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Three-dimensional scapulothoracic motion during active and passive arm elevation

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Abstract

Background. Scapulothoracic muscle activity is believed to be important for normal scapulothoracic motion. In particular, the trapezius and serratus anterior muscles are believed to play an important role in the production and control of scapulothoracic motion. The aim of this study was to determine the effects of different levels of muscle activity (active versus passive arm elevation) on three-dimensional scapulothoracic motion.

Methods. Twenty subjects without a history of shoulder pathology participated in this study. Three-dimensional scapulothoracic motion was determined from electromagnetic sensors attached to the scapula, thorax and humerus during active and passive arm elevation. Muscle activity was recorded from surface electrodes over the upper and lower trapezius, serratus anterior, anterior and posterior deltoid, and infraspinatus muscles. Differences in scapulothoracic motion were calculated between active and passive arm elevation conditions.

Findings. Scapular motion was observed during the trials of passive arm elevation; however, there was more upward rotation of the scapula, external rotation of the scapula, clavicular retraction, and clavicular elevation under the condition of active arm elevation. This was most pronounced for scapular upward rotation through the mid-range (90–120°) of arm elevation.

Interpretation. The upper and lower trapezius and serratus anterior muscles have an important role in producing upward rotation of the scapula especially throughout the mid-range of arm elevation. Additionally, it appears that capsuloligamentous and passive muscle tension contribute to scapulothoracic motion during arm elevation. Assessment of the upper and lower trapezius and serratus anterior muscles and upward rotation of the scapula should be part of any shoulder examination.

Keywords: Biomechanics; Shoulder; Scapula; Muscle activity

1. Introduction

Motion of the scapula on the thorax is essential for normal function of the upper extremity (Kibler and McMullen, 2003). Scapulothoracic motion has been studied using two-dimensional (2-D) (Doody et al., 1970; Poppen and Walker, 1976) and more recently three-dimensional (3-D) (Karduna et al., 2001; Ludewig and Cook, 2000; McClure et al., 2001) measurement techniques. The orientation of the scapula relative to the thorax and the position of the scapula on the thorax are used to describe 3-D scapulothoracic motion (Karduna et al., 2001). Scapular rotations used to describe the orientation of the scapula relative to the thorax include upward and downward rotation, external and internal rotation, and posterior and anterior tilting (Karduna et al., 2001). Rotations of the clavicle are used to describe the position of the scapula on the thorax and include protraction and retraction and elevation and

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depression (Karduna et al., 2001). As the arm is elevated the scapula progressively upwardly rotates, externally rotates, posteriorly tilts (McClure et al., 2001; Ludewig et al., 1996), and the clavicle retracts and elevates (McClure et al., 2001; Ludewig et al., 2004). This pattern has been demonstrated in asymptomatic individuals under static (Ludewig et al., 1996; Lukasiewicz et al., 1999) and dynamic conditions (Karduna et al., 2001; Ludewig et al., 2004).

Amongst the 14 muscles that surround and attach to the scapula, the upper and lower portions of the trapezius and the serratus anterior muscles are believed to be important for scapulothoracic motion (Inman et al., 1944; Bagg and Forrest, 1988; Ludewig et al., 1996). These muscles are typically described as producing upward rotation and retraction of the scapula (Bagg and Forrest, 1988; Inman et al., 1944; Ludewig et al., 1996). Additionally, the upper and lower trapezius and serratus anterior muscles have been proposed to play a role in producing external rotation and posterior tilt of the scapula (Ludewig et al., 1996; Kent, 1971; Perry, 1978).

One way to determine how muscle activity influences scapulothoracic motion is to compare scapular motion during active and passive arm elevation. Qingyun and Gongyi (1998) used X-ray fluoroscopy to investigate active and passive shoulder motion in eighteen healthy subjects. From the X-rays, an angle between the glenoid surface and pivot of the humerus (GHA) was measured. Their description of the GHA angle was not clear and this makes the interpretation of their results difficult. However, their findings indicate that motion at the scapulothoracic and glenohumeral joints was different during active arm elevation compared with passive arm elevation. McQuade and Smidt (1998) used 3-D measures of scapular and humeral motion to study scapulohumeral rhythm (scapular upward rotation relative to humeral elevation) in 25 healthy subjects under three different conditions of arm elevation; (1) active elevation, (2) active elevation against resistance, and (3) passive elevation. Total arm elevation was divided into five different phases and the scapulohumeral rhythm for each condition in each phase was determined. For the first three phases of motion there was less upward rotation of the scapula during the passive condition compared to the active condition. In the final two phases of motion there was more upward rotation of the scapula for the passive condition compared to the active condition. Price et al. (2000) used 3-D measurement techniques to compare scapular motion during active and passive arm elevation. Bilateral measurements were obtained on 10 healthy subjects at 10° intervals from 10° to 50° of humeral elevation in the coronal plane. The authors noted that elevation beyond 50° was not performed in order to avoid humeral impingement against the coracoacromial arch and decrease the chance of the scapula being pulled along the thorax by the humerus. No differences in 3-D scapular motion were found between active and passive arm elevation trials.

Collectively the results from these studies (McQuade and Smidt, 1998; Price et al., 2000; Qingyun and Gongyi, 1998) indicate that scapulothoracic motion is influenced by whether the arm is actively or passively elevated. However, these studies are limited by the use of 2-D measurement techniques (Qingyun and Gongyi, 1998), assessment of motion through a limited range (Price et al., 2000), reporting on only one scapular rotation despite the use of 3-D measurement techniques (McQuade and Smidt, 1998), and lack of muscle activity quantification (McQuade and Smidt, 1998; Qingyun and Gongyi, 1998; Price et al., 2000) which makes it is difficult for the reader to get a sense of how relaxed the muscles were during passive arm elevation trials. Additional studies that address these issues are needed to further the understanding of how scapulothoracic muscle activity influences scapulothoracic motion. This information will provide a basis for clarifying the role that scapulothoracic muscles have in the production and control of scapulothoracic motion. Additionally it will provide a basis for further understanding of the contribution of muscle dysfunction to shoulder pathologies. Therefore, the purpose of this study was to determine the effects of different levels of muscle activity (active versus passive arm elevation) on 3-D scapulothoracic motion.

2. Methods

2.1. Subjects

Twenty subjects (10 male and 10 female) without a history of shoulder pathology or pain in at least one shoulder voluntarily participated in the study (mean age = 22.5; range 18–30 yr, height = 166.5 cm; range 150–182.5 cm, weight = 66.4 kg; range 47.2–99.9 kg). All subjects underwent a brief clinical examination which consisted of a history and shoulder range of motion and manual muscle testing measures. Subjects were required to be at least 18 years of age, and have a minimum of 120° of humeral elevation. For three subjects, electromyographic (EMG) data from their passive elevation trials exceeded the maximum cut-off value (20% of the value recorded during a maximum voluntary isometric contraction) and therefore their data were not included. Therefore, the final sample consisted of 17 subjects (9 male and 8 female) (mean age = 22.5; range 18–30 yr, height = 165.9 cm; range 150–182.5; weight = 64.2 kg; range 47.2–86.3 kg). The dominant arm (arm used for writing) was tested in nine subjects and the non-dominant arm was tested in eight subjects. In all subjects except two, the arm to be tested was determined randomly. Two subjects had a history of shoulder injury on their non-dominant arm; therefore their dominant arm was tested. Approval for this study was obtained from the institutional review board at Drexel University. Each subject read and signed a consent form prior to participation in the study.

2.2. Instrumentation

The Noraxon MyoSystem 1200 (Noraxon, USA, Inc., Scottsdale, AZ) was used to collect raw surface EMG data. This unit provides signal amplification (1000×), band pass filtering (10–500 Hz), common mode rejection ratio greater than 100 dB, and differential input impedance greater than 10 MΩ. Pre-amplification of the EMG signal was not performed. Output from the Noraxon was linked to an analog to digital board in a personal computer and raw data were monitored and collected in LabView (National Instruments, Austin, TX, USA) at a frequency of 1024 Hz. Disposable silver–silver chloride surface electrodes with an inter-electrode distance of 2.5 cm (Respitech Medical, Lancaster, PA, USA) were used.

Three-dimensional kinematic data from the scapula, humerus, and trunk were collected at 40 Hz with the Polhemus 3Space Fastrak (Colchester, VT, USA). This electromagnetic tracking device consists of a transmitter, three receivers, and a digitizing stylus, all of which are hardwired to a systems electronic unit. The transmitter emits electromagnetic fields that are detected by the digitizer and receivers. The system's electronic unit determines the relative orientation and position of the receivers, and this information is sent to a computer where the data are collected. This system has been used in a number of studies that have investigated shoulder girdle motion (Karduna et al., 2001; Ludewig and Cook, 2000).

2.3. Experimental procedure

2.3.1. EMG

Surface electrodes were placed over the upper and lower trapezius, serratus anterior, anterior deltoid, posterior deltoid, and infraspinatus muscles following previously reported placement sites (Fig. 1) (Hintermeister et al., 1998; McQuade et al., 1998). A ground electrode was placed over the ipsilateral clavicle. To allow for normalization of EMG measures, EMG data were collected during three trials of a 5-s maximum voluntary isometric contractions (MVIC) for each muscle following standard manual muscle testing procedures (Kelly et al., 1996; Kendall et al., 1993). Multiple options exist for performing a manual muscle test of the serratus anterior and anterior and posterior deltoid muscles. In this study the serratus anterior was tested by asking the subjects to lie supine with the shoulder flexed to 90°. Subjects were instructed to reach up towards the ceiling while the examiner exerted downward pressure against their fist. The anterior deltoid was tested with the subjects in a seated position, and the shoulder elevated to 90° in the plane of the scapula. Manual resistance was given just proximal to the elbow in a downward direction. The posterior deltoid was tested with the subjects in a prone position with the shoulder abducted to 90°. Manual resistance was provided at the elbow in a downwards direction. The averaged value from a 1-s time period (3.5–4.5 s) was used as the normalization reference.

2.3.2. Kinematics

Three Polhemus receivers were attached to each subject (Fig. 1). The first receiver was attached, by double-sided tape and Spirit Gum Matte Adhesive, to the skin overlying the third thoracic spinous process. The second receiver was attached to a thermoplastic cuff which was placed distally on the humerus just proximal to the epicondyles and was held in place with an elastic strap (Ludewig et al., 2002). The third receiver was mounted to a scapular tracker device (Karduna et al., 2001). This device was attached with Velcro strips and Spirit Gum Matte Adhesive to the skin overlying the spine of the scapula and the flat superior surface of the acromion. The base of the scapular tracker was attached to Velcro strips placed above and below the scapular spine, and the footpad of the tracker was attached to the Velcro on the superior aspect of the acromion. The use of surface mounted sensors for tracking scapular and humeral motion during arm elevation has been investigated and the average root-mean-square errors were less than 5° when compared with sensors that were directly attached to the scapula and humerus by bone pins (Karduna et al., 2001; Ludewig et al., 2002). The transmitter was attached to an upright plastic pole, and acted as the global reference frame. The coordinate axes of the transmitter were aligned with the cardinal planes of the body. This was accomplished by having the subjects sit in a chair with their eyes fixed forward. The chair was place directly in front of the transmitter and was aligned with the axes of the transmitter. A bubble level was used to adjust the orientation of the transmitter to a level position.

With subjects in a seated position, several bony landmarks on the thorax, humerus and scapula were palpated and digitized in order to allow the arbitrary axis system defined by the Polhemus to be converted to a meaningful anatomical axis system (Karduna et al., 2001). The anatomical axis system was identical to that described previously (Karduna et al., 2001, 2000; McClure et al., 2001), and was determined from three points on the thorax, scapula and humerus. For the purpose of this study, the body segments and their corresponding digitization points were: Thorax: T1, T7, sternal notch; Scapula: acromioclavicular joint, root of the scapular spine, inferior angle of the scapula; Humerus: medial

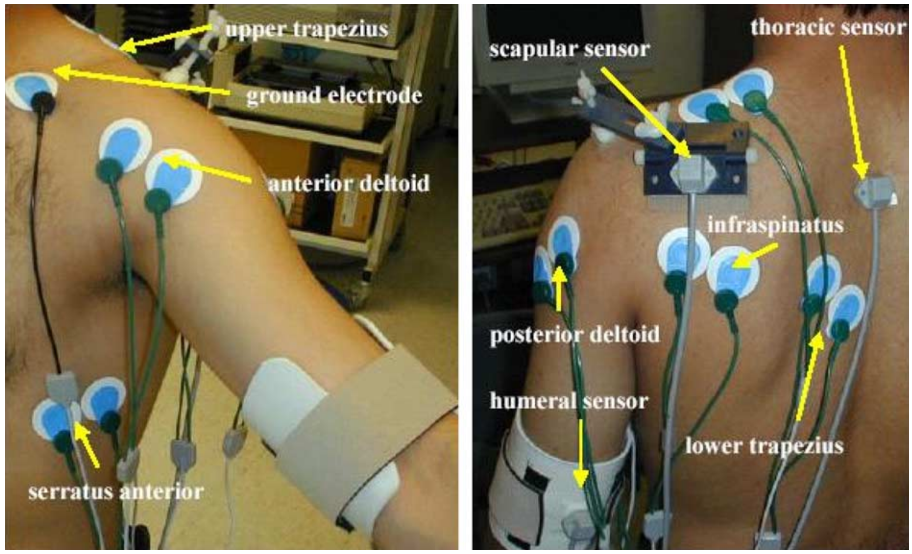

Fig. 1. Anterior and posterior view of EMG surface electrode and Polhemus sensor placement.

epicondyle, lateral epicondyle, humeral head. The center of the humeral head was calculated using a least squares algorithm and was defined as the point that moved the least during several small arcs of motion (Harryman et al., 1990). The long axes of the trunk, scapula, and humerus were defined as follows; trunk: a line connecting T1 and T7; scapula: a line connecting the root of the scapular spine and acromioclavicular joint; humerus: a line connecting the center of the humeral head with the point mid-way between the medial and lateral humeral epicondyles.

2.3.3. Arm elevation trials

Following the digitization process, kinematic and EMG data were simultaneously collected during trials of maximal active and passive scapular plane arm elevation. For these trials subjects sat upright in a low back wooden chair. The top of the chair back reached the lower thoracic/upper lumbar level in all subjects and did not contact the scapula during any of the tests. Active and passive arm elevation took place in the scapular plane which was defined as 40° (±10°) anterior to the frontal plane. A plastic pole was positioned along the lateral aspect of the subjects' arms and acted as a guide to maintain the plane of elevation. For the active trials, subjects were told to raise and lower their hands over their heads with their thumbs pointing up while maintaining light contact with the plastic pole. For the passive trials, subjects' wrists were placed in a splint that was attached to a rope which went to an overhead pulley system. The examiner used the other end of the rope to passively elevate the subjects' arms. During the active and passive trials the elbow was allowed to move. In the first phase of the motion (resting position to approximately 90° of elevation) the elbow moved into flexion. In the second phase of motion (90° to full elevation) the elbow moved into extension. The pattern of elbow motion was kept consistent between the active and passive trials. Each trial of active and passive arm elevation was performed to a count of 8 s; 4 s to raise the arm and 4 s to lower it. Correct performance of active and passive trials was defined as the motion being performed in the appropriate amount of time and plane of elevation (40° ± 10° anterior to the frontal plane). Subjects were allowed to practice the active motion until they were able to perform it correctly. Practice trials of passive elevation were conducted until the motion was performed correctly and the examiner felt that subjects were relaxed and did not assist with the motion. Due to the fact that normalized EMG data was calculated after the testing session, the examiner relied on his assessment of the subjects' arm weight in order to determine if they were able to adequately relax their arm during the passive trials. Once these criteria were met, data collection began. Active elevation trials were always performed prior to passive elevation trials in an attempt to enhance subject relaxation during the passive elevation trials by familiarizing them with the procedure during the active trials. For all subjects except two, the tested extremity was randomized. Two of the subjects had a history of a shoulder injury; therefore their non injured side was tested. Surface electrodes and sensors were not removed between the active and passive trials.

2.4. Data reduction

The kinematic data for scapular orientation and position were described using three scapular rotations and two clavicular rotations as dependent variables that were plotted against humeral elevation as the independent variable. The orientation of the scapula relative to the trunk was described using an Euler angle sequence of external/internal rotation (Z_S-axis), upward/downward rotation (Y_S-axis), and posterior/anterior tilt (X_S-axis). Two clavicular rotations, protraction/retraction and elevation/depression were used to describe scapular position. The basis and details of this approach have been described previously (Karduna et al., 2001; McClure et al., 2001). Following collection of the kinematic data, a linear interpolation program was used to obtain data in 5° increments and data from the three trials were averaged.

Resting EMG values for each muscle were determined from a 2-s time period that preceded each MVIC. These values were subtracted from the EMG values collected during the MVICs and trials of active and passive arm elevation. The largest EMG value for each muscle during the MVICs was considered the maximal (100%) EMG value. The EMG values from the three trials of arm elevation were averaged for both the active and passive conditions. These averaged values were then expressed as a percentage of the MVIC EMG values by dividing the motion EMG values by the MVIC values and multiplying by 100. If a subject's averaged EMG values from the passive trials exceeded 20% MVIC at 60°, 90°, or 120° of elevation, their data were excluded from the study. Muscle activity levels less than 20% MVIC have been described as slight to minimal, and these levels are associated with commonly prescribed passive range of motion exercises (Glousman et al., 1986; McCann et al., 1993; Dockery et al., 1998). Furthermore, this cut off value was based on earlier pilot work conducted in our lab which indicated that different amounts of scapular rotation could be detected between active and passive arm elevation when muscle activity during passive elevation was below 20% MVIC.

2.5. Data analysis

Reliability statistics for trial to trial kinematic measurements included intraclass correlation coefficients (ICC 3,1) and the standard error of the measurement (SEM). A 2-factor analysis of variance (ANOVA) with two repeated factors, muscle condition (active and passive) and humeral elevation angle (minimum, 60°, 90°, 120°, and maximum), was performed on each dependent variable. The dependent variables of interest in this study were scapular external/internal rotation, upward/downward rotation, posterior/anterior tilting, and clavicular protraction/retraction and elevation/depression. For the 2-factor analyses, a significance level of 0.05 was used for each dependent variable. Paired t-tests were used for follow up analyses when a significant interaction was present. A Bonferonni factor was used to correct for multiple comparisons and the significance level for the paired t-tests was set at 0.01.

3. Results

Trial-to-trial ICC values for the kinematic dependent variables for both elevation conditions ranged from 0.74 to 0.99 indicating moderate to good reliability (Portney and Watkins, 2000), and standard error of the measurement for both elevation conditions ranged from 0.5° to 3.0° (Table 1). The averaged passive EMG values were under 10% MVIC for all muscles across all positions of humeral elevation with the exception of the serratus anterior muscle at 150° of elevation where the averaged activity level was 11.9%. Averaged EMG data for all muscles during the active and passive elevation trials are presented in Fig. 2.

Scapulothoracic motion for both the active and passive conditions is presented in Fig. 3 and descriptive statistics are listed in Table 2. During active trials of scapular plane elevation, the predominant scapular motion was upward rotation which progressively increased as the arm was elevated. The scapula underwent a small amount of posterior tilt up to 90° of elevation after which it moved into an anteriorly tilted position. A small amount of external rotation occurred from the beginning of the motion up to 90° after which the

Table 1
Intraclass correlation coefficient values (and SEM) for scapular and clavicular motion across arm elevation angles

		Scapular rotations (°)			Clavicular rotations (°)	
		Posterior tilt	Upward rotation	External rotation	Protraction	Elevation
30°	Active	0.99 (0.7)	0.88 (2.0)	0.96 (1.7)	0.93 (1.3)	0.97 (1.0)
	Passive	0.99 (0.7)	0.97 (1.0)	0.98 (1.1)	0.97 (0.7)	0.99 (0.5)
60°	Active	0.98 (0.9)	0.84 (1.7)	0.96 (1.7)	0.93 (1.2)	0.98 (0.9)
	Passive	0.99 (0.6)	0.92 (1.9)	0.97 (1.3)	0.97 (0.7)	0.98 (0.7)
90°	Active	0.96 (1.7)	0.74 (2.8)	0.95 (2.4)	0.89 (1.7)	0.95 (1.3)
	Passive	0.98 (1.1)	0.89 (2.2)	0.98 (1.3)	0.95 (1.0)	0.98 (0.7)
120°	Active	0.96 (2.1)	0.74 (2.9)	0.95 (2.8)	0.88 (1.8)	0.96 (1.3)
	Passive	0.98 (1.1)	0.92 (2.0)	0.98 (1.4)	0.96 (0.9)	0.98 (0.7)
150°	Active	0.96 (2.6)	0.94 (1.4)	0.97 (3.0)	0.97 (0.9)	0.98 (0.8)
	Passive	0.97 (1.6)	0.97 (1.6)	0.97 (2.5)	0.98 (0.7)	0.99 (0.8)

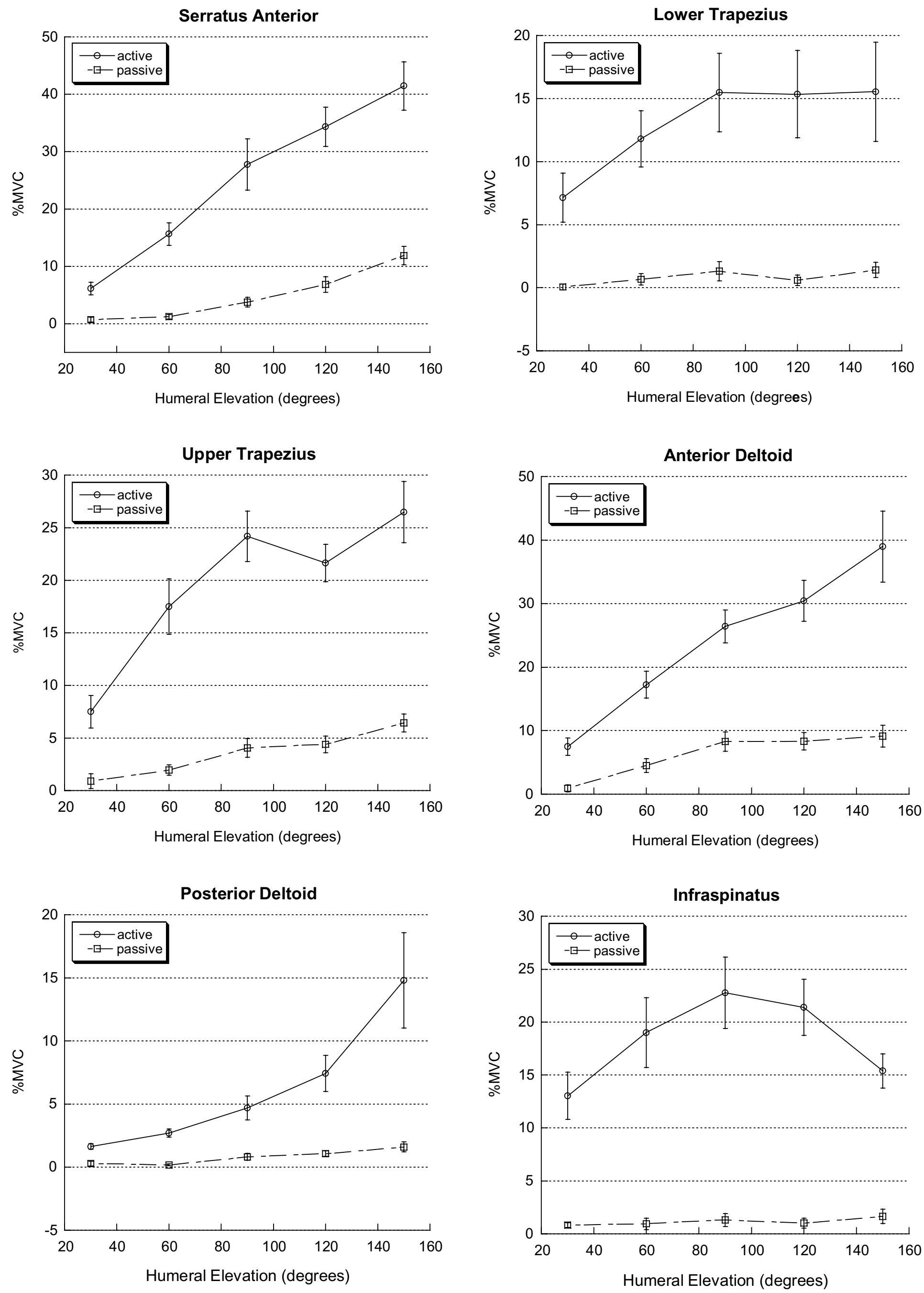

Fig. 2. Averaged EMG activity and standard error of the mean of the upper and lower trapezius, serratus anterior, anterior and posterior deltoid, and infraspinatus muscles during active and passive arm elevation.

motion reached a plateau. The general pattern for clavicular motion was for the clavicle to retract and elevate throughout the motion. Scapular and clavicular motion during the passive elevation trials followed a similar pattern with the exception of scapular external/internal motion. During the passive motion trials the overall motion of the scapula was into internal rotation.

For scapular upward rotation, there was a significant effect of muscle condition ($df = 1$, $F = 38.09$, $P < 0.001$) and humeral elevation angle ($df = 1.9$, $F = 594.28$, $P < 0.001$). Additionally there was a significant interaction between muscle condition and humeral elevation angle ($df = 1.9$, $F = 22.40$, $P < 0.001$). Follow up paired t-test revealed that subjects demonstrated more scapular upward rotation at the 90° ($df = 16$, $t = 4.12$, $P < 0.001$), 120° ($df = 16$, $t = 9.80$, $P < 0.001$), and maximum positions ($df = 16$, $t = 3.75$, $P < 0.002$) when the arm was raised actively (Fig. 3).

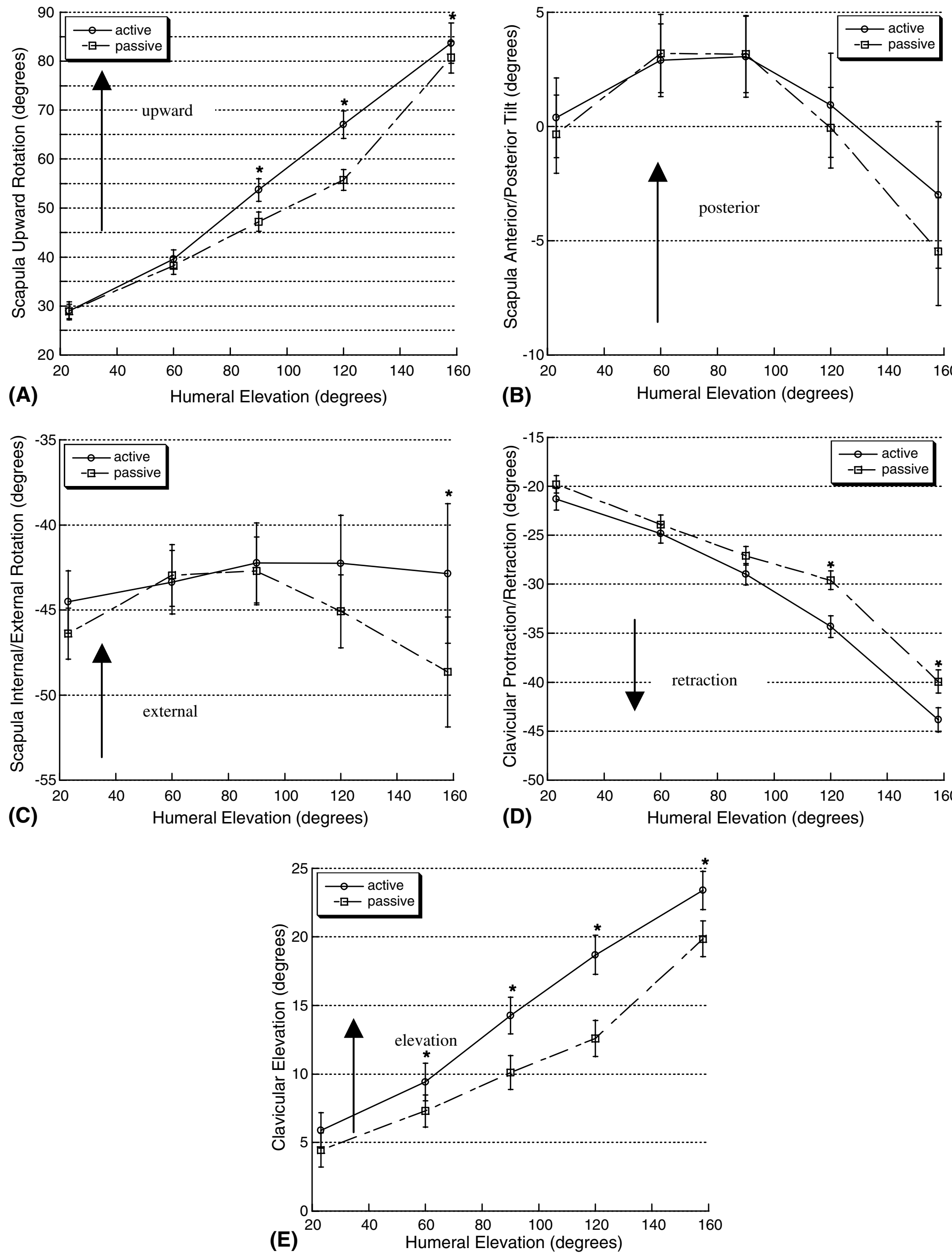

Fig. 3. Averaged scapular and clavicular rotations and standard error of the mean for active and passive arm elevation. A = scapular upward rotation; B = scapular anterior/posterior tilt; C = scapular internal/external rotation; D = clavicular protraction/retraction; E = clavicular elevation. Asterisk (✱) indicates significant difference between active and passive conditions (paired t-tests, P, 0.01).

For clavicular retraction there was a significant effect of muscle condition (df = 1, $F = 19.35$, $P < 0.001$) and humeral elevation angle (df = 1.9, $F = 342.43$, $P < 0.001$). Additionally there was a significant interaction between muscle condition and humeral elevation angle (df = 2.0, $F = 11.88$, $P < 0.001$). Follow up paired t-tests revealed that subjects demonstrated more clavicular retraction at the 120° (df = 16, $t = -6.18$, $P < 0.001$) and maximum positions (df = 16, $t = -5.47$, $P < 0.001$) when the arm was raised actively (Fig. 3).

For clavicular elevation there was a significant effect of muscle condition (df = 1, $F = 56.10$, $P < 0.001$) and humeral elevation angle (df = 1.6, $F = 371.26$, $P < 0.001$). Additionally there was a significant interaction between muscle condition and humeral elevation angle (df = 2.7, $F = 23.85$, $P < 0.001$). Follow up paired t-tests revealed that subjects demonstrated more clavicular elevation at the 60° (df = 16, $t = 3.65$, $P < 0.002$), 90° (df = 16, $t = 6.85$, $P < 0.001$), 120° (df = 16, $t = 9.97$, $P < 0.001$), and maximum (df = 16, $t = 6.55$, $P < 0.001$) positions when the arm was raised actively (Fig. 3).

For scapular external rotation, there was a significant interaction between muscle condition and humeral

Table 2
Means (and standard deviation) for scapular and clavicular motion across arm elevation angles

		Scapular rotations (°)			Clavicular rotations (°)	
		Posterior tilt	Upward rotation	External rotation	Protraction	Elevation
Min	Active	0.38 (7.8)	29.0 (5.4)	−44.5 (8.2)	−21.3 (4.9)	5.9 (5.8)
	Passive	−0.34 (7.7)	28.9 (5.8)	−46.4 (6.7)	−19.8 (3.9)	7.3 (5.3)
60°	Active	2.9 (7.1)	39.6 (4.2)	−43.4 (8.4)	−24.8 (4.3)	9.4 (6.1)*
	Passive	3.2 (7.7)	38.2 (6.2)	−42.9 (8.1)	−23.9 (4.4)	7.3 (5.3)
90°	Active	3.1 (7.9)	53.7 (5.4)*	−42.2 (10.5)	−28.9 (4.9)	14.3 (6.0)*
	Passive	3.2 (7.5)	47.2 (6.6)	−42.7 (8.9)	−27.1 (4.3)	10.1 (5.6)
120°	Active	0.93 (10.2)	67.0 (5.6)*	−42.2 (12.6)	−34.3 (4.9)*	18.7 (6.3)*
	Passive	−0.06 (7.9)	55.8 (6.2)	−45.1 (9.6)	−29.6 (4.3)	12.6 (5.9)
Max	Active	−3.0 (14.4)	83.7 (5.8)*	−42.9 (18.3)*	−43.8 (5.6)*	23.4 (6.2)*
	Passive	−5.5 (10.6)	80.8 (6.4)	−48.6 (14.5)	−39.9 (5.3)	19.9 (5.8)

Asterisk (*) indicates significant difference between active and passive conditions (paired *t*-tests, *P*, 0.01).

elevation angle (df = 2.1, $F = 8.06$, $P < 0.001$). Follow up paired *t*-tests revealed that subjects demonstrated more scapular external rotation at the max position (df = 16, $t = 2.9$, $P = 0.01$) when the arm was raised actively (Fig. 3). Although the amount of scapular posterior tilt changed across the humeral elevation angles, there were no differences between the active and passive conditions.

4. Discussion

In this study we demonstrated that the orientation and position of the scapula on the thorax is influenced by whether the arm is elevated actively or passively. Some of the reported kinematic differences in this study were small. However, we believe that kinematic differences as small as 4–5° may be important. Recent studies have shown that 4–5° differences in scapular kinematics are associated with shoulder impingement (Ludewig and Cook, 2000; Lukasiewicz et al., 1999) and decreased subacromial clearance (Karduna et al., 2002).

Decreased amounts of scapular upward rotation were noted when the arm was passively elevated which agrees with the overall findings of McQuade and Smidt (1998). This difference was most evident through the mid-range of motion (6.5° at 90° of humeral elevation and 11.2° at 120° of humeral elevation). This pattern suggests that the upper and lower portions of the trapezius and the serratus anterior muscles play an important role in the production of scapular upward rotation through this range. This role is important as decreased upward rotation of the scapula has been proposed to be a mechanism that contributes to the development of subacromial impingement syndrome by reducing the size of the subacromial space (Michener et al., 2003; Ludewig and Cook, 2000; Kibler and McMullen, 2003). This range of humeral elevation has also been shown to produce the highest subacromial pressures (Flatow et al., 1994). Recently Ludewig and Cook (2000) demonstrated decreased levels of serratus anterior activity and upward rotation of the scapula in subjects with subacromial impingement syndrome. Additionally, decreased scapular upward rotation is believed to play a role in glenohumeral instability by altering the optimal alignment between the humeral head and glenoid fossa (Itoi et al., 1992; Ozaki, 1987; Paletta et al., 1997).

In the early phase (23–60°) of arm elevation the difference in upward rotation was less than 1.5°, and at the end of the motion (max position) it was 2.9°. The differences in the early phase of motion are within the SEM for scapular upward rotation at 30° and 60°, and are greater than the SEM at 150°. The findings from the early phase of arm motion in this study were not statistically significant and are in agreement with those reported by Price et al. (2000). This finding may be explained by the release of passive tension in the superior soft tissues associated with the glenohumeral joint which occurs with both active and passive arm elevation. When the arm is at the side, the supraspinatus tendon and superior aspect of the glenohumeral joint capsule are under tension which may contribute to the resting position of scapular upward rotation (Pratt, 1994). As the arm is raised, either actively or passively, the tension in these tissues should decrease thereby allowing the scapula to assume a more upwardly rotated position. Likewise the small active–passive difference noted at the end of humeral elevation could be secondary to the development of tension in the inferior portion of the glenohumeral joint capsule which would pull the scapula into upward rotation.

Although the findings related to scapular upward rotation in this study agree with the overall findings of McQuade and Smidt (1998), the magnitude and pattern of these differences are not similar. Overall, this study reported larger differences in upward rotation between the active and passive conditions than did (McQuade and Smidt, 1998) (11.2° versus 4.7° respectively). In this study there was less upward rotation of the scapula for the passive condition across all levels of humeral elevation. For the unloaded (passive) condition in McQuade and Smidt (1998) study they reported less upward rotation during the first three phases of motion and more upward rotation during the final two phases of motion. These discrepancies could be attributable to different methods of passively elevating the arm resulting in different amount of muscle activity. Several methods of performing passive arm elevation were tried prior to conducting this study. We found that the method described in this study allowed for optimal muscle relaxation which is supported by our averaged EMG values during the passive trials being less than 10% MVIC for the majority of muscles. Although EMG was used in McQuade and Smidt (1998) study, they did not report actual EMG values during active and passive arm elevation.

We found less clavicular retraction towards the end range of motion when the arm was raised passively. We are unaware of any other study that has compared clavicular retraction between active and passive arm elevation. In this study, for both the active and passive conditions, the clavicle moved to a more retracted position as the arm was elevated which agrees with the findings of Ludewig et al. (2004). Due to the rigid link between the clavicle and scapula, the scapula also moved into a more retracted position during arm elevation. Scapular retraction is a translatory motion consisting of the scapula gliding along the thoracic wall towards the spinous processes and should not be confused with scapular internal/external rotation. The middle trapezius and rhomboid muscles act to retract the scapula (Pratt, 1991; Perry, 1978). Although we did not record EMG activity from either muscle, we believe that the differences in clavicular retraction could be a reflection of different levels of muscle activity during active and passive arm elevation.

We found a reduction in the amount of clavicular elevation across all levels of humeral elevation for the condition of passive arm elevation. The muscle primarily responsible for clavicular elevation is the upper trapezius muscle (Kent, 1971; Perry, 1978; Pratt, 1994), which was obviously more active during the active condition. The increased activity level in the upper trapezius muscle during active arm elevation seems to explain this finding.

For both clavicular retraction and elevation, we found that the overall pattern of motion during arm elevation was the same whether the arm was raised actively or passively. This suggests that mechanisms other than muscle activity contribute to these motion (Fung et al., 2001). For example, passive tension in the coracoclavicular and acromioclavicular ligaments may have contributed to clavicular elevation.

We did not find a difference in scapular tilting between the active and passive conditions. Due to the relatively small sample size and considerable measurement variation, the lack of statistical significance may have been secondary to a lack of power (type II error). We considered a 5° difference between arm elevation conditions to be meaningful. Using the obtained standard deviation of the difference scores at each angle of humeral elevation, the power in this study was >0.80 for all angles of elevation to detect a 5° difference between conditions for scapular tilting. We believe that this indicates that patterns of scapular tilting are similar during active and passive arm elevation. Factors other than muscle activity may primarily be responsible for producing scapular tilting motion. These factors may include, but are not limited to, the length of the pectoralis minor muscle and posterior glenohumeral joint capsule, gender, body morphology and subject activity level all of which are worthy of further study.

There are a few limitations to this study that should be noted. First, we did not record EMG activity from all of the muscles believed to have an influence on scapulothoracic motion. Invasive techniques such as fine wire EMG would have been required to study deeper muscles such as the pectoralis minor and supraspinatus muscles and at the time of this study we were not equipped to perform such techniques. However, we believe that the muscles selected in this study adequately represented the major muscles responsible for arm elevation. A second limitation was the fact that the condition of passive arm elevation was not truly passive. Although we attempted to get the subjects to completely relax their arms, there was still some muscle activity present which may have contributed to the observed motions. Cadaver models, nerve blocks, or general/regional anesthesia are possible methods for studying scapulothoracic kinematics under truly passive conditions. Thirdly, it is possible that skin motion artifact influenced patterns of scapular motion, especially towards the end range where greater errors in measurement occur with skin based techniques (Karduna et al., 2001).

5. Conclusions

This study has shown that decreased levels of muscle activity results in altered scapulothoracic kinematics including upward rotation of the scapula, external rotation of the scapula, clavicular retraction, and clavicular elevation. The greatest effect was noted for upward rotation of the scapula through the mid-range of arm elevation. There was significantly more upward rotation of the scapula when the arm was raised actively compared to when it was raised passively. This reinforces the important role that the trapezius (upper and lower portions) and serratus anterior muscles have in producing scapular upward rotation especially throughout the mid-range of arm elevation. Careful assessment of these muscles and upward rotation of the scapula in the mid-range of arm elevation should be an important component of any shoulder examination.

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