

Thoracic Hyperkyphosis affects Scapular Orientation and Trunk Motion During Unconstrained Arm Elevation

Jae-man Park¹, MSc, PT, Jong-duk Choi², PhD, PT, Song-i Han³, MSc, PT

¹Dept. of Physical Therapy, College of Graduate School, Daejeon University

²Dept. of Physical Therapy, College of Health & Medical Science, Daejeon University

³Dept. of Physical Therapy, Daejeon Barun mind hospital

Abstract

Background: Shoulder function is achieved by the coordinated movements of the scapula, humerus, and thoracic spine, and shoulder disorders can be associated with altered scapular kinematics. The trunk plays an important role as the kinematic chain during arm elevation.

Objects: The purpose of this study was to determine the effects of thoracic hyperkyphosis on scapular orientation and trunk motion.

Methods: Thirty-one subjects (15 in the ideal thorax group and 16 in the thoracic hyperkyphosis group) performed right-arm abduction and adduction movements in an unconstrained plane. The scapular orientation and trunk motion were recorded using a motion analysis system.

Results: Those subjects with thoracic hyperkyphosis displayed greater scapular posterior tilting at a 120° shoulder elevation, greater scapular internal rotation throughout the arm raising phase, and greater trunk axial rotation at the upper ranges of the shoulder elevation, compared to those subjects with an ideal thorax ($p < .05$).

Conclusion: Thoracic hyperkyphosis can cause scapular instability, greater trunk rotation and greater scapular posterior tilting, and may contribute to preventing the achievement of a full range of humeral abductions in an unconstrained plane.

Key Words: Scapular orientation; Shoulder abduction; Thoracic hyperkyphosis; Trunk.

Introduction

Due to scapula placement on the posterior-lateral plane of thorax, the glenoid fossa is towards the direction of about 35° anterior to the coronal plane. This plane has been defined as the scapular plane, and motion of the scapula and humerus tend to be performed across this plane during arm elevation over head (Meumann, 2010). But scapular position is altered in poor upper body posture; this position can bring about reduced shoulder abduction strength and altered activity of the scapular stabilizer, because the orientation of the scapula affects the length-tension relationship of the muscles associated with the

shoulder complex (Kebaetese et al. 1999; Mottram, 1997; Thigpen et al. 2010; Wegner et al. 2010). It has been suggested that altered shoulder biomechanics could be an effect of shoulder disorders and pain. Recent work has found that patients with shoulder disorders have the decreased upward scapular rotation and posterior tilting, and researchers have suggested that this scapula position leads to a decrease in the subacromial space (Borstad and Ludewig, 2002; Ludewig and Cook, 2000; Mell et al. 2005). The alignment of the cervical and thoracic spine is associated with neck pain (Lau et al. 2010). Also, a slouched posture with greater thoracic kyphosis creates a decrease in shoulder range of mo-

Corresponding author: Jong-duk Choi, choidew@dju.kr

tion (ROM) (Bullock et al. 2005; Kebaetse et al. 1999). Some studies have suggested that restricted ROM and dysfunction of the shoulder results from altered scapular kinematics and muscle imbalance and weakness (Finley and Lee 2003; Kebaetse et al. 1999; Thigpen et al. 2010; Yang et al. 2009).

The thoracic spine plays an important role in the kinematic sequence of arm elevation (Crosbie et al. 2008, Theodoridis and Ruston, 2002). Lateral flexion and axial rotation of the thoracic spine are strongly coupled. The ranges and patterns of coupled-motion lateral flexion and axial rotation in the thoracic spine vary according to thoracic posture and initial motion, as well as thoracic spine segment (Edmondston et al. 2007; Sizer et al. 2007). The trunk contributes to the kinematic chain for arm movement. It has been suggested that the increased trunk movement in patients with shoulder tightness may compensate for impaired arm elevation (Fayad et al. 2008).

Despite this close relationship among thoracic kyphosis, scapular kinematics, and trunk movement during arm elevation, studies of the effects of increased thoracic kyphosis posture on scapular and trunk motion have so far been lacking. The purpose of this study was to determine the effects of increased thoracic kyphosis posture on scapular and trunk motion during arm elevation. We hypothesized that individuals with increased thoracic kyphosis would display increased trunk motion as well as altered scapular motion compared to individuals with ideal thorax posture.

Methods

Thoracic angle measurement

Thoracic kyphosis angle was assessed in 35 volunteers divided into two groups (ideal thorax group and thoracic hyperkyphosis group) using a motion analysis system (LUKOtronic AS202, Lutz-Kovasc-Electronics, Innsbruck, Austria). Active infrared skin markers were placed over the spinous processes of

first, fifth and tenth thoracic vertebrae. Next, participants were instructed to look straight ahead in a natural standing posture with their arms resting at their sides. Thoracic kyphosis angle was recorded while they maintained this posture for three seconds. The thoracic kyphosis angle was derived from the line segments between T1-T5 and T5-T10. In this study, the ideal thorax group was defined as having a thoracic kyphosis angle $\leq 25^\circ$, while the thoracic hyperkyphosis group was defined as having a thoracic kyphosis angle $\geq 35^\circ$ (Claus et al, 2009).

Subjects

Thirty-one healthy right-hand dominant university students who met the thoracic angle parameters as described above in the 35 volunteers were recruited for the study. Mean (standard deviation) height, weight, and age were 163.63 (5.18) cm, 56.47 (9.12) kg, and 21.8 (1.9) years in the ideal thorax group (men=3, women=12), and 165.94 (8.71) cm, 56.69 (8.84) kg, and 22.13 (1.75) years in the thoracic hyperkyphosis group (men=6, women=10). Thoracic kyphosis angle was $21.03 (5.85)^\circ$ in the ideal thorax group and $37.09 (4.19)^\circ$ in the thoracic hyperkyphosis group, and there was a significant difference between groups ($p=.000$). Subjects did not have a history of shoulder girdle surgery, fracture and/or injury, current shoulder and/or neck limited ROM and pain, or scoliosis. Prior to data collection all subjects read and signed a consent form.

Data acquisition

The scapular and trunk kinematics were recorded using a motion analysis system (LUKOtronic AS202, Lutz-Kovasc-Electronics, Innsbruck, Austria). This system consists of three cameras and active infrared skin markers. All kinematics data were recorded at a rate of 100 Hz. Active infrared skin markers were attached on the following anatomical landmarks (Wu et al. 2005): spinous processes of the first and tenth thoracic vertebrae, right and left tenth posterior rib 10 cm from midline, inferior angle and spinal root of

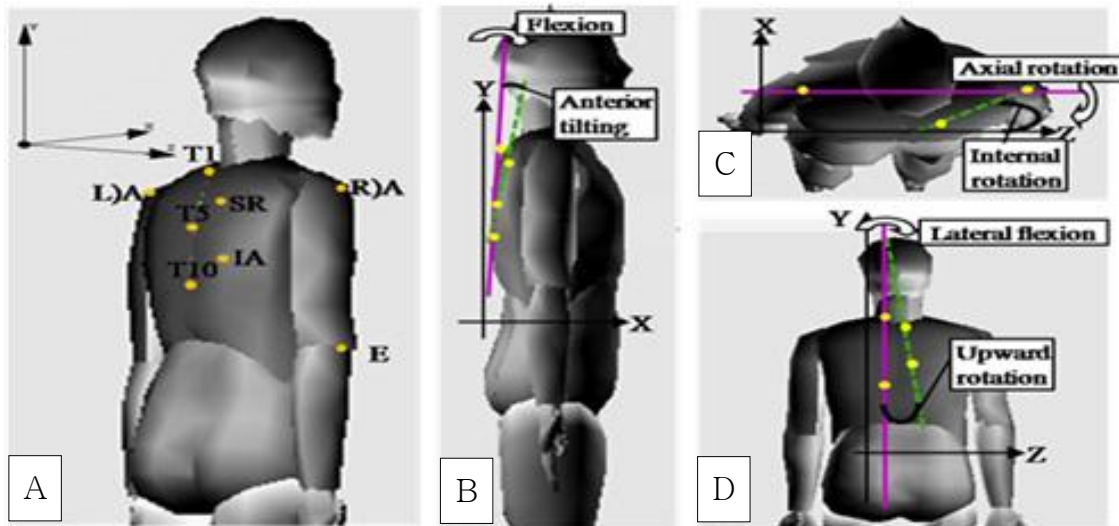


Figure 1. Angle setting (a) location of the infra-red markers used for analysis of scapular orientation and trunk motion, (b) scapular orientation and trunk motion in the sagittal plane, (c) scapular orientation and trunk motion in the transverse plane, (d) scapular orientation and trunk motion in the frontal plane.

the scapula, posterior-lateral acromion, and lateral epicondyle of humerus on the right side. Reliability of scapular orientation measurement using three-dimensional motion analysis ranged between .99 and 1.0 in upward rotation, between .97 and .99 in posterior tilting, and between .78 and .98 in internal rotation (Yano et al. 2010).

In this study, scapular internal border, scapular spine, humerus, and thoracic spine were defined as the line from the spinal root to the inferior angle of the scapula, as the line from the spinal root of the scapula to the acromion, as the line from the acromion to the lateral epicondyle of humerus, and as the line from T1 to T10, respectively.

Data analysis

Humeral angle, trunk motions, and scapular orientations were collected while subjects performed dynamically to raise and lower the arm. Scapular orientations included upward rotation, anterior tilting, and internal rotation of the scapula. Trunk motions included flexion, lateral flexion, and axial rotation. The humeral angle was calculated from the angle between the humerus and the thoracic spine. The

angle of upward rotation, anterior tilting, and internal rotation were calculated from the angle between the scapular internal border and the thoracic spine in the frontal plane, from the angle between the scapula and the thoracic spine in the sagittal plane, and from the angle between the scapular spine and a horizontal line in the transverse plane, respectively (Emery et al. 2010; Kebaetse et al. 1999; Yano et al. 2010). The angle between the thoracic spine and a pure vertical line was projected in the sagittal and frontal plane for collection of flexion and lateral flexion of the trunk, and the angle between the line from right to left of the tenth posterior rib and a horizontal line was projected in the transverse plane for collection of trunk axial rotation (Emery et al, 2010; Fayad et al. 2008) (Figure 1).

Experimental procedure

The motion analysis system was set up in a laboratory. The participants was standing and kept looking straight ahead in a natural static posture with arms resting at their sides. After calibration was completed, each subject performed five abduction and adduction trials in an unconstrained plane while

Table 1. Mixed model analysis of variance for the effects of group (ideal thorax, hyperkyphosis thracic), phase (raising, lowering) and shoulder angle (30°, 60°, 90° ,120°) on scapular orientation and trunk motion

Parameters	ANOVA factor	df	F-ratio	p-value
Scapular orientation				
Upward rotation	Group	1	.000	.986
	Group x humeral angle	3	.960	.962
	Group x phase	1	3.560	.677
	Group x humeral angle x phase	3	.192	.902
Anterior tilting	Group	1	2.459	.128
	Group x humeral angle	3	4.973	.003*
	Group x phase	1	.066	.799
	Group x humeral angle x phase	3	.518	.671
Internal rotation	Group	1	1.632	.212
	Group x humeral angle	3	.355	.786
	Group x phase	1	4.730	.038*
	Group x humeral angle x phase	3	.571	.635
Trunk motion				
Flexion	Group	1	2.699	.111
	Group x humeral angle	3	2.279	.085
	Group x phase	1	3.851	.059
	Group x humeral angle x phase	3	1.941	.129
Lateral flexion	Group	1	.000	.985
	Group x humeral angle	3	.070	.976
	Group x phase	1	.000	.999
	Group x humeral angle x phase	3	.131	.941
Axial rotation	Group	1	8.615	.006*
	Group x humeral angle	3	5.442	.002*
	Group x phase	1	1.124	.298
	Group x humeral angle x phase	3	1.385	.253

*Indicates statistical significance where $p < .05$.

we recorded their scapular and trunk kinematics. They attempted to raise the arm in four seconds (raising phase), maintain maximum elevation for one second, and then lower the arm in four seconds (lowering phase). Subjects were allowed a thirty seconds rest between trials. This task did not control the plane of elevation or elbow and hand position, and only required the subject to reach maximal abduction range comfortably and to lower to the starting arm position for adduction. The scapular and trunk kinematics were collected continuously at a

rate of 100 Hz for the five trials, and scapular orientations and trunk motions at 30°, 60°, 90°, and 120° of the humeral angle in the middle three of the five trials were averaged for data analysis.

6. Statistical analysis

Mixed model ANOVAs (groups-humeral angle x phase) were used to compare scapular orientation (upward rotation, anterior tilting and internal rotation) and trunk motion (flexion, lateral flexion and axial rotation) (dependent variables) between ideal thorax

Table 2. Mean and standard deviation of scapular orientation across groups, phases or shoulder angles

Parameters	Ideal thorax group					Hyperkyphosis thoracic group				
	30°	60°	90°	120°	Phase total	30°	60°	90°	120°	Phase total
Upward rotation										
Raising (°)	1.34 (7.89) ^a	11.04 (9.46)	21.68 (8.73)	31.10 (9.04)	16.29 (2.01)	2.39 (6.86)	11.42 (8.18)	21.55 (9.58)	30.07 (9.68)	16.57 (1.95)
Lowering (°)	3.10 (7.46)	11.45 (7.92)	21.71 (8.83)	30.73 (9.97)	16.97 (1.85)	3.92 (7.06)	11.92 (6.44)	21.15 (7.67)	30.12 (9.08)	16.78 (1.79)
HA ^b total (°)	2.66 (1.85)	11.25 (1.96)	21.70 (2.16)	30.91 (2.42)		3.14 (1.79)	11.67 (1.9)	21.35 (2.09)	30.54 (2.34)	
Group total (°)					16.63 (1.89)					16.68 (1.82)
Anterior tilting										
Raising (°)	-1.12 (2.61)	-5.06 (1.82)	-6.85 (1.74)	-9.95 (3.64)	-5.74 (.67)	-1.56 (2.68)	-5.44 (2.96)	-9.19 (3.56)	-13.78 (4.59)	-7.49 (.65)
Lowering (°)	-1.65 (5.21)	-6.11 (4.53)	-8.37 (4.63)	-10.59 (4.75)	-6.68 (.94)	-2.66 (2.54)	-6.39 (2.70)	-9.96 (3.88)	-13.77 (4.28)	-8.20 (.91)
HA total (°)	-1.38 (.74)	-5.58 (.69)	-7.61 (.83)	-10.27* (1.07)		-2.11 (7.1)	-5.92 (.67)	-9.58 (.81)	-13.77* (1.04)	
Group total (°)					-6.21 (.75)					-7.84 (.72)
Internal rotation										
Raising (°)	21.93 (6.20)	20.35 (6.07)	19.44 (6.00)	17.67 (6.08)	19.85 [†] (1.71)	26.55 (7.51)	25.44 (7.02)	23.86 (7.20)	23.47 (8.72)	24.83 [†] (1.66)
Lowering (°)	22.53 (7.52)	20.52 (7.54)	18.60 (10.37)	18.71 (11.9)	20.09 (2.01)	24.45 (7.56)	20.78 (7.29)	20.32 (7.42)	20.71 (8.54)	21.56 (2.01)
HA total (°)	22.23 (1.76)	20.43 (1.70)	19.02 (1.87)	18.19 (2.20)		25.50 (1.71)	23.11 (1.65)	22.09 (1.81)	22.09 (2.13)	
Group total (°)					19.97 (1.82)					23.20 (1.76)

^amean±standard deviation, ^bhumeral angle, *thoracic hyperkyphosis group's anterior tilting angle at 120° < ideal thorax group, [†]thoracic hyperkyphosis group's internal rotation angle at raising phase > ideal thorax group.

and thoracic hyperkyphosis groups (independent variable). Each analysis included humeral angles (30°, 60°, 90° and 120°) and phase (raising phase and lowering phase) as within subject factors. Statistical significance was set at $\alpha < .05$ for all analyses and effect sizes were calculated. Post-hoc Tukey tests with Bonferroni adjustments were run where statistically significant interactions were noted. All statistical analyses were performed using SPSS for Windows

software ver. 25.0, (IBM corp., Armonk, NY, USA).

Results

Scapular orientation

For scapular upward rotation, there were no significant main effects for the group, and interactions for the group by humeral angle, group by phase, or

Table 3. Mean and standard deviation of trunk motion across groups, phases or shoulder angle

Parameters (°)	Ideal thorax group				Phase total	Hyperkyphosis thoracic group				Phase total
	30°	60°	90°	120°		30°	60°	90°	120°	
Flexion										
Raising	4.96 (4.77) ^a	5.36 (4.39)	3.93 (4.61)	3.63 (4.22)	4.47 (1.64)	7.97 (7.49)	7.72 (7.77)	7.40 (8.11)	7.59 (9.10)	7.67 (1.59)
Lowering	4.10 (4.42)	3.03 (5.54)	2.50 (5.38)	1.80 (6.06)	2.86 (1.77)	8.23 (7.60)	7.20 (8.17)	7.27 (8.78)	6.85 (8.32)	7.39 (1.72)
HA ^b total	4.53 (1.6)	4.20 (1.68)	3.22 (1.79)	2.72 (1.74)		8.10 (1.55)	7.46 (1.63)	7.33 (1.73)	7.22 (1.97)	
Group total					3.66 (1.69)					7.53 (1.64)
Lateral flexion										
Raising	.50 (2.73)	2.44 (2.93)	3.42 (3.37)	5.44 (4.26)	2.95 (.73)	.39 (2.05)	2.43 (2.21)	3.59 (2.81)	5.31 (3.73)	2.93 (.70)
Lowering	1.18 (2.89)	2.15 (3.52)	3.24 (3.60)	4.95 (4.48)	2.88 (.81)	1.00 (2.28)	2.27 (2.62)	3.27 (3.06)	4.88 (3.68)	2.86 (.79)
HA total	.84 (.62)	2.29 (.71)	3.33 (.81)	5.19 (1.03)		.70 (.60)	2.35 (.69)	3.43 (.78)	5.10 (1.00)	
Group total					2.91 (.76)					2.89 (.73)
Axial rotation										
Raising	.48 (.30)	-1.29 (2.97)	-2.46 (4.01)	-5.34 (5.63)	-2.15 (.73)	.44 (.28)	-3.65 (2.83)	-6.95 (4.14)	-10.82 (4.77)	-5.24 (.71)
Lowering	.64 (4.80)	-3.87 (4.37)	-5.55 (6.69)	-7.28 (5.64)	-4.01 (1.13)	-2.24 (4.76)	-7.53 (4.42)	-10.54 (4.65)	-12.21 (5.07)	-8.13 (1.09)
HA total	.56 (.61)	-2.58* (.81)	-4.00* (1.10)	-6.31* (1.30)		-.91 (.59)	-5.59* (.79)	-8.74* (1.06)	-11.51* (1.26)	
Group total					-3.70* (.51)					-6.07* (.78)

^amean±standard deviation, ^bhumeral angle, *thoracic hyperkyphosis group's axial rotation angle at 60°, 90° and 120° >ideal thorax group, † thoracic hyperkyphosis group's axial rotation angle >ideal thorax group

group by humeral angle by phase (Table 1).

For scapular anterior tilting, there was a significant group by humeral angle interaction (p=.003; effect size=.146) (Table 1). Scapular tiling angles in the raising and lowering phase at each humeral angle were averaged for further analysis of each humeral angle; there was a significant main effect of the group at 120° of humeral angle (p=.026; effect size=.16) (Table 2). There were no other significant main effects of group or interactions for group by phase, or group by humeral angle by phase.

For scapular internal rotation, there was a significant group by phase interaction (p=.038; effect

size=.14) (Table 1). Scapular internal rotation angles at 30°, 60°, 90° and 120° of the humeral angle at each phase were averaged for further analysis of each phase, there was a significant main effect of the group at the raising phase (p=.46; effect size=.131) (Table 2). There were no other significant main effects of the group or interactions for the group by humeral angle, or group by humeral angle by phase.

Trunk motion

For trunk flexion, there were no significant main effects of the group or interactions for the group by

humeral angle, group by phase, or group by humeral angle by phase (Table 1).

For trunk lateral flexion, there were no significant main effects of the group or interactions for the group by humeral angle, group by phase or group by humeral angle by phase (Table 1).

For trunk axial rotation, there was a significant main effect of the group ($p=.006$; effect size=.229) (Table 1). Average trunk axial angles in the thoracic hyperkyphosis group displayed greater trunk axial rotation angles than the ideal thorax group (Table 3). There was a significant group by humeral angle interaction ($p=.002$; effect size=.158) (Table 1). Trunk axial rotation angles in the raising and lowering phase at each humeral angle were averaged for further analysis of each humeral angle; there was a significant main effect of the group at 60° , 90° , and 120° of the humeral angle ($p=.013$; effect size=.194, $p=.004$; effect size=.249, $p=.008$; effect size=.221, respectively) (Table 3). There were no other significant interactions for group by phase, or group by humeral angle by phase.

Discussion

Scapular orientation

We had assumed that the scapular plane in individuals with thoracic hyperkyphosis posture would naturally be altered due to altered scapular position. Therefore, subjects were instructed to abduct and adduct across their natural plane. In the current study, individuals with thoracic hyperkyphosis posture displayed significant greater posterior tilting at 120° of the humeral angle compared to those with ideal thorax posture, though scapular upward rotation was not significantly different between groups. In past studies, no significant relationship was revealed between thoracic posture and impingement (Lewis et al. 2005; McClure et al. 2006). Previous studies had reported that less scapular upward rotation, less posterior tilting, and greater internal rotation were dis-

played in shoulders with impingement or rotator cuff disease, and less scapular upward rotation and posterior tilting of these would result in a lack of elevation of the anterior acromion, contributing to impingement (Ludewig and Braman, 2011; Ludewig and Cook, 2000; Ludewig and Reynodls, 2009). Our results can explain that thoracic hyperkyphosis posture may not produce an alteration of scapular orientation that could cause impingement or rotator cuff disease.

A previous study reported that when the same subjects adopted a slouched posture compared to an erect posture during abduction in the scapular plane, the posterior tilting relative to the thoracic spine was increased at rest and horizontal arm position and decreased at maximal arm position, and shoulder maximal abduction angle was decreased (Kebaetse et al. 1999). The scapular posterior tilting as well as humeral external rotation occurred remarkably after 90° of abduction in the scapular plane and were essential secondary motion for greater humeral elevation, whereas scapular upward rotation occurred approximately linearly through humeral elevation (Yano et al. 2009). Scapular posterior tilting and upward rotation were accompanied by humeral external rotation (McClure et al, 2001). It has been suggested that increases in scapular orientation appeared in order to assist reduced motion of the glenohumeral joint and for protection of the subacromial space (Chopp et al. 2011, McClure et al. 2006). Therefore, an increase of scapular posterior tilting at 120° in subjects with thoracic hyperkyphosis posture may contribute to achievement of full range of humeral elevation.

In our study, subjects in the thoracic hyperkyphosis group displayed greater internal rotation at the raising phase; this result is consistent with reports examining the effects of forward head position and rounded shoulder posture on scapular rotation angle during reaching tasks (Thigpen et al. 2010). The greater scapular internal rotation produced a protraction such of the scapula that scapular medial border moves away from the thorax (Bourne et al. 2007). Previous studies have found that this position

leads to altered activity of the upper and lower trapezius and serratus anterior, reduced shoulder abduction, and external/internal rotation strength due to instability of the scapulothoracic and glenohumeral joints (Ludewig and Reynolds, 2009; Picco et al. 2010; Smith et al. 2003; Smith et al. 2006). A previous study found that greater upper thoracic angle as well as a lesser craniovertebral angle are displayed in a person with neck pain, and the upper thoracic angle has stronger correlation with neck pain severity than forward head angle (Lau et al. 2010). We suggest that it is possible to cause neck pain if the increased thoracic kyphosis angle related to a greater incline of the cervical spine and protraction of the scapula was sustained for a prolonged period.

We found that subjects with thoracic hyperkyphosis posture have greater axial rotation of the trunk during arm elevation. In a previous report comparing trunk motion between subjects without and with frozen shoulder, increased axial rotation of the trunk was displayed during abduction in subjects with frozen shoulder compared to healthy subjects, suggesting that increased trunk motion may compensate for impaired arm elevation (Fayad et al. 2008). We may state that the trunk has an important role as kinematic chain during arm elevation, and increased trunk torsion in subjects with thoracic hyperkyphosis posture may represent compensatory motion for greater range of humeral elevation.

Limitations

Subjects in this study were healthy individuals in their early 20 s without pain in the neck or shoulder. It was difficult to represent the general population or, the relationship between pain and degree of thoracic kyphosis. Altered actions of shoulder musculature can change the motion of scapulothoracic and glenohumeral joints. There is some lack of explanation as to why there seems to be a difference between our study and previous study results, because we did not measure muscle activity or other spine alignment. We measured global trunk motion, whereas the pre-

vious study measured rotation within the thoracic spine. This difference between measurements should be considered in the interpretation of these results.

Conclusion

The results of this study show that subjects with thoracic hyperkyphosis posture free from neck/shoulder pain displayed greater scapular posterior tilting at 120° of shoulder elevation, greater scapular internal rotation throughout arm raising, as well as greater trunk axial rotation at the upper ranges of shoulder elevation. Our finding provides evidence that thoracic hyperkyphosis posture leads to scapular instability by placing the scapula in a protraction position. Greater trunk rotation and greater scapular posterior tilting was compensatory for full range of abduction instead of scapular instability.

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