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Effect of different trunk postures on scapular muscle activities and kinematics during shoulder external rotation

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Scapular angles with different trunk postures

1 Title page

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3 external rotation

4

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21

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25

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27

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28 **Abstract**

29 [Background]

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

35 [Methods]

36 Fourteen healthy men performed active shoulder external rotation at 90° of abduction
37 with the dominant arm in 15 trunk postures. At maximum shoulder external rotation in
38 15 trunk postures, including 4 flexion-extension, 6 trunk rotation, and 4 trunk
39 side-bending postures, as well as upright posture as a control, scapular muscle activities
40 and kinematics were recorded using surface electromyography and an electromagnetic
41 tracking device, respectively. The data obtained in the flexion-extension, trunk rotation,
42 and trunk side-bending postures were compared with those obtained in the upright
43 posture.

44 [Results]

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

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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.

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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 al³⁹ 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.

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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

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100 upward, externally rotated, and posteriorly tilted and these muscle activities increase
101 during the given conditions.

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

111

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112

113 2. Material and Methods

114 2.1 Subjects

115 A controlled experimental study was conducted. Fourteen healthy men (mean age,
116 24.2 ± 1.9 years) without orthopedic or nervous system disease of the upper limb or
117 trunk were included in the study. All subjects provided consent after receiving written
118 and oral explanations regarding the study. This study conformed to the principles of the
119 Declaration of Helsinki. The sample size was based on a 1-way analysis of variance
120 (ANOVA) with repeated measures (effect size of 0.25, α error of .05, and power of 0.8)
121 by use of G*Power (version 3.1; Heinrich Heine University, Dusseldorf, Germany)
122 before the recruitment of subjects. On the basis of the calculation results, the sample
123 size required was 13; this study thus met the statistical power requirement.

124

125 2.2 Experimental procedure

126 Scapular kinematics and muscle activity at ER measured in 14 trunk postures were
127 compared with those in the upright posture to evaluate the effect of trunk posture. The
128 scapular angles, muscle activities, and shoulder external rotation angles were measured
129 at maximum shoulder external rotation. Subjects sat on a platform with an ascent and
130 descent function and placed both feet on the floor with the knee joints at 90° of flexion

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131 and the pelvis not fixed during the task. This posture of the feet and pelvis was the same
132 in all testing postures, and only the trunk posture was changed during the task. Subjects
133 performed 15 trunk postures: upright posture as the control posture; 4 trunk
134 flexion-extension conditions (maximum flexion [$\text{Flex}_{\max}$], 20° of flexion [Flex_{20}], 20°
135 of extension [Ext_{20}], and maximum extension [$\text{Ext}_{\max}$]); 6 trunk rotation conditions
136 (maximum contralateral rotation [$\text{CR}_{\max}$], contralateral rotation of 30° [CR_{30}],
137 contralateral rotation of 15° [CR_{15}], ipsilateral rotation of 15° [IR_{15}], ipsilateral
138 rotation of 30° [IR_{30}], and maximum ipsilateral rotation [$\text{IR}_{\max}$]); and 4 trunk
139 side-bending conditions (contralateral lateral bending at 30° [CLB_{30}], contralateral
140 lateral bending at 15° [CLB_{15}], ipsilateral lateral bending at 15° [ILB_{15}], and ipsilateral
141 lateral bending at 30° [ILB_{30}]). Three optical markers were attached to the seventh
142 cervical spinous process (C7), 10th thoracic spinous process (T10), and third lumbar
143 spinous process (L3). The flexion-extension angle was made by the line connecting C7
144 with T10 and the line connecting L3 with T10 in the sagittal plane. In the upright
145 posture, the angle was 0°. $\text{Flex}_{\max}$ was the posture in which each subject achieved the
146 maximum trunk flexion angle by relaxing. The flexion angle for $\text{Flex}_{\max}$ in all subjects
147 was over 20°. The trunk rotation angle was the angle between the line linking the
148 bilateral posterior anterior iliac spine and the line linking the bilateral acromion. The

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149 trunk side-bending angle was the angle between the line linking C7 and T10 and the line
150 linking L3 and T10 in the coronal plane.

151

152 **2.3 Active shoulder external rotation task**

153 Subjects performed the active ER task to the maximum shoulder external rotation angle
154 with random trunk postures directed from 12 trunk postures except $CR^{\max}$, $IR^{\max}$, and
155 $Ext^{\max}$ (Fig. 1). Then, they performed the active ER task with randomly directed trunk
156 postures from the remaining 3 trunk postures. Before measurement of scapular
157 kinematics and muscle activity during the shoulder external rotation task, the active
158 maximum shoulder external rotation angle was measured using a goniometer at 90° of
159 abduction of the shoulder joint in the directed trunk posture. Subsequently, subjects
160 actively maintained the maximum shoulder external rotation position for 5 seconds. The
161 measurement was performed once in each trunk posture to avoid the effect of fatigue.

162

163 **2.4 EMG protocol**

164 During the shoulder external rotation task, scapular muscle activities were collected
165 using surface electromyography (EMG) (TeleMyo 2400; Noraxon, Scottsdale, AZ,
166 USA) with sampling at 1500 Hz. Electrodes were placed on the UT, MT, LT, SA,

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167 infraspinatus, and latissimus dorsi (LD) in the dominant upper limb with fixed 2.5-cm
168 spacing parallel to the muscle fibers. Skin at the electrode sites was shaved and cleaned
169 using scrubbing gel and alcohol. Electrode placement was based on previous studies or
170 Surface Electromyography for the Non-invasive Assessment of Muscles (SENIAM)
171 recommendations. The locations of the electrodes for each muscle were as follows: The
172 UT electrode is at the midpoint between C7 and the acromion of the scapula.¹⁹ The MT
173 electrode is at the midpoint between the medial border of the scapula and T3. The LT
174 electrode is at the point located at two-thirds on the line from the trigonum spinae (TS)
175 to T8. The infraspinatus electrode is at the midpoint on the line connecting the midpoint
176 of the spine of the scapula and angulus inferior scapulae.¹⁴ The SA electrode is at the
177 halfway point between the anterior border of the LD muscle and the inferior border of
178 the pectoralis major muscle on the seventh rib.⁹ The LD electrode is 2 to 3 cm below the
179 angulus inferior scapulae.³² The raw EMG signals during the shoulder external rotation
180 task were recorded and analyzed for 3 seconds at the shoulder maximum external
181 rotation angle. The EMG signals of the maximal voluntary contraction were recorded
182 for 3 seconds on each muscle. The method was referred to the manual muscle test and
183 previous studies^{2,5,17,32} before subjects began the task. The raw EMG signals were band
184 pass filtered (15-500 Hz, Butterworth) and then smoothed using the root mean square.

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

187

188 **2.5 Scapular kinematics**

189 Three-dimensional kinematics of the scapula and thorax was quantified during the
190 shoulder external rotation task using a 6-df electromagnetic tracking device (Liberty;
191 Polhemus, Colchester, VT, USA) at 120 Hz. This system was composed of a transmitter,
192 5 sensors, and a digitizing stylus connecting the Liberty electronic unit. The transmitter
193 was fixed on a rigid wooden stand at 100 cm in height. This transmitter generated the
194 electromagnetic fields, which constituted the global coordinate system, with the x-axis
195 orienting forward, the y-axis orienting upward, the z-axis orienting right, and the origin
196 located at the transmitter. The sensors were placed on the bony landmarks of the
197 subjects using tape. The thoracic sensor was placed at the sternum just below the jugular
198 notch; the humeral sensor, on the halfway point of the humerus with a thermoplastic
199 cuff; and the scapular sensor, on the flat surface of the acromion. With reference to the
200 positions of these sensors, the local coordinate systems (LCSs) of the thorax, humerus,
201 and scapula were built by digitizing each bony landmark while subjects sat in the
202 anatomic upper-limb position.

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

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

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221 posterior (+) and anterior (–) tilt.

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

227

228 **2.6 Data analysis**

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

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239 postures with the upright posture.

241 Figure 1 Different trunk postures during 2nd ER.

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

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

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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

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275 GH, glenohumeral; Flex_{max}, maximum flexion; Flex20, 20° of flexion; Ext20, 20° of extension; Ext_{max}, maximum extension; CR_{max},
276 maximum contralateral rotation; CR30, contralateral rotation of 30°; CR15, contralateral rotation of 15°; IR15, ipsilateral rotation of
277 15°; IR30, ipsilateral rotation of 30°; IR_{max}, maximum ipsilateral rotation; CLB30, contralateral lateral bending at 30°; CLB15,
278 contralateral lateral bending at 15°; ILB15, ipsilateral lateral bending at 15°; ILB30, ipsilateral lateral bending at 30°; F, Fishers value.
279 Data are presented as mean ± standard deviation. The P value for each value is shown in brackets.
280 * Significantly different ($P < .05$) compared with upright posture.
281 †The Ext20 values were not included in the analysis because only 5 subjects achieved Ext20. The values are shown as reference values.
282

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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

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

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

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

293

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294

295 3 Results

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

305

306 3.1 Kinematics data

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

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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

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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

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348 posture during ER. Kebaetse et al¹⁶ reported that shoulder abduction range of motion
349 and the angle of scapular upward rotation and posterior tilt during arm elevation
350 decreased with a slouch posture. In addition, they indicated that the acromion may
351 create a bony block that may cause or contribute to impingement pathology with
352 repetitive overhead activity. Our study similarly indicated a decrease in the scapular
353 posterior tilt angle with trunk flexion, which could also cause a bony block. The angle
354 of scapular external rotation decreased whereas the angle of scapular upward rotation
355 did not change in Flex_{max} compared with that in the upright posture—a finding that
356 was partially incongruent with the results of Kebaetse et al. This is considered to be
357 due to the difference in examination posture; their study was not on ER but rather on
358 arm elevation. In Ext_{max} in our study, the angle of scapular upward rotation and the
359 activity of the SA significantly increased compared with those in the upright posture,
360 which is logical considering that the SA has the function of scapular upward
361 rotation.^{10,28} The difference of approximately 2° in the scapular upward rotation angle
362 between the upright posture and Ext_{max} is small. Nonetheless, Shaheen et al³⁴ reported
363 that rigid and elastic taping techniques changed the scapular internal rotation and
364 posterior tilt angles by less than 5° and reduced pain in patients with shoulder
365 impingement syndrome. Therefore, the change of 2° maximum with extension may be

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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 al³⁹ reported that maximum ipsilateral trunk rotation during ER increased the scapular external rotation angle and the activities of the UT, MT, and LT.

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

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

398 The low activity in the muscles could cause the decrease in scapular posterior tilt.
399 However, there were no decreases in the activities of the LT and SA- the posterior tilt
400 muscles- in trunk postures that showed a significant decrease in the scapular posterior
401 tilt angle. Therefore, the decrease in the scapular posterior tilt angle was not caused by

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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

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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

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438 shoulder abduction. Similarly, Ext_{max} and CR_{max} would facilitate SA activity during
439 such shoulder exercise. From the perspective of intensive training of those muscles,
440 future studies are needed to research scapular muscle activities at maximum shoulder
441 external rotation torque.

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444 **5 Conclusion**

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

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596 Table legends

597 Table I. Kinematics data

598 Table II. EMG data

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600 Figure I. Trunk postures

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