Three-dimensional motion of the scapula and shoulder during activities of daily living

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The purpose of this study was to describe 3-dimensional scapular motion during the activities of daily living (ADL) and the full range of arm motion, and to suggest a standardized method for evaluating scapular mobility. Eight healthy subjects between the ages of 25-40, with no prior history of shoulder pathology or surgery for the past 12 months, were recruited for this study. Touching 8 predetermined landmarks on the head and the trunk was used to simulate ADL. Touching the contralateral ear and contralateral shoulder resulted in the maximum scapular protraction 46° (8°) and 48° (8°), respectively, and the maximum degrees of the scapular anterior tilt, -11° (4°) and -11° (5°), respectively. Asking patients to reach to the back of the neck, and the contralateral shoulder, the clinician can evaluate the overall scapular mobility in all directions. A protocol controlling the performance variability during ADL tasks was suggested to improve the clinical evaluation of the shoulder joint complex. Findings of this study can guide clinicians to identify specific tasks which may relate to particular shoulder girdle dysfunction. (J Shoulder Elbow Surg 2008;17:936-942.)

The kinematics of the shoulder joint consist of coordinated movements of the clavicle, scapula, and humerus. Because of technical difficulties and technological limitations, previous studies of the upper extremity have disregarded the biomechanical analysis of scapular motion in the description of the activities of daily living (ADL).[24] However, scapular motion is a main part of shoulder function activities, and a comprehensive understanding of biomechanics of the scapular movements may provide better knowledge of the shoulder pathologic problems. Establishing the precise normative range of motion of the scapula for clinical evaluation of the upper extremity requires an accurate kinematic measurement device, standard methods of evaluation and reporting of kinematic data, and various simple tasks to be used during routine clinical evaluation.

Recent 3-dimensional (3D) evaluation techniques, such as electromagnetic devices and fast speed cameras,[4] provide reasonable tools for more accurate measurements compared to 2-dimensional (2D) goniometers,[5,21] fluoroscopy,[16,23] and x-ray techniques.[2,6] Karduna et al established the validity of electromagnetic devices compared to scapular pins[10] and reported accurate measurements for scapula motion when motion of the humerus-thorax angle of elevation was below 120°.

Recently, in an attempt to standardize data collection and reporting, the International Society of Biomechanics (ISB) has suggested a standard protocol for defining joint coordinate systems, as well as processing and reporting of upper extremity kinematic data.[27] It is expected that the adoption of the ISB recommendation will result in less ambiguity surrounding the published literature that previously adapted various coordinate systems for data collection and methods of analysis and reporting.[22,24]

Quantification of upper extremity movements during ADL is challenging because of the high degrees of freedom, coordinated movement from multiple joints, and between-trial and between-individual variability in the execution of functional tasks. Unlike gait analysis in the lower extremity, no specific function has been identified to test the basic function of the upper extremity. The upper extremity is adaptive, having the ability to perform the same tasks using different kinematic strategies.[3] It is meaningful to examine how much range of motion is required in healthy subjects during various functional tasks, as a reference for shoulder patients, to analyze the movement patterns in patients with various shoulder problems.

The aims of this study are: 1) to measure maximal range of motion of the scapula during dynamic tasks; 2) to compare the range of motion of the scapula during static clinical evaluation tasks, which mimic ADL tasks, to their maximal range of motion; and 3) to suggest a method of clinical evaluating scapular mobility with least performance variability.

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MATERIALS AND METHODS

The MotionMonitor system, comprised of the Polhemus Liberty 240 electromagnetic tracking system with 4 sensors and software for data collection, was used to collect kinematic data at 120 Hz. The scapular tracker, as described by Karduna et al,[10] was used to track scapular motion, as described in the published literature.[7,10,13,14]

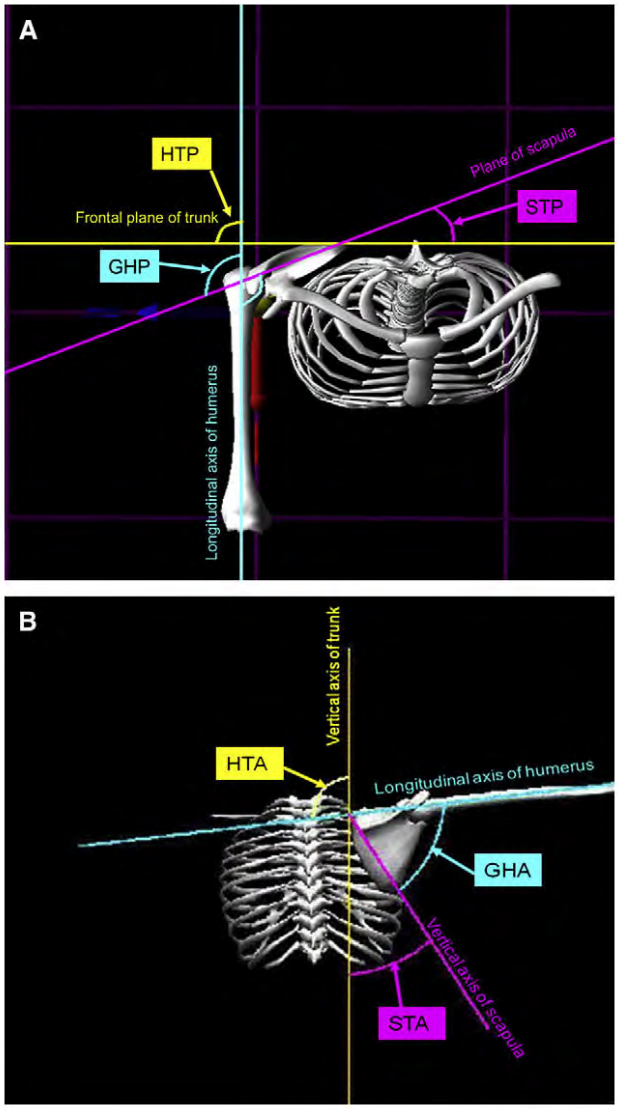
Coordinate systems by ISB[27] were used to describe all possible joint motions. In the scapulothoracic joint, the movements are protraction/retraction, medial/lateral rotation, and anterior/posterior tilt. In scapulohumeral (glenohumeral) joints, there are the plane of elevation, angle of elevation, and internal/external rotation. Compared to traditional clinical descriptions (ie, shoulder forward flexion of 30° and abduction of 75°), this method can describe all possible continuous movements of the scapula and the humerus. For instance, continuous movement of the upper extremity from one position to another (ie, from picking up a coin on the floor to putting it in a pocket) cannot be described by the clinical terminology, but the ISB method can describe precisely not only the amount of movement but the instant of the movement as well.

Eight healthy subjects (6 male and 2 female) ages 25-40, with mean age of 32 years (range, 23-50) and with no prior history of shoulder pathology or surgery, as well as no shoulder pain or symptoms for the past 12 months, were recruited. Other exclusion criteria included documented musculoskeletal disease. Each subject was instructed to wear appropriate attire to expose his or her shoulder. Females would need a razor-backed sports bra and males would remove their shirts entirely.

The testing procedure and aim of the study were explained to each subject, who then were asked to sign an informed consent form that was approved by the NYU IRB. The test administrator marked the standardized bony landmarks on the subject's right arm, shoulder, and hand, according to Meskers[19,20] and ISB[27] protocols. Landmarks included C7, T8, and T12 spinous processes, jugular notch, xyphoid process, acromial angle, trigonum spinaea of the scapula, inferior angle of the scapula, medial epicondyle, and lateral epicondyle of humerus.[27]

The Polhemus Liberty system was calibrated in accordance with the company guidelines (Innovative Sport, Inc., Chicago, IL). The scapular tracker and sensors were affixed to the subject with double-sided tape and Velcro straps, according to the protocol of Karduna et al.[10,17] Three magnetic sensors were placed on the thorax, scapula, and upper arm, and each segmental axis was configured based on the ISB[17,27] protocols. Figure 1 demonstrates the range of the scapula motion during the 3 planes of elevation, rolling, and horizontal abduction, according to ISB's protocol (Figure 1). In the ISB protocol, the clinical terms of shoulder abduction and forward flexion are represented by shoulder elevation in the respective 0° and 90° planes of elevation.

During dynamic motions, subjects were instructed to move their arm at a slow rate without stopping. Based on previous literature,[10] an 8-second movement pace (4 for each ascending and descending) was maintained by practice. Each subject practiced several trials prior to data collection to ensure the understanding of appropriate movement



Figue 1 Definition of segmental angles measured in this study: the planes of elevation (**A**) and angles of elevation (**B**) - STP: plane of elevation of scapular to trunk, a measured arc of protraction and retraction of the scapula with respect to the thorax; GHP: plane of elevation of humerus to scapula, a measured arc of horizontal adduction and abduction of the humerus with respect to the scapula; HTP: plane of elevation of humerus to trunk, a measured arc of horizontal adduction and abduction of the humerus with respect to the thorax; STA: angle of elevation of scapular to trunk, a measured arc of medial and lateral rotations of the scapula with respect to the thorax; GHA: angle of elevation of humerus to scapula, a measured arc of adduction and abduction (also can be flexion and extension based on the plane of elevation) of the humerus with respect to the scapula; HTA: angle of elevation of humerus to trunk, a measured arc of adduction and abduction (also can be flexion and extension based on the plane of elevation) of the humerus with respect to the thorax. When the movement at acromioclavicular joint is negligible, the amount of HTP and HTA is equal to the summation of the other two angles.

pace during dynamic trials. Any feedback to control pace of movement was not provided in an effort to limit disturbances to the natural motion.

Two types of tasks, ADL and full scapula range of motion, were performed to investigate 3D motion of the scapula and humeral bones. The testing sequence was randomized. The tasks included full range of motion of the shoulder joint complex and full range of motion of scapula. Subjects were asked to move their arm in the following three planes: 1) shoulder elevation in the frontal plane: humeral elevation in the frontal plane (0° of plane of elevation) with the elbow in full extension and the thumb pointed up, clinically known as shoulder abduction; 2) shoulder elevation in the sagittal plane: humeral elevation in the sagittal plane (90° of plane of elevation) with the elbow in full extension and the thumb pointed up, clinically known as shoulder flexion; 3) shoulder elevation in the scapular plane: humeral elevation at 40° (10) anterior to the frontal plane with the elbow in full extension and the thumb pointed up.

A protocol was developed which accounted for natural movement patterns, as well as a way to give general guidelines for staying within a plane of motion. To maintain the movement within the plane of elevation, a flashlight was attached to the subject's forearm and the elbow joint was immobilized using a wooden stick and Velcro. Testing planes were visualized by placing painter's tape on the floor and walls. Subjects were asked to follow the strip of tape with the light.

Subjects performed 3 dynamic arm movements in each plane. All movements were performed bilaterally to minimize the compensatory movement of the trunk; however, only 1 side was measured. Dynamic tasks were performed in slow speed but without stopping.

Two sets of activities were performed to measure the range of motion of the scapula. First, subjects were asked to perform shoulder rolling by making a big circle with their shoulder 3 times forward (forward rolling: scapular protraction, elevation, retraction, and depression) and 3 times backward (backward rolling: scapular retraction, elevation, protraction, and depression) while keeping their arm on their sides. Second, subjects were asked to abduct their arms horizontally (moving arm from the mid-sagittal line to abduction in the frontal plan) while maintaining angles of elevation at 60°, 90°, and 120°.

To simulate ADL tasks such as tooth brushing, face washing, and hair combing, the subject was asked to touch his/her chin, forehead, top of the head, occipital notch, and back of the neck using their index finger and hold the positions for 3 seconds each, to touch his/her ipsilateral and contralateral ear lobe and to touch the contralateral shoulder and hold the positions for 3 seconds each.

Data processing

Data between the ranges of 30° to 120° of humeral elevation referenced to the trunk were processed for descriptive data analysis. The angles for each joint were extracted for every degree of humeral elevation to the trunk with a tolerance of ±0.25°. The trial data were averaged for each individual data, and the individual data were then averaged for the group data.

RESULTS

The results of the multivariate analysis showed a significant effect on subject ($P < .0001$) and task ($P < .001$), with no main effect of trials ($P > .999$). Therefore on scapula range of motion, the average value of the 3 trials was used in all data processing and analysis.

The box plots demonstrate the distribution of the scapular range of motion during the 3 planes of elevation, rolling, and horizontal abduction (Figure 2). Table I shows the maximal range of motion of the scapula observed in this study. The maximal range of motion of the scapula was about 51° degrees around the vertical axis (retraction/protraction); 46° around the anterior-posterior axis (lateral/medial rotation); and 27° around the mediolateral axis (anterior/posterior tilt). The widest range of the scapular protraction/retraction and posterior/anterior tilt was observed during rolling, followed by horizontal abduction. However, the highest degree of protraction, 56°, was observed during horizontal abduction. The widest range of the scapular medial/lateral range of motion was observed during 3 planes of shoulder elevation. The highest range of lateral/medial rotation, 44°, was during shoulder elevation in the frontal plane.

The dynamic tasks demonstrated maximum scapular anterior tilt, -18° (5°), and posterior tilt, 9° (5°). Among the dynamic tasks, sagittal abduction demonstrated the highest scapular lateral rotation (-41° +/- 5°), and shoulder rolling demonstrated the highest scapular medial rotation (5° +/- 5°) (Table I and Figure 2).

Table II shows the range of motion of the scapula, GH, and HT joints observed during various static tasks. Bold numbers indicate the minimum and maximum values for each measurement. For instance, maximal scapular protraction (48 ± 8°) was observed during the task of reaching the contralateral shoulder.

As shown in Table II, the maximum scapular protraction was observed during touching the contralateral shoulder, 48° (8°), about 86% of maximum range, and the maximum scapular retraction was observed during touching back of the neck, 29° (8°) (Figure 3, *A*). Touching the back of the neck demonstrated the highest scapular lateral rotation, -36° (7°), about 88% of maximum range, and touching the chin demonstrated the lowest value, -3° (5) (Figure 3, *B*). Touching the contralateral ear and contralateral shoulder resulted in the highest degrees of the scapular anterior tilt, -11° (4°), about 61% of maximum range, and -11° (5°), respectively (Figure 3, *C*).

As shown in Table II, the maximum HT plane of elevation was observed during touching the contralateral shoulder, 111° (8°), and the minimum was observed during touching the head and chin, 47° (11°) (Figure 4, *A*). Maximum HT angle of elevation was

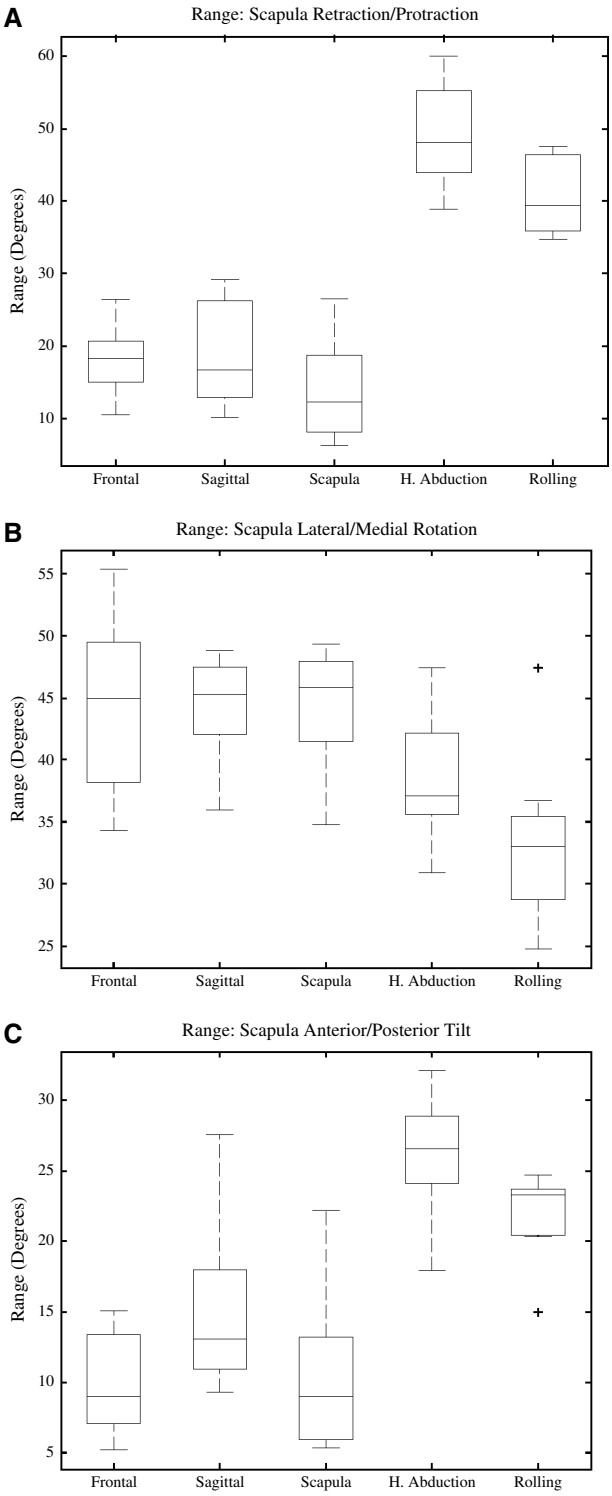


Figure 2 Box plots of scapula protraction/retraction (**A**), medial/lateral rotation (**B**), and posterior/anterior tilt (**C**) during three elevations, rolling, and horizontal abduction.

Table I Maximal angle of scapular motion observed in this study

		Rolling mean (Std)	Task observed
Scapula retraction (-)/ protraction (+)	Max	56 (7)	Horizontal abduction
	Min	5 (10)	Shoulder rolling
Scapula lateral (-)/ medial (+) rotation	Max	5 (5)	Shoulder rolling
	Min	−41 (5)	Shoulder elevation in frontal and scapula plane
Scapula anterior (-)/ posterior (+) tilt	Max	9 (5)	Horizontal abduction
	Min	−18 (5)	Horizontal abduction

observed during touching back of the neck and the minimum was during touching the chin, -38°(4°), (Figure 4, *B*). Touching the back of the head demonstrated the highest HT external rotation, -42° (15°), (Figure 4).

DISCUSSION

This study was intended to provide the scapular and shoulder ranges of motion during the functional tasks used in clinical evaluations of the ADL. The 3D range of motion (ROM) obtained by these simplified ADL tasks should guide clinicians in identifying specific tasks that may relate to particular shoulder girdle dysfunction.

Several dynamic tasks have been used to test the scapular movement during ADL[24]; however, the variability of individual dynamic motion is inherently very high and makes the comparison between studies difficult. For instance, one of the dynamic tasks was combing hair; however, the task of combing hair can be achieved in many different ways, depending on the instruction provided. The instructions can be varied for the starting and ending points of the combing motion, speed of movement, and the specification of combing stroke. To control the variability in the performance, the investigator was often demonstrating the motion in front of the subjects.

As a solution, a series of standardized static tasks can successfully simplify the complex dynamic ADL tasks with maintaining the same level of physical demand as this study. In this way, the clinical ADL evaluation can be more consistent and provide standardized information for comparison. To test scapular protraction, reaching the contralateral ear or contralateral shoulder is the most demanding. For lateral rotation, reaching to the back of the neck requires 36°, while reaching the top of head needs about 28°. This normal data of movement patterns are useful to analyze the movement patterns in patients with various orthopaedic problems.

Table II Mean and standard deviation (Stdev) of angle of shoulder motion during various static tasks (GH: glenohumeral or humerus to scapula; HT: humerus to thorax). Bold numbers indicate minimal and maximal values for each measurement

	Chin		Forehead		Top of the head		Back of the head		Back of the neck		Ipsilateral ear		Controlateral ear		Controlateral shoulder	
	Mean	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
Scapula retraction/ protraction	38	6	41	7	38	7	33	7	**29**	8	36	7	46	8	**48**	8
Scapula lateral/ medial rotation	**-3**	5	−12	4	−28	4	−30	6	**-36**	7	−12	5	−16	5	−17	9
Scapula anterior/ posterior tilt	−8	5	−7	4	−4	4	−1	5	**0**	6	−6	5	**−11**	4	**−11**	5
GH plane of elevation	50	9	48	12	21	11	**13**	8	14	5	41	13	67	11	**77**	10
GH angle of elevation	**-42**	5	−60	6	−81	11	−82	13	**-91**	13	−60	8	−64	6	−58	7
GH internal/ external rotation	**-45**	10	−54	10	−50	10	−50	11	−52	14	−54	11	−55	8	**-60**	11
HT plane of elevation	77	12	80	13	59	13	**47**	13	**47**	11	70	12	102	12	**111**	8
HT angle of elevation	**-38**	4	−64	7	−105	9	−110	10	**-124**	13	−65	5	−62	3	−54	9
HT internal/ external rotation	**-32**	15	−39	12	−36	12	**-42**	15	−42	17	−41	12	−34	11	−37	17

Additionally, the study provides more efficient methods to test scapular mobility. For instance, if a person can reach the chin and the back of the neck, his/her scapular lateral rotation would not cause a problem in reaching other points of the body used in this study. In this sense, by asking patients to reach to the chin, back of the neck, and contralateral shoulder, the clinician can evaluate the overall scapular mobility in all directions.

Several factors are important in the interpretation of the results of this study, as well as other 3D ADL studies that used a similar methodology.[22,25,26] First, the ADL tasks may present a large between-trial and between-individual variability.[3,3,15,25] While it is possible to reduce the variability by instructing the subject and including various controls, which may result in more controlled motion, normative ADL data should represent more realistic patient performance with no control. In addition to pain and shoulder dysfunction, the subject's instruction[22] may influence ADL outcome. In this study, the examiner demonstrated the ADL for each subject; however, the subjects were not instructed to perform functional tasks in a specific way.

Second, the variability presented in the data may partially reflect the inherent variability in the method and posture used during calibration.[8,9,17] In this case, variability in the joint range of motion and initial offset may be due to initial calibration errors instead of actual subject variability. This suggests that only within subject difference and relative value should be used for analysis and interpretation of ADL data, rather than absolute values of ROM and group means. This may partially explain the high standard deviation observed during performance of the tasks, such as combing hair in previous studies of the healthy population.[15,24] This is especially beneficial in the analysis of patients' data, as subjects may adapt a unique movement pattern due to shoulder pain and dysfunction.

Third, various postural variables, such as sitting versus standing, bilateral versus unilateral [1,12] arm motion, trunk posture,[11] and trunk slouching presumably, can affect the ROM of the scapula and GH joint during the ADL. In this study, all trials were performed bilaterally to reduce the effect of arm elevation on the trunk's lateral and transverse motion. Shoulder abduction may influence the trunk posture in the frontal plane, and shoulder flexion can influence trunk posture in the sagittal plane. The trunk posture alterations during shoulder activities directly affect kinematic measurement and reporting of the scapula-thoracic and glenohumeral angles.

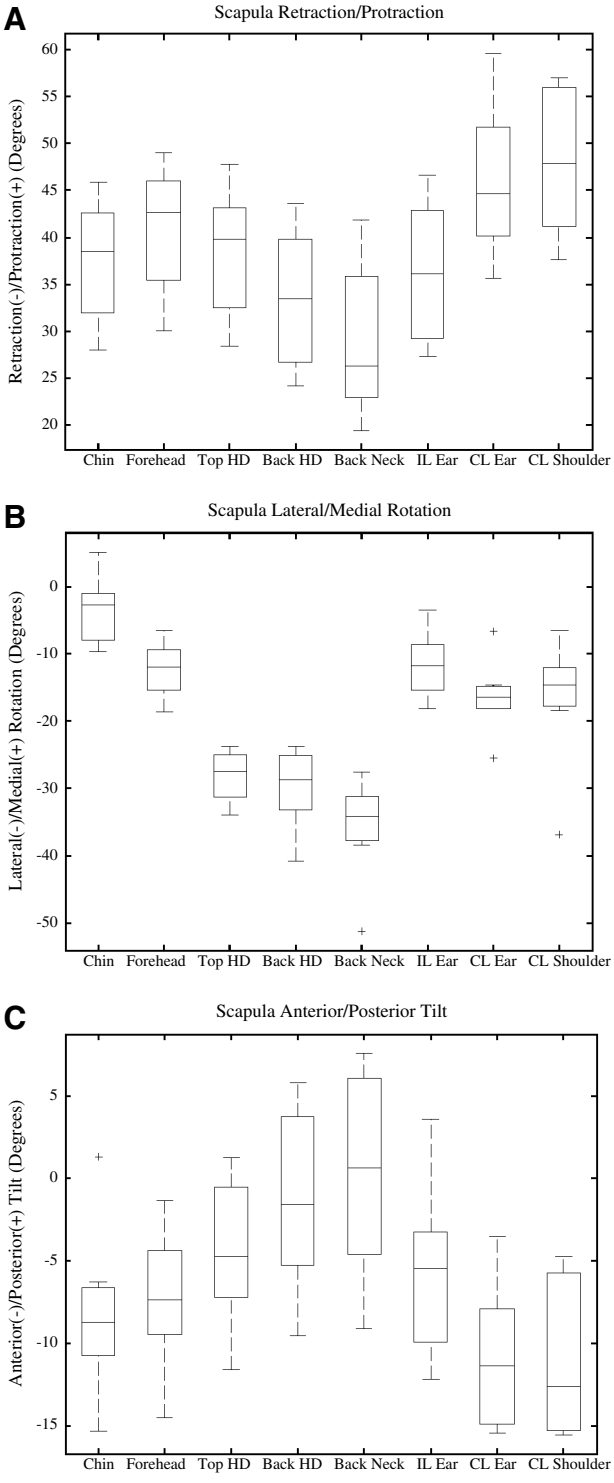


Figure 3 Box plots of scapula retraction/protraction (**A**), scapula lateral/medial rotation (**B**), scapular anterior/posterior tilt (**C**), during eight static tasks.

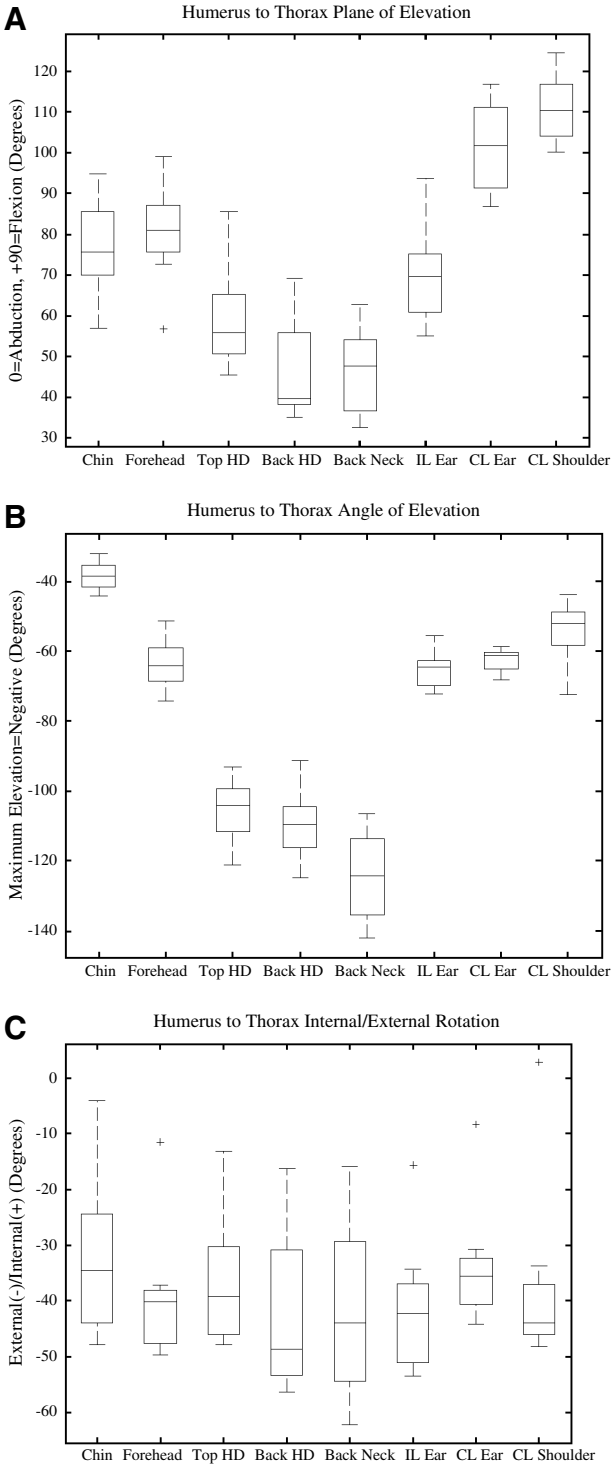


Figure 4 Box plots of the plane of elevation of HT (**A**), HT angle of elevation (**B**), HT internal/external rotation (**C**), during eight static tasks.

In this study, we presented group means as well as within subject differences. Both data suggest that touching the back of the neck provides the highest scapular lateral rotation; while contra-lateral shoulder touching provides the highest scapular anterior tilt and protraction. ADL involving reaching and touching the top of the head or the back of the head or neck requires more than 100° of humeral-thoracic angle of elevation.

In order to provide more meaningful information for clinicians, the humeral-thoracic ROM was reported rather than glenohumeral motion. This may provide difficulty for comparing other studies, which only reported glenohumeral motion.[15]

Similar to other noninvasive, 3D, kinematic measurement studies,[18] the accuracy of the data presented in this study is limited by the accuracy of the sensor placement over the skin, the soft-tissue motion during performance,[8] the calibration method, and the definition of the neutral position. Karduna et al[10] has shown that the similar method adopted in this study provides reasonable kinematic information for ranges below 120° in the scapular and the sagittal planes.

In summary, the result of the present study provides a better understanding of the motion of the shoulder joint complex during functional tasks. Understanding normal scapular motion may assist in the identification of abnormal motion associated with various shoulder disorders. A protocol controlling the performance variability during ADL tasks was suggested to improve the clinical evaluation of the shoulder joint complex.

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