic rotation and lateral flexion as well as flexion/extension [19,20]. Thoracic extension is critical during throwing tasks because we demonstrated that this motion increases both scapular external rotation and posterior tilting. However, any influence of thoracic lateral flexion and rotation on the scapulothoracic and glenohumeral motion remain unclear. In addition, our findings may not be completely applied to other overhead sports, such as tennis, requiring different patterns of shoulder and trunk motions from those required in baseball throwing [21]. Further studies are needed to investigate the influence of thoracic postures in the other planes.

Regarding clinical relevance, avoiding excessive glenohumeral motion is of key importance for avoiding shoulder injuries with throwing. Miyashita et al. [7] postulated that deficient thoracic and scapular motion at MSER could result in increased mechanical demand in the glenohumeral joint. Another study demonstrated that a slouched posture during throwing reduced shoulder abduction without a change in shoulder external rotation [22]. These findings suggest that a certain degree of shoulder external rotation is required to perform throwing movements even with an inadequate thoracic posture. Our findings suggest that thoracic extension can contribute to reducing mechanical demand in the glenohumeral joint at MSER during throwing, thereby reducing throwing injuries to the shoulder joint.

5. Conclusion

In the thoracic extension posture, scapular posterior tilting and external rotation during eccentric shoulder external rotation motion were significantly greater than when in the thoracic flexion posture. At the same time, thoracic extension also significantly reduced glenohumeral horizontal extension. The findings of this study suggest that thoracic extension can contribute to increased scapular motion and reduce mechanical demand in the glenohumeral joint, as well as allow increased MSER.

Conflict of interest

The authors declare no conflicts of interest.

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