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Title page

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Abstract

[Background]

Shoulder external rotation at abduction (ER) is a notable motion in overhead sports because it could cause strong stress to the elbow and shoulder joint. However, no study has comprehensively investigated the effect of different trunk postures during ER. This study aimed to investigate the effect of different trunk postures on scapular kinematics and muscle activities during ER.

[Methods]

Fourteen healthy men performed active shoulder external rotation at 90° of abduction with the dominant arm in 15 trunk postures. At maximum shoulder external rotation in 15 trunk postures, including 4 flexion-extension, 6 trunk rotation, and 4 trunk side-bending postures, as well as upright posture as a control, scapular muscle activities and kinematics were recorded using surface electromyography and an electromagnetic tracking device, respectively. The data obtained in the flexion-extension, trunk rotation, and trunk side-bending postures were compared with those obtained in the upright posture.

[Results]

In the flexion-extension condition, scapular posterior tilt and external rotation

significantly decreased, but the muscle activities of the lower trapezius and infraspinatus significantly increased in maximum trunk flexion. Moreover, scapular upward rotation and the activity of the serratus anterior significantly increased in maximum trunk extension. In the rotation condition, scapular posterior tilt and external rotation significantly decreased, but the activity of the serratus anterior significantly increased in the maximum contralateral trunk rotation posture. In the trunk side-bending condition, scapular posterior tilt and the external rotation angle significantly decreased.

[Conclusion]

Trunk postures affected scapular kinematics and muscle activities during ER. Our results suggest that different trunk postures activate the lower trapezius and serratus anterior, which induce scapular posterior tilt.

Level of evidence

Basic Science Study; Kinesiology

Keywords

Scapula; muscle activity; kinematics; trunk posture; shoulder external rotation; exercise.

1. Introduction

Shoulder joint motion is the harmonious motion by the scapula, humerus, clavicle, and rib cage. In shoulder motion, the role of the scapula is especially important because nonoptimal scapular motion leads to increased stress on peripheral soft tissues of the shoulder joint and could induce shoulder dysfunction and pain.[3,12,18,20,22,36] Therefore, it is important to focus on the muscle controlling scapular motion. Some studies have suggested that the upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA) muscles coordinately work as a force couple in arm elevation to upwardly rotate the scapula.[6,7,13,15,19,20]

The effect of trunk posture on scapular motion and muscle activity has also been studied.[16,29,39] Yamauchi et al[39] reported that maximum ipsilateral trunk rotation increased the activity of the middle trapezius (MT) and LT muscles and posterior tilt of the scapular angle in arm elevation. However, the investigated trunk postures were limited (eg, trunk ipsilateral rotation or trunk extension). Therefore, our study reports the effects of comprehensive trunk flexion, extension, bilateral side-bending, and bilateral rotation postures during shoulder external rotation at shoulder abduction. Moreover, we sought to investigate the effects of the degree of the trunk angle on scapular kinematics and muscle activity.

Arm elevation motion has often been selected to evaluate scapular muscle activity and kinematics.[16,29,39] However, overhead sports players frequently perform motions with shoulder external rotation at abduction (ER) with different trunk postures. Some previous studies reported scapular kinematics during overhead sports,[26,30,31] and one study described that the scapula posteriorly tilts, externally rotates, and rotates upward at shoulder external rotation during baseball pitching.[25] Moreover, the scapular muscles stabilize the scapula, and an imbalance of these muscles might contribute to injury risk.[11] In pitching, the shoulder abduction angle from foot strike to release is approximately 90°.[8,37] Therefore, shoulder external rotation is commonly measured at 90° of abduction in baseball players,[4,27,37] which may be a position that reflects the scapular kinematics during pitching. Giving the overhead motion, accordingly, the assessment of scapular muscle activities and kinematics during shoulder ER is necessary.

The scapular motions during ER are upward rotation, external rotation, and posterior tilt.[23,33] The UT, LT, and SA muscles work to upwardly rotate the scapula during ER.[10,28] In addition, previous studies have reported that the LT and SA muscles work to posteriorly tilt the scapula during arm elevation.[21,24] It is assumed that these muscles have an important role in scapular kinematics during ER because the scapula is rotated upward, externally rotated, and posteriorly tilted and these muscle activities increase during the given conditions.

Examination of the effect of trunk posture on scapular kinematics and muscle activity during shoulder external rotation is crucial during overhead sports activity. The purpose of this research was to evaluate the effects of the difference in trunk posture on scapular kinematics and muscle activity during ER. Trunk extension or ipsilateral rotation has been shown to increase scapular posterior tilt, the external rotation angle, and LT muscle activity during shoulder flexion.[16,29,39] We hypothesized that the scapular posterior tilt and external rotation angles and the activity of the SA and LT muscles, which contribute to scapular posterior tilt, would increase with trunk extension and ipsilateral rotation during ER.

2. Material and Methods

2.1 Subjects

A controlled experimental study was conducted. Fourteen healthy men (mean age, 24.2 ± 1.9 years) without orthopedic or nervous system disease of the upper limb or trunk were included in the study. All subjects provided consent after receiving written and oral explanations regarding the study. This study conformed to the principles of the Declaration of Helsinki. The sample size was based on a 1-way analysis of variance (ANOVA) with repeated measures (effect size of 0.25, α error of .05, and power of 0.8) by use of G*Power (version 3.1; Heinrich Heine University, Dusseldorf, Germany) before the recruitment of subjects. On the basis of the calculation results, the sample size required was 13; this study thus met the statistical power requirement.

2.2 Experimental procedure

Scapular kinematics and muscle activity at ER measured in 14 trunk postures were compared with those in the upright posture to evaluate the effect of trunk posture. The scapular angles, muscle activities, and shoulder external rotation angles were measured at maximum shoulder external rotation. Subjects sat on a platform with an ascent and descent function and placed both feet on the floor with the knee joints at 90° of flexion and the pelvis not fixed during the task. This posture of the feet and pelvis was the same in all testing postures, and only the trunk posture was changed during the task. Subjects performed 15 trunk postures: upright posture as the control posture; 4 trunk flexion-extension conditions (maximum flexion [Flex$_{max}$], 20° of flexion [Flex20], 20° of extension [Ext20], and maximum extension [Ext$_{max}$]); 6 trunk rotation conditions (maximum contralateral rotation [CR$_{max}$], contralateral rotation of 30° [CR30], contralateral rotation of 15° [CR15], ipsilateral rotation of 15° [IR15], ipsilateral rotation of 30° [IR30], and maximum ipsilateral rotation [IR$_{max}$]); and 4 trunk side-bending conditions (contralateral lateral bending at 30°[CLB30], contralateral lateral bending at 15° [CLB15], ipsilateral lateral bending at 15° [ILB15], and ipsilateral lateral bending at 30° [ILB30]). Three optical markers were attached to the seventh cervical spinous process (C7), 10th thoracic spinous process (T10), and third lumbar spinous process (L3). The flexion-extension angle was made by the line connecting C7 with T10 and the line connecting L3 with T10 in the sagittal plane. In the upright posture, the angle was 0°. Flex$_{max}$ was the posture in which each subject achieved the maximum trunk flexion angle by relaxing. The flexion angle for Flex$_{max}$ in all subjects was over 20°. The trunk rotation angle was the angle between the line linking the bilateral posterior anterior iliac spine and the line linking the bilateral acromion. The trunk side-bending angle was the angle between the line linking C7 and T10 and the line linking L3 and T10 in the coronal plane.

2.3 Active shoulder external rotation task

Subjects performed the active ER task to the maximum shoulder external rotation angle with random trunk postures directed from 12 trunk postures except CR^{max}, IR^{max}, and Ext^{max} (Fig. 1). Then, they performed the active ER task with randomly directed trunk postures from the remaining 3 trunk postures. Before measurement of scapular kinematics and muscle activity during the shoulder external rotation task, the active maximum shoulder external rotation angle was measured using a goniometer at 90° of abduction of the shoulder joint in the directed trunk posture. Subsequently, subjects actively maintained the maximum shoulder external rotation position for 5 seconds. The measurement was performed once in each trunk posture to avoid the effect of fatigue.

2.4 EMG protocol

During the shoulder external rotation task, scapular muscle activities were collected using surface electromyography (EMG) (TeleMyo 2400; Noraxon, Scottsdale, AZ, USA) with sampling at 1500 Hz. Electrodes were placed on the UT, MT, LT, SA, infraspinatus, and latissimus dorsi (LD) in the dominant upper limb with fixed 2.5-cm spacing parallel to the muscle fibers. Skin at the electrode sites was shaved and cleaned using scrubbing gel and alcohol. Electrode placement was based on previous studies or Surface Electromyography for the Non-invasive Assessment of Muscles (SENIAM) recommendations. The locations of the electrodes for each muscle were as follows: The UT electrode is at the midpoint between C7 and the acromion of the scapula.[19] The MT electrode is at the midpoint between the medial border of the scapula and T3. The LT electrode is at the point located at two-thirds on the line from the trigonum spinae (TS) to T8. The infraspinatus electrode is at the midpoint on the line connecting the midpoint of the spine of the scapula and angulus inferior scapulae.14 The SA electrode is at the halfway point between the anterior border of the LD muscle and the inferior border of the pectoralis major muscle on the seventh rib.[9] The LD electrode is 2 to 3 cm below the angulus inferior scapulae.[32] The raw EMG signals during the shoulder external rotation task were recorded and analyzed for 3 seconds at the shoulder maximum external rotation angle. The EMG signals of the maximal voluntary contraction were recorded for 3 seconds on each muscle. The method was referred to the manual muscle test and previous studies[2,5,17,32] before subjects began the task. The raw EMG signals were band pass filtered (15-500 Hz, Butterworth) and then smoothed using the root mean square.

The root-mean- square amplitude was divided by the maximal voluntary contraction of each muscle for normalization.

2.5 Scapular kinematics

Three-dimensional kinematics of the scapula and thorax was quantified during the shoulder external rotation task using a 6-df electromagnetic tracking device (Liberty; Polhemus, Colchester, VT, USA) at 120 Hz. This system was composed of a transmitter, 5 sensors, and a digitizing stylus connecting the Liberty electronic unit. The transmitter was fixed on a rigid wooden stand at 100 cm in height. This transmitter generated the electromagnetic fields, which constituted the global coordinate system, with the x-axis orienting forward, the y-axis orienting upward, the z-axis orienting right, and the origin located at the transmitter. The sensors were placed on the bony landmarks of the subjects using tape. The thoracic sensor was placed at the sternum just below the jugular notch; the humeral sensor, on the halfway point of the humerus with a thermoplastic cuff; and the scapular sensor, on the flat surface of the acromion. With reference to the positions of these sensors, the local coordinate systems (LCSs) of the thorax, humerus, and scapula were built by digitizing each bony landmark while subjects sat in the anatomic upper-limb position.

All LCSs were defined according to the shoulder standardization proposal of the International Society of Biomechanics.[38] The distal coordinate system was rotated with respect to the proximal coordinate system in accordance with the recommendation on the Euler angle of the International Society of Biomechanics. In the LCS of the scapula, the origin was the acromial angle (AA). The axes were defined as follows: The x-axis (Xs) was the normal vector of the plane including the TS, AA, and inferior angle. The z-axis (Zs) was directed from the TS to the AA. The y-axis (Ys) was the normal vector of the x-axis and z-axis. In the LCS of the thorax, the origin was the sternal notch. The y-axis (Yt) was directed from the midpoint between the xiphoid process and T8 to the midpoint between the SN and C7. The z-axis (Zt) was the normal vector of the plane including the midpoint between the xiphoid process and T8, SN, and C7. The direction was right. The x-axis (Xt) was the normal vector of the y-axis and z-axis.

The rotation of the thoracic segment relative to the global coordinate system around Xt was defined as right (+) and left (–) bending, that around Yt was defined as rotation to the left (+) and rotation to the right (–), and that around Zt was defined as extension (+) and flexion (–). The rotation of the scapular segment relative to the thoracic segment around Xs was defined as downward (+) and upward (–) rotation, that around Ys was defined as internal (+) and external (–) rotation, and that around Zs was defined as posterior (+) and anterior (–) tilt.

The humeral external rotation angle was defined as the difference between the apparent shoulder external rotation angle measured by a goniometer and the thoracic extension angle and scapular posterior tilt angle. The scapular angle of each trunk posture was the average of kinematic data for 3 seconds at the shoulder maximum external rotation angle.

2.6 Data analysis

The statistical analysis software used in this study was SPSS, version 22 (IBM, Armonk, NY, USA). For the scapular angle and muscle activity, 1-way ANOVA with repeated measures on 1 factor (trunk posture) was used to evaluate the effect of trunk posture on each parameter. Then, trunk postures were classified into 4 conditions: upright as the control condition, flexionextension condition (Flexmax, Flex20, Ext20, and Extmax), rotation condition (IR15, IR30, IRmax, CR15, CR30, and CRmax), and side-bending condition (CLB30, CLB15, ILB15, and ILB30). For the scapular angle and muscle activity, 1-way ANOVA with repeated measures on a factor (trunk posture) was used in each condition including upright posture. When a significant main effect was detected, the Dunnett test as the post hoc test was conducted to compare the trunk postures with the upright posture.

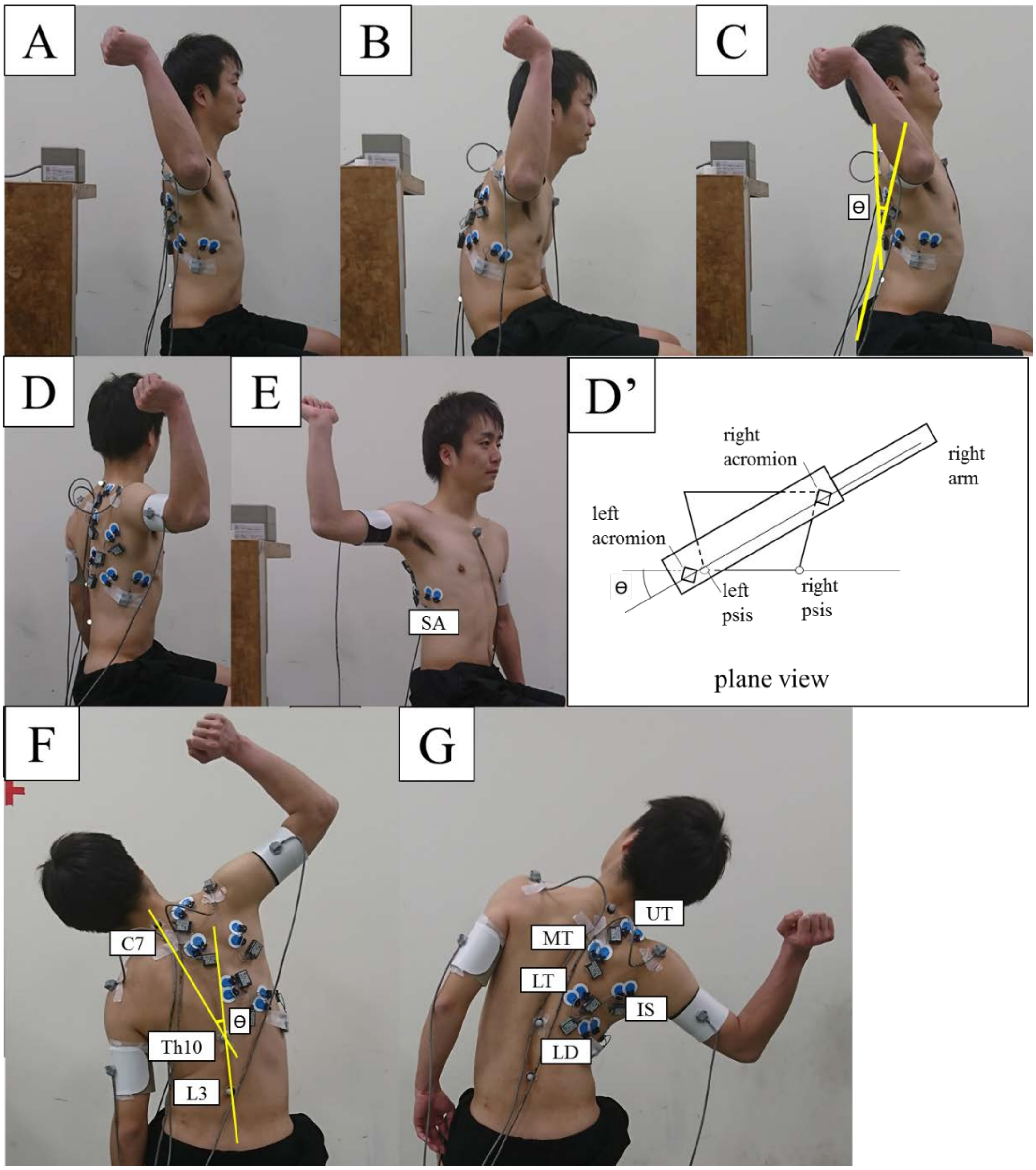

Figure 1 Different trunk postures during 2nd ER.

Participants performed shoulder external rotation at shoulder 90° abduction with different trunk postures. Electromyography electrodes were placed on UT (upper trapezius muscle), MT (middle trapezius muscle), LT (Lower trapezius muscle), SA (serratus anterior), IS (infraspinatus muscle), and LD (latissimus dorsi). Three optical markers were attached to the 7th cervical spinous process (C7), 10th thoracic spinous process (Th10), and 3rd lumbar spinous process (L3). θ means contralateral lateral bending angle. A: upright posture. B: Flexion posture. C: Extension posture. D:

Contralateral rotation. E: Ipsilateral rotation. F: Contralateral lateral bending. G: Ipsilateral lateral bending. D’ shows trunk rotation angle defined by the line linking the bilateral acromion and the line linking the bilateral posterior anterior iliac spine (psis). θ, contralateral lateral bending angle.

Table I. Kinematics data

		GH (°)	Scapula (°)		
	Posture	External rotation	Posterior tilt	Upward rotation	Internal rotation
Control	Upright	89±14	13±6	10±10	12±7
Flexion and Extension	Flex$_{max}$	83±16 [.534]	7±8* [.000]	12±11 [.078]	19±6* [.001]
	Flex20	84±12 [.607]	10±7 [.103]	9±10 [.650]	14±5 [.722]
	(Ext20)	(88±10)	(12±9)	(13±11)	(13±10)
	Ext$_{max}$	97±11 [.259]	12±6 [.591]	12±12* [.027]	10±6 [.347]
	Main effect	F=3.26, p=.029	F=8.66, p<.001	F=3.46, p=.026	F=9.79, p<.001
Rotation	CR$_{max}$	79±11* [.001]	8±7* [.000]	10±11	17±6* [.001]
	CR30	82±10* [.020]	11±6 [.059]	11±10	14±5 [.102]
	CR15	87±12 [.836]	11±6 [.122]	10±10	15±5* [.046]
	IR15	91±10 [1.000]	14±6 [.615]	11±10	13±6 [.659]
	IR30	90±12 [.980]	14±6 [.287]	11±11	14±6 [.447]
	IR$_{max}$	88±17 [.991]	13±6 [1.000]	11±12	12±7 [1.000]
	Main effect	F=6.57, p<0.001	F=14.74, p<.001	F=1.36, p=.241	F=3.75, p=.002
Lateral bending	ILB30	90±10	9±6* [.015]	11±10 [.979]	15±6 [.170]
	ILB15	85±11	11±6 [.456]	11±11 [.925]	14±6 [.407]
	CLB15	86±13	9±7* [.018]	11±10 [.879]	18±7* [.001]
	CLB30	90±11	7±7* [.001]	10±9 [.996]	16±5* [.018]
	Main effect	F=1.86, p=.132	F=4.62, p=.003	F=0.36, p=.838	F=4.68, p=.003

GH, glenohumeral; Flex$_{max}$, maximum flexion; Flex20, 20° of flexion; Ext20, 20° of extension; Ext$_{max}$, maximum extension; CR$_{max}$, maximum contralateral rotation; CR30, contralateral rotation of 30°; CR15, contralateral rotation of 15°; IR15, ipsilateral rotation of 15°; IR30, ipsilateral rotation of 30°; IR$_{max}$, maximum ipsilateral rotation; CLB30, contralateral lateral bending at 30°; CLB15, contralateral lateral bending at 15°; ILB15, ipsilateral lateral bending at 15°; ILB30, ipsilateral lateral bending at 30°; F, Fishers value.

Data are presented as mean ± standard deviation. The P value for each value is shown in brackets.

* Significantly different ($P < .05$) compared with upright posture.

†The Ext20 values were not included in the analysis because only 5 subjects achieved Ext20. The values are shown as reference values.

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Table II. EMG data

	Muscle activation (%MVC) Muscle	UT	MT	LT	IS	SA	LD
Control	Upright	15.9±13.4	23.3±15.3	30.3±18.9	40.7±30.2	27.1±16.6	6.6±5.0
Flexion and Extension	Flex max	18.7±13.1 [.160]	32.1±15.8	45.7±28.3* [.027]	54.5±41.2* [.019]	22.2±9.1[.953]	5.7±4.0
	Flex20	19.7±12.5 [.069]	29.0±15.4	43.0±28.2 [.090]	50.6±38.4[.125]	25.0±10.8 [.554]	6.5±4.3
	(Ext20)	(13.3±18.2)	(10.9±11.0)	(15.0±15.8)	(35.1±27.9)	(29.0±16.0)	(9.6±10.8)
	Ext max	14.6±11.5 [.957]	25.1±19.1	27.0±16.8 [.937]	45.9±31.3[.633]	42.5±23.8 * [.006]	7.4±4.2
	Main effect	F=3.63, p=.021	F=1.86, p=.153	F=4.93, p=.005	F=3.04, p=.040	F=3.47, p=.014	F=1.63, p=.199
Rotation	CR max	16.4±13.7 [.999]	23.1±15.0 [1.000]	18.7±10.1 [.349]	53.4±31.0	36.3±15.9* [.003]	7.9±4.3
	CR30	16.2±11.7 [1.000]	21.5±13.2 [.991]	25.1±13.3 [.945]	50.4±42.8	31.1±19.1 [.863]	7.4±5.2
	CR15	16.6±12.8 [.651]	23.5±16.8 [1.000]	26.2±15.6 [.999]	42.9±32.1	27.4±11.0[1.000]	7.0±4.9
	IR15	18.1±15.2 [.597]	29.9±19.2 [.375]	44.1±28.3 [.172]	44.3±29.4	27.3±10.5 [1.000]	6.3±4.6
	IR30	20.1±15.1 [.155]	33.8±25.7* [.020]	48.2±30.8* [.050]	46.4±36.9	28.1±14.3[1.000]	6.5±4.0
	IR max	21.7±17.2* [.015]	31.6±20.9 [.117]	49.5±33.6* [.025]	40.8±26.1	25.1±12.3[.996]	6.2±4.2
	Main effect	F=2.48, p=.030	F=20.77, p<.001	F=6.58, p<.001	F=2.00, p=.076	F=3.92, p=.002	F=2.08, p=.065
Lateral bending	ILB30	15.1±12.4	26.4±13.2 [.862]	27.0±18.3	39.7±30.4 [.997]	35.2±17.5 [.153]	5.9±3.7
	ILB15	14.0±10.9	26.9±19.3 [.831]	31.0±21.5	38.4±24.5 [.968]	36.8±18.1 [.471]	5.9±3.7
	CLB15	22.2±19.8	31.1±16.1 [.250]	32.1±19.2	51.5±37.0 [.109]	19.4±9.5 [.680]	5.2±2.6
	CLB30	22.8±26.2	39.3±20.0* [.006]	37.3±26.7	53.5±36.9* [.044]	22.0±23.7 [.891]	4.6±2.3
	Main effect	F=1.90, p=.124	F=3.20, p=.020	F=0.79, p=.539	F=4.20, p=.005	F=3.47, p=.014	F=1.80, p=.143

MVC, maximal voluntary contraction; UT, upper trapezius muscle; MT, middle trapezius muscle; LT, lower trapezius muscle; IS, infraspinatus muscle; SA, serratus anterior; LD, latissimus dorsi; $Flex_{max}$, maximum flexion; Flex20, 20° of flexion; Ext20, 20°of extension; Ext_{max}, maximum extension; CR_{max}, maximum contralateral rotation; CR30, contralateral rotation of 30°; CR15, contralateral rotation of 15°; IR15, ipsilateral rotation of 15°; IR30, ipsilateral rotation of 30°; IR_{max}, maximum ipsilateral rotation; CLB30, contralateral lateral bending at 30°; CLB15, contralateral lateral bending at 15°; ILB15, ipsilateral lateral bending at 15°; ILB30, ipsilateral lateral bending at 30°; F, Fishers value. Data are presented as mean ± standard deviation. The P value for each value is shown in brackets.

* Significantly different ($P < .05$) compared with upright posture.

†The Ext20 values were not included in the analysis because only 5 subjects achieved Ext20. The values are shown as reference values.

3 Results

All subjects achieved the rotation and side-bending conditions. However, only 5 subjects performed the Ext20 task, and another subject performed Ext_{max} at a trunk angle of less than 20° of extension. Therefore, the data are shown as reference values but were not included in the analysis. The maximum trunk angle in each trunk condition was 37° ± 6_ for maximum trunk flexion, 14° ± 8° for maximum trunk extension, 44° ± 8° for maximum contralateral trunk rotation, and 42° ± 7° for maximum ipsilateral trunk rotation. The kinematic data of 1 subject for Ext_{max} were excluded because of measurement failure. The kinematic and muscle activity data are described in the following sections.

3.1 Kinematics data

The angles of the scapula and shoulder are presented in Table I. One-way ANOVA indicated a main effect in all conditions for the angle of glenohumeral joint external rotation. The post hoc test revealed that the angle of external rotation in CR_{max} and CR30 significantly decreased compared with that in the upright posture. For scapular posterior tilt, a main effect in all conditions was shown. Scapular posterior tilt in

Flex$_{max}$, CR$_{max}$, ILB30, CLB15, and CLB30 significantly decreased compared with that in the upright posture. For the angle of scapular upward rotation, a main effect was shown in the flexion-extension condition only. The scapula in Ext$_{max}$ was slightly upwardly rotated compared with that in the upright posture. For the scapular external rotation angle, a main effect was shown in all conditions. The angle in Flex$_{max}$, CR$_{max}$, CR15, CLB15, and CLB30 significantly decreased.

3.2 Muscle activity data

All muscle activities are presented in Table II. In the UT, 1- way ANOVA showed a main effect in the flexion-extension and rotation conditions. The muscle activity in IR$_{max}$ significantly increased compared with that in the upright posture. In the MT, a main effect was shown in the rotation and side-bending conditions. The muscle activity in IR30 and CLB30 significantly increased compared with that in the upright posture. In the LT, a main effect was shown in the flexion-extension and rotation conditions. The muscle activity significantly increased in Flex$_{max}$, IR30, and IR$_{max}$. In the infraspinatus, a main effect was shown in the flexion-extension and side-bending conditions. The muscle activity in Flex$_{max}$ and CLB30 significantly increased compared with that in the upright posture. In the SA, a main effect was shown in all conditions. Ext_{max} and CR_{max} increased the muscle activity more significantly than the upright posture. In the LD, there were no main effects in all conditions.

4 Discussion

In this study, we examined the effect of trunk posture on scapular kinematics and muscle activity at maximum shoulder external rotation. To our knowledge, this is the first research study to demonstrate that flexion, extension, rotation, and lateral bending of the trunk minimize the effects of hip motions on scapular kinematics and muscle activity. We hypothesized that extension or ipsilateral rotation of the trunk would contribute to increases in the scapular posterior tilt angle, external rotation angle, and activities of the SA and LT, which are the posterior tilt muscles of the scapula. Our results showed that the scapular posterior tilt angle did not change whereas the SA and LT activities increased with trunk extension and IR_{max}, respectively. It was assumed that this upright posture was relatively close to extension of the trunk considering that only a few subjects achieved trunk extension over 20°. In addition, there were no trunk postures in which both LT and SA activities increased.

In the trunk flexion-extension condition, the angles of scapular posterior tilt and external rotation significantly decreased in $Flex_{max}$ compared with those in the upright posture during ER. Kebaetse et al[16] reported that shoulder abduction range of motion and the angle of scapular upward rotation and posterior tilt during arm elevation decreased with a slouch posture. In addition, they indicated that the acromion may create a bony block that may cause or contribute to impingement pathology with repetitive overhead activity. Our study similarly indicated a decrease in the scapular posterior tilt angle with trunk flexion, which could also cause a bony block. The angle of scapular external rotation decreased whereas the angle of scapular upward rotation did not change in $Flex_{max}$ compared with that in the upright posture —a finding that was partially incongruent with the results of Kebaetse et al. This is considered to be due to the difference in examination posture; their study was not on ER but rather on arm elevation. In Ext_{max} in our study, the angle of scapular upward rotation and the activity of the SA significantly increased compared with those in the upright posture, which is logical considering that the SA has the function of scapular upward rotation.[10,28] The difference of approximately 2° in the scapular upward rotation angle between the upright posture and Ext_{max} is small. Nonetheless, Shaheen et al[34] reported that rigid and elastic taping techniques changed the scapular internal rotation and posterior tilt angles by less than 5° and reduced pain in patients with shoulder impingement syndrome. Therefore, the change of 2° maximum with extension may be clinically significant. We assumed that the differences between the Ext_{max} and upright postures were not enough for some subjects to increase the angle of scapular tilt in Ext_{max} compared with that in the upright posture.

In the trunk rotation condition, the angles of scapular posterior tilt and external rotation significantly decreased in CR_{max} compared with those in the upright posture. Scapular external rotation significantly decreased in CR15 compared with that in the upright posture, whereas in CR_{max} and CR30, the glenohumeral joint external rotation angle significantly decreased. This restriction of shoulder external rotation is predictably caused by the stretched LD, which contributes as a shoulder internal rotator, has the origin at the spine and pelvis, and inserts in the humerus.[1] In IR30 and IR_{max}, the angle of scapular upward rotation did not significantly increase whereas the activity of the LT on scapular upward rotation significantly increased. The increase in LT activity without an increment in scapular upward rotation could be evoked by the physical restriction of the scapular motion by the thorax or the increase in activity of the scapular downward rotators such as the rhomboids,[10] which was not measured in this study.

Yamauchi et al[39] reported that maximum ipsilateral trunk rotation during ER increased the scapular external rotation angle and the activities of the UT, MT, and LT.

This study showed no significant differences in scapular kinematics whereas UT and LT activities significantly increased. The methodology regarding posture differed between our study and this previous study. Subjects performed our task in the sitting position because the purpose of this study was to investigate the effects of trunk posture only. In the study by Yamauchi et al, subjects performed active ER in the standing position; therefore, their study included pelvis rotation. In addition, the upright posture in our study was relatively in a trunk-extended posture. It was assumed that the variance of the results was caused by the definition of postures.

In the side-bending condition, the angles of scapular posterior tilt and external rotation significantly decreased in CLB30 compared with those in the upright posture. In CLB15, only the scapular external rotation angle significantly decreased. It was considered that trunk contralateral bending disturbed scapular external rotation and that MT activity compensatively increased to resist it. In ILB30, the angle of scapular posterior tilt significantly decreased compared with that in the upright posture.

The low activity in the muscles could cause the decrease in scapular posterior tilt. However, there were no decreases in the activities of the LT and SA- the posterior tilt muscles- in trunk postures that showed a significant decrease in the scapular posterior tilt angle. Therefore, the decrease in the scapular posterior tilt angle was not caused by the alteration in scapular muscle activities. The trunk posture was only the factor that differed among these conditions. Consequently, it was considered that the thorax physically restricted the scapular movement, resulting in a decrease in the scapular posterior tilt angle. Moreover, the trunk postures that decreased the angle of scapular external rotation roughly duplicated the trunk postures in which the scapular posterior tilt angle decreased. The decrease in the scapular external rotation angle might also be due to the scapular movement restriction by the thorax.

Our hypothesis was that the activities of the LT and SA that contribute to scapular posterior tilt would synchronously change with it. However, the increase or decrease in the activities of the 2 muscles did not happen simultaneously. On the contrary, the activity of 1 muscle tended to increase in a certain trunk posture while the activity of the other decreased in the same trunk posture. These results suggested that there was a superiority among muscles that have similar action, which may be replaced based on the difference in the trunk posture. These muscle activities might be coordinated to be the most effective muscle force balance for the task because the superiority did not change based on the increase or decrease in the scapular posterior tilt angle.

This study has some limitations. First, the trunk postures were uniquely defined based on the body surface markers, although some previous studies used similar angle definitions. [27,35] Second, the upright posture did not take into account individual specificity. Trunk posture was suggested to be better defined on the basis of the individual trunk range of motion and neutral trunk posture. If the natural trunk posture (neutral trunk posture) was based on the aforementioned definition of trunk posture, all the participants might have achieved Ext20. Finally, surface EMG was not able to measure the deep muscles. The effects of trunk posture on the deep muscles in the present research are unknown.

In clinical sites, if clinicians use training or interventions focusing on scapular kinematics during ER, it is suggested to choose a trunk extension posture rather than a trunk flexion posture because the angles of scapular posterior tilt and external rotation decreased during the task of ER with Flex$_{max}$ in this study. In addition, ipsilateral rotation of the trunk increased the scapular posterior tilt angle and LT activity, which is important in ER; therefore, adding ipsilateral rotation to trunk extension is recommended.

Trunk flexion and ipsilateral rotation postures may resist scapular upward rotation. The activation of the LT with these trunk postures suggests that the LT may be effective for scapular upward rotation in these postures. We suggest that Flex$_{max}$, IR$_{max}$, and IR30 would facilitate LT activity during shoulder external rotation at 90_ of shoulder abduction. Similarly, Ext_{max} and CR_{max} would facilitate SA activity during such shoulder exercise. From the perspective of intensive training of those muscles, future studies are needed to research scapular muscle activities at maximum shoulder external rotation torque.

5 Conclusion

This study showed that the difference in trunk posture affected scapular kinematics and muscle activity during active shoulder external rotation at 90° of abduction. The LT and SA, which both contribute to scapular posterior tilt, were activated by different trunk postures.

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Table legends

Table I. Kinematics data

Table II. EMG data

Figure I. Trunk postures