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Functional activities characteristics of shoulder complex movements: Exploration with a 3-D electromagnetic measurement system

Jiu-jenq Lin, PT, PhD;[1,2*] William P. Hanten, PT, PhD;[1] Sharon L. Olson, PT, PhD;[1] Toni S. Roddey, PT, PhD, OCS, FAAOMPT;[1] David A. Soto-Quijano, MD;[3] Hyun K. Lim;[3] Arthur M. Sherwood, PhD[4]

[1]School of Physical Therapy, Texas Woman's University, Houston, TX; [2]National Taiwan University Hospital, College of Medicine, National Taiwan University, Taipai, Taiwan; [3]Department of Physical Medicine and Rehabilitation, Baylor College of Medicine, Houston, TX; [4]National Institute for Disability and Rehabilitation Research, Department of Education, Washington, DC

Abstract—The high prevalence of shoulder-related dysfunction has focused increased attention on functional activity assessment. This study (1) tested the reliability of three-dimensional shoulder complex movements during four functional tasks representing different levels of task difficulty, (2) characterized the four functional tasks, and (3) examined the relationships between age and shoulder movements. Twenty-five asymptomatic subjects, all veterans aged 30–82, performed the four functional tasks. Good within-session reliability was found (movement pattern: similarity index = 0.81 to 0.97, peak values: intraclass correlation coefficients = 0.88 to 0.99). The raising arm to overhead height task (hard task) placed the greatest demand on scapular motions and humeral elevation ($p < 0.005$). During the functional tasks, significant correlations existed between age and scapular tipping, humeral elevation, and scapular upward rotation ($r = -0.62$ to 0.50, $p < 0.05$). Correlation results indicated that elderly subjects have a greater potential for serratus anterior muscle weakness and shoulder capsule tightness.

Key words: biomechanics, electromagnetic measurement, functional activity, glenohumeral joint, rehabilitation, reliability, rotation, scapula, shoulder, three-dimensional movement.

INTRODUCTION

Shoulder-related dysfunction can affect an individual's ability to function independently, consequently decreasing quality of life [1–3]. The prevalence of shoulder dysfunction has been reported in various patient populations as 34 percent of persons 65 and older [4], 64 percent of patients with a stroke [5], and 78 percent of spinal cord injury patients [6]. Additionally, some occupational activities, such as polishing, sanding, and grinding, as well as certain recreational activities, such as overhead sports and wheelchair athletics, have been found to increase shoulder dysfunction [7–9].

The prevalence and impact of shoulder-related dysfunction have fostered the development of functional activity assessments, including numerous self-reports [3,10–12] and subject-performed functional tasks [13–14],

Abbreviations: ANOVA = analysis of variance, CI = confidence interval, ICC = intraclass correlation coefficient, ROM = range of motion, SD = standard deviation, SEM = standard error of measurement, 3-D = three-dimensional, VA = Department of Veterans Affairs.

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*Address all correspondence to Jiu-jenq Lin, PhD, PT; School and Graduate Institute of Physical Therapy, College of Medicine, National Taiwan University, No. 1 Jen Ai Road, Section 1, Taipei, 100, Taiwan, R.O.C; 886-2-23123456, ext. 7559; fax: 886-2-23313598. Email: lxjst@ha.mc.ntu.edu.tw

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for use in both research and clinical practice. Despite the valuable subjects' perceptions from self-reports, subjective information and various self-reports have been criticized for their applicability [3,14]. As an alternative, assessment of subject-performed functional tasks with a motion analysis system can provide objective information and identify specific impaired movements. Recently, electromagnetic tracking methods with multiple sensors have provided high resolution and allowed investigators to record three-dimensional (3-D) scapular and humeral motions simultaneously without invasive techniques [1,14–19]. However, the feasibility of the use of this approach to assess subject-performed functional tasks has not been confirmed.

Information regarding the reliability of recording 3-D shoulder movements during functional tasks is limited. During arm elevations, the appropriate reliability values of 3-D shoulder movements have been reported, with intraclass correlation coefficients (ICCs) ranging from 0.62 to 0.98 and standard errors of measurement (SEMs) ranging from 2° to 4° recorded in arm elevations [15–21]. Greater variability, however, in the recorded 3-D shoulder movements during functional tasks may be expected. The motoric noise (different individual muscle force distributions), different individual morphologies, muscle strength, functional demands, habitual activities, and/or motor strategies have been reported or speculated on to account for the variability in measurement [17,22]. Thus, investigating the shoulder complex movements during functional tasks in asymptomatic individuals to provide a basis for further understanding shoulder-related dysfunction remains crucial. We investigated four functional tasks in this study to (1) test the reliability of the shoulder complex kinematic data during functional tasks in asymptomatic subjects, (2) characterize functional tasks in terms of 3-D shoulder complex movements, and (3) examine the relationships between age and shoulder complex movements during the functional tasks. In addition, skin motion artifact was evaluated.

METHODS

This study took place at the Department of Rehabilitation Medicine at the Michael E. DeBakey Department of Veterans Affairs (VA) Medical Center in Houston, Texas, and was approved by the local VA Human Studies Committee and the Baylor College of Medicine's (Houston, TX) Institutional Review Board.

Subjects

Twenty-five male subjects without any known shoulder dysfunctions voluntarily participated in this study. The inclusion criteria were male adults at least 18 years old. Subjects were excluded if they had (1) less than 150° of glenohumeral flexion or abduction range of motion (ROM) at their shoulders, or medial/lateral rotation ROM less than 50°; (2) a history of pain, trauma, or dislocation of the glenohumeral or acromioclavicular joint; (3) current infectious medical diseases, cancer, or any neurological or cardiovascular disease; or (4) major surgery within the previous year. The mean age of the sample was 52.8 years (standard deviation [SD] = 14.1, range = 30–82 years). All subjects were right-hand dominant and tested on their right arms and shoulders. Each subject was given a written and verbal explanation of the purposes and procedures of the study, and each signed an informed consent form that was approved by the institutional review board.

Functional Tasks

We selected 4 of the 33 functional tasks used for the self-reported Flexilevel Scale in Cook et al.'s study [11] for objective and quantitative measure in our study. In the Flexilevel Scale, the 33 functional tasks were categorized into five groups (easy task, middle and easy task, middle task, middle and hard task, and hard task) and the functional tasks in each group were similar. To ensure a time-efficient measure, we selected the four representative functional tasks for our study because they involved similar moment arm and similar mass center from the center of the shoulder joint, but different difficulties (**Figure 1** and **Table 1**). Task B is a routine single question task, while tasks A, C, and D represent hard, medium, and easy levels of function, respectively.

FASTRAK Motion Analysis System

We used the FASTRAK motion analysis system (Polhemus, Colchester, VT) to measure shoulder complex movements. The FASTRAK sensors were attached to the bony landmarks with adhesive tape according to previous studies [5,14,23]. These surface sensors were placed on the sternum, on the flat superior bony surface of the scapular acromial process, and at the point on the distal humerus between the lateral and medial epicondyles,

Figure 1.
FASTRAK measurement setup. **S**ubject was seated in electromagnetic field of FASTRAK system. Sensors were attached on sternum, humerus, and acromion of scapula.

where they were secured with Velcro straps. We used a fourth sensor, attached to a stylus, to digitize palpated anatomical coordinates (bony landmarks: sternal notch, xyphoid process, seventh cervical vertebra, eighth thoracic vertebra, acromioclavicular joint, root of the spine of the scapula, inferior angle of the scapula, lateral epicondyle, and medial epicondyle—the glenohumeral joint rotation center was defined by the anterior humeral joint and posterior humeral joint). Within a 76 cm source-to-sensor separation, the root-mean-square system accuracy is 0.15° for orientation and 0.3 to 0.8 mm for position [20,24]. Additionally, we calibrated this system before the main test and verified the measurement accuracy using a calibration table for the absolute distance and angles between markers.

The thorax, scapula, and humerus were palpated and tracked (30 Hz sampling rate) while the subjects sat with their arms relaxed at their sides. Kinematics were collected for 5 s in this resting seated posture. Subjects were then asked to perform four functional tasks. For each task, the beginning position was subjects seated with their arms relaxed at their sides, while the end position was completion of each task. A tone signal was given when the subjects were to start and end the arm movements. The investigator used a hand-held event-timer switch to mark the beginning and end of the arm movements for all tasks. The event timer generated an electrical signal that was collected with the FASTRAK system. The order of functional tasks was randomized. Once subjects were familiar with the functional tasks, they were instructed to perform each activity a total of three consecutive times at their self-selected speed (about 2 to 3 s). The subjects were given approximately 2 to 3 min of rest between test conditions.

Data Reduction and Analysis

The absolute axes defined by the sensor of the FASTRAK device were converted to anatomically defined axes derived from digitized bony landmarks. Raw kinematic data were low-pass filtered at a 6 Hz cutoff frequency and converted into anatomically defined rotations based on standard matrix transformation methods. Scapular orientation relative to the thorax was described with a Euler angle sequence of rotation about Z_S (medial rotation/lateral rotation), rotation about Y'_S (upward/downward rotation), and rotation about X''_S (anterior/posterior tipping) [15,20,25] (**Figure 2**). Humeral orientation relative to the scapula was described with a Euler angle sequence in which the first rotation represented the plane of elevation, the second rotation defined the amount of elevation, and the third rotation described the amount of axial rotation [15,23–24] (**Figure 2**). All kinematic variables from the three trials of each testing task were used in the following analyses.

We calculated ICCs (2, 1) to show the reliability of the single measurement, while ICCs (2, 3) were calculated to show the reliability of the mean of three trials for each functional task [26]. The kinematic measurements included peak scapular upward rotation, peak scapular tipping, peak scapular protraction, peak humeral elevation, peak humeral rotation, and plane of humeral elevation at peak humeral elevation. The SEM was calculated (SEM = SD × $\sqrt{(1-\mathrm{ICC})}$). We calculated Pearson bivariate correlations to assess the movement similarity among three trials during the functional tasks. One-way repeated analysis

Table 1.
Description of four functional tasks.

Task	Description
A: Overhead Height Task (hard task)	While sitting on wooden chair (height = 450 mm), subjects used right arms to lift and place object (bottle filled with 0.45 L of water) on near-edge of height-adjustable desk at constant distance (300 mm) from wooden chair and at height of top of subject's head.
B: Shoulder Height Task (routine task)	While sitting on wooden chair, subjects used right arms to lift and place object on near edge of height-adjustable desk at shoulder height.
C: Sliding a Box Task (medium task)	While sitting on wooden chair, subjects used right arms to slide box (weight = 4.5 kg) across table at desk height (760 mm) by pushing it away from them.
D: Reaching for Salt Shaker Task (easy task)	While sitting on wooden chair, subjects reached across to middle of desk (height = 760 mm) with right arms to get salt shaker (weight = 0.3 kg) and bring it to near edge of desk.

Note: Placement of object or salt shaker in testing tasks A, B, and D was at near edge of desk in sagittal plane of acromion process of scapula. Distance for subjects to push box and to reach for salt shaker in testing tasks C and D was 1.2 times arm length of each subject in sagittal plane and measured from acromion process of scapula. Arm lengths were measured from acromion process of scapula to end of middle finger while subjects sat with arms extended at sides.

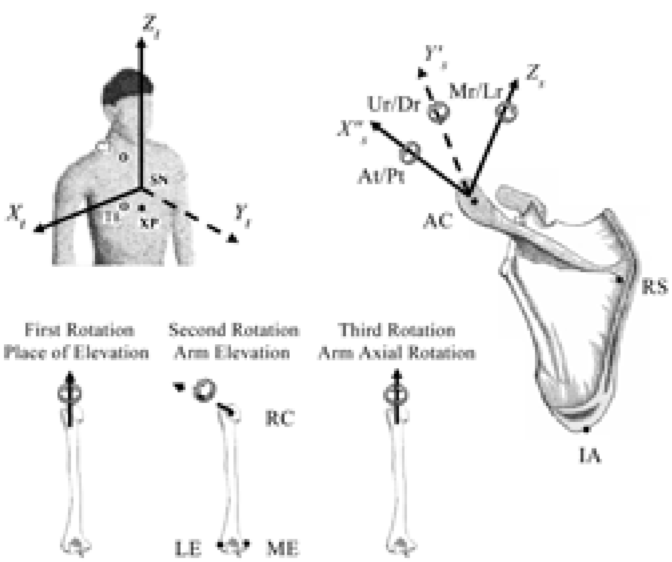

Figure 2.
Coordinate systems for thorax, scapula, and humerus. C7 = spinous process of seventh cervical vertebra, T8 = spinous process of eighth thoracic vertebra, XP = xiphoid process, SN = sternal notch, RS = root of spine of scapula, IA = inferior angle of scapula, AC = acromioclavicular joint, ME = medial epicondyle, LE = lateral epicondyle, RC = glenohumeral joint rotation center, At/Pt = anterior tipping/posterior tipping, Ur/Dr = upward rotation/downward rotation, Mr/Lr = medial rotation/lateral rotation. Trunk axes are aligned with cardinal planes. X_t is directed laterally, Y_t is directed anteriorly, and Z_t is directed superiorly. X''_s is directed laterally from RS to AC, Y'_s is directed anteriorly perpendicular to plane of scapula, and Z_s is directed superiorly perpendicular to X''_s and Y'_s.

of variance (ANOVA) models with factors of task (four functional tasks) were calculated for each kinematic variable. We used Bonferroni follow-up analyses to adjust for multiple pairwise comparisons at a significance alpha level of 0.05. The relationships between the kinematic measurements and age were analyzed with the Spearman rank-order correlation.

Additionally, we used three techniques to evaluate the skin motion error, which has the potential to affect the accuracy of the data. First, we considered anthropometric variables as possible covariates using analysis of covariance, including body weight and body height. Karduna et al. validated the sensor placement method with sensors fixed to pins embedded in the bone and indicated that scapular skin motion artifacts occur to a greater degree as end range elevation is approached [25]. Second, we compared the scapular kinematic variables by dividing the subjects into two groups: those with humeral elevation less than 120° during the tasks and those with humeral elevation greater than 120° during the tasks. Karduna et al. also found scapular motion to be over-represented by an average of 6° when acromial-based surface sensor techniques are used [25]. Third, we adjusted the data based on assumed bias by adding 6° to the humeral elevations that were greater than 120°, which adjusted for this error.

RESULTS

Representative kinematic data from a subject during the overhead height task (task A) are presented in **Figure 3**. Although substantial variability existed among tasks and subjects, the major components of the four functional tasks were scapular posterior tipping, scapular upward rotation, scapular protraction, humeral elevation, humeral elevation in an anterior plane, and humeral lateral rotation.

Within-Session Reliability of Kinematic Variables

The ICC (2, 1) values ranged from 0.78 to 0.99, and the ICC (2, 3) values ranged from 0.91 to 0.99. The SEMs were less than 2° for all kinematic variables. The similarity index ranged from 0.81 to 0.97, indicating that movement patterns were similar among trials during the four functional tasks.

Difference of Kinematic Variables Among Tasks

The average time for performing the tasks was 2.6 s (SD = 0.2 s, range = 2.2 to 2.8 s). We used the means of the three trials for all kinematic variables to test differences among the tasks. Significant differences existed among the tasks on all kinematic variables ($p < 0.0005$; $N = 25$) (**Figures 4** and **5**). Overall, posterior tipping, upward rotation, and protraction of the scapula were greatest during the overhead height task (task A) and least during the shoulder height task (task B, tipping and protraction) or salt shaker task (task D, upward rotation). Humeral elevation was greatest during the overhead height task (task A) and least during the shoulder height task (task B). Humeral rotation was greatest in the sliding box task (task C).

Relationships Between Age and Kinematic Variables

Significant negative correlations existed between the age and kinematic variables during tasks A and C (**Table 2** and **Figure 6**): peak scapular tipping ($r = -0.62$ and –0.54, $p < 0.01$) and peak humeral elevation ($r = -0.59$ and –0.53, $p < 0.01$), respectively. Significant positive correlations were also found between age and peak scapular upward rotation during tasks A and C ($r = 0.50$ and 0.27, $p < 0.05$). The negative correlation means that the older subjects exhibited lesser degrees of peak scapular tipping and peak humeral elevation during tasks A and C. The positive correlation means that the older subjects exhibited greater degrees of peak scapular upward rotation during tasks A and C.

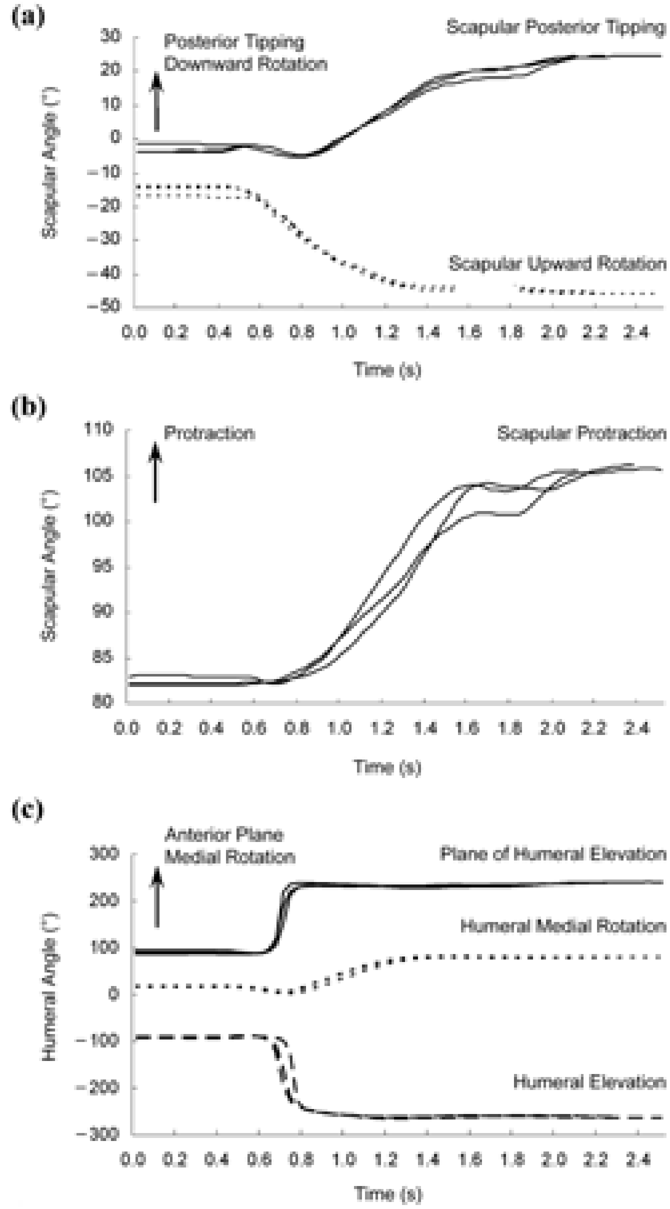

Figure 3.
Data for one representative subject when he used right arm to place object at height just overhead: **(a)** scapular posterior tipping and scapular upward rotation, **(b)** scapular protraction, and **(c)** humeral motions. Data were based on mean of three trials.

Skin Motion Error Evaluation

First, none of the two covariates (body weight and body height) significantly influenced the results of the analysis ($p > 0.05$). Second, no difference was found in the scapular kinematic variables between the two groups with humeral elevations < or > 120° during the tasks ($p > 0.05$). Third, even with the addition of the adjusted bias, neither the correlation trend nor the

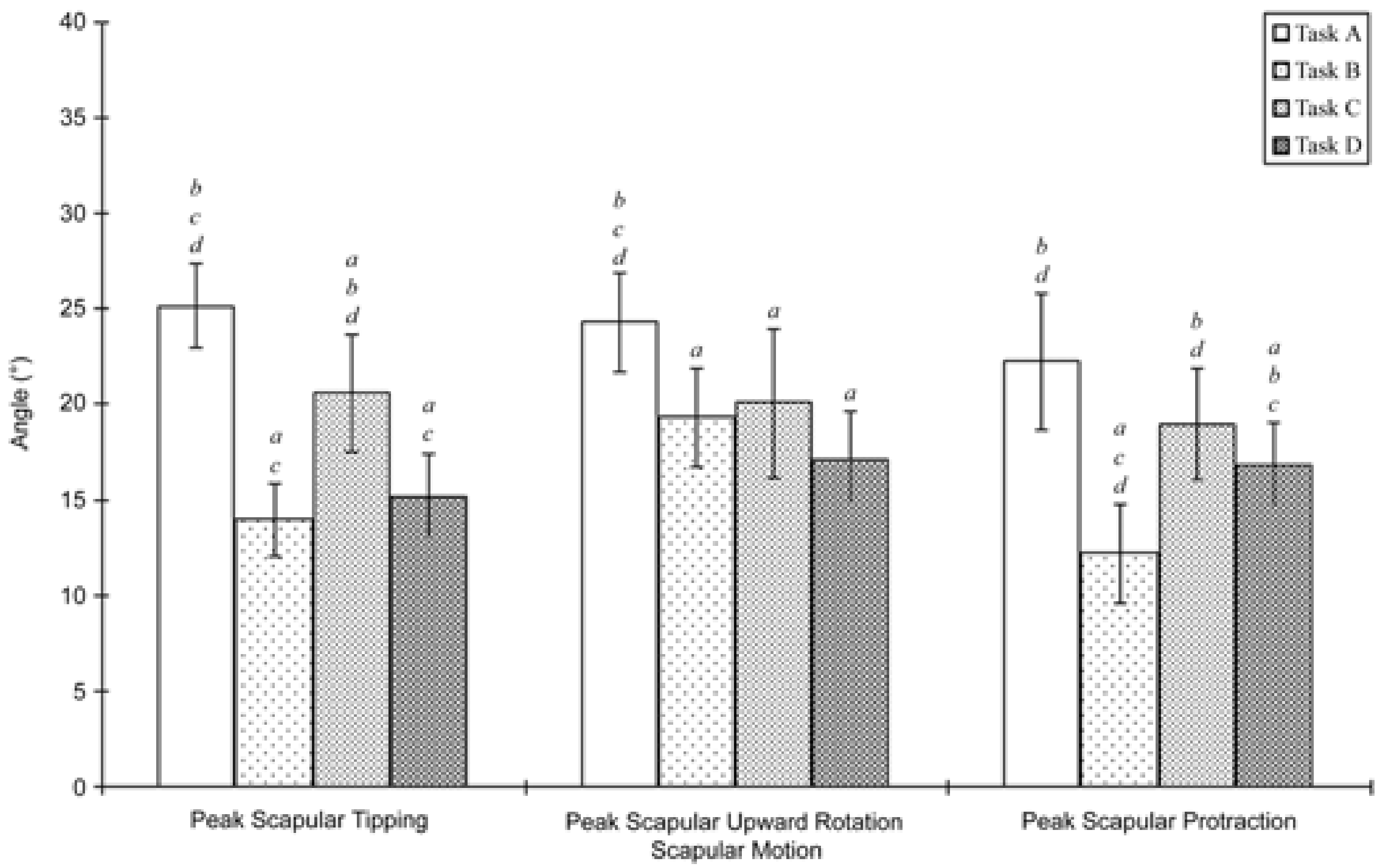

Figure 4.
Summary of scapula movement kinematic data (N = 25). Tasks A to D: (A) overhead height task, (B) shoulder height task, (C) sliding a box task, and (D) reaching for salt shaker task. Bar represents mean of three trials. Line represents standard deviation. *a* = significant difference compared to A. *b* = significant difference compared to B. *c* = significant difference compared to C. *d* = significant difference compared to D.

ANOVA results changed (correlations between age and peak humeral elevation in tasks A and C, r = –0.58 and –0.50, $p < 0.01$; ANOVA, $p < 0.0005$). Therefore, the skin motion artifact likely had little impact on the functional task results.

DISCUSSION

This study evaluated the capability of the 3-D FASTRAK motion system to characterize subject-performed functional tasks in terms of 3-D shoulder complex kinematics, including scapular and humeral movements. We found that the four functional tasks can be consistently and objectively quantified by the FASTRAK motion analysis system. In general, the characterized 3-D scapular and humeral movements reflected the level of task difficulty. The high variability of humeral rotation was also found in the four functional tasks. Significant correlations between the age and kinematic variables were also found during the functional tasks.

Reliability of Shoulder Complex Kinematics During Functional Tasks

The results of this study indicate that 3-D shoulder complex kinematics during the four functional activities can be reliably quantified by the FASTRAK motion analysis system. The means of the three trials are better than those from a single measurement to consistently characterize these functional activities. Since the average time for each testing task was only 2.6 s, we suggest that assessment of the functional task be based on three trials [ICC (2, 3) = 0.91 to 0.99] rather than a single measurement [ICC (2, 1) = 0.78 to 0.99]. Studies by Jordan et al. [15] and Ludewig and Cook [20] have employed the FASTRAK system to investigate the reliability of shoulder

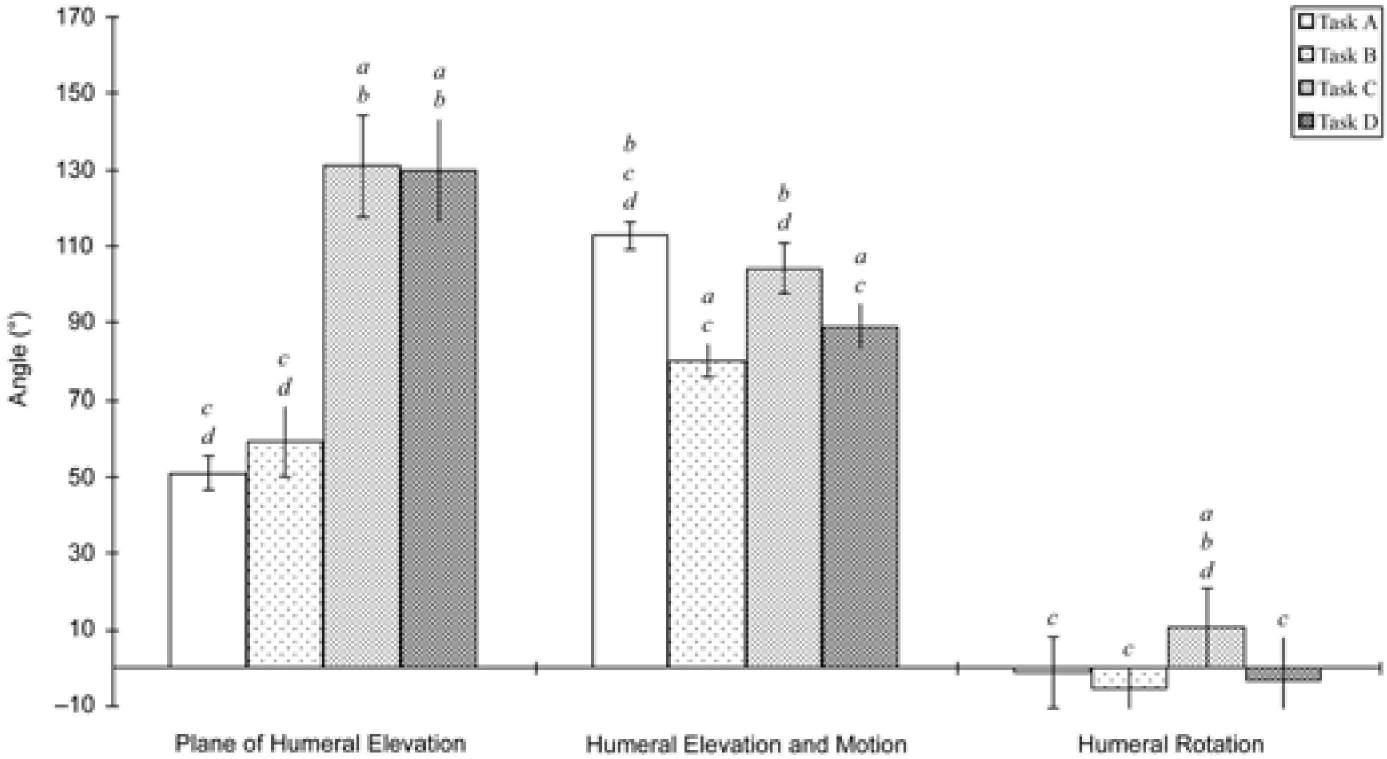

Figure 5.
Summary humeral movement kinematic data (n = 25). Tasks A to D: (A) overhead height task, (B) shoulder height task, (C) sliding a box task, and (D) reaching for salt shaker task. Bar represents mean of three trials. Line represents standard deviation. *a* = significant difference compared to A. *b* = significant difference compared to B. *c* = significant difference compared to C. *d* = significant difference compared to D.

Table 2.
Relationships between age and kinematic variables during four functional tasks.

Movement	Task A Overhead Height Task (Hard Task)	Task B Shoulder Height Task (Routine Task)	Task C Sliding a Box Task (Medium Task)	Task D Reaching Salt Shaker Task (Easy Task)
Peak Scapular Tipping	–0.62*	–0.06	–0.54*	–0.13
Peak Scapular Upward Rotation	0.50*	0.22	0.27†	0.17
Peak Scapular Protraction	–0.20	–0.20	–0.19	–0.12
Plane of Humeral Elevation	–0.34	–0.26	0.13	0.48
Peak Humeral Elevation	–0.59*	–0.05	–0.53*	–0.05
Peak Humeral Rotation	0.11	0.09	–0.03	–0.01

Note: Correlations analyzed using Spearman rank-order correlation. *$p < 0.01$ †$p < 0.05$

complex movements during arm elevations. Ludewig and Cook reported trial-to-trial, within-session ICC (2, 1) values from 0.73 to 0.98 [20]. Jordan et al. reported lower but comparable ICC (2, 1) values (0.62 to 0.81) [15]. Jordan et al.'s study measured subject performance on three occasions at an interval of 2 weeks between each session, which might explain their lower ICC values as compared to the within-session ICC (2, 1) values (0.78 to 0.99) in our study. To improve the feasibility of this method, we recommend further investigation of between-session reliability of 3-D shoulder complex kinematics during functional activities.

The SEM reflects the repeatability between repeated trials, such as repeatability of the instrumentation and the ability of the subjects to replicate the functional task. Barnett et al. tested the reliability of scapular and

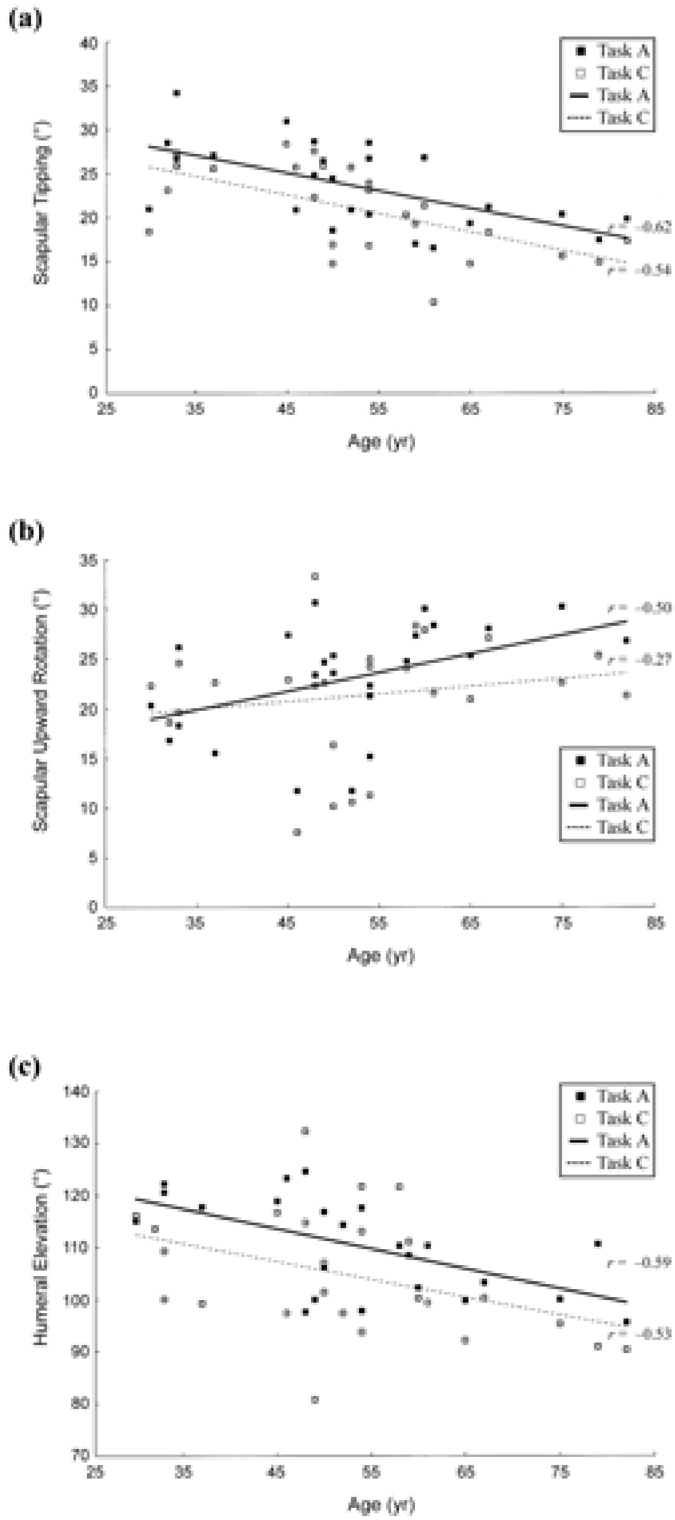

Figure 6.
Scatter diagram showing relationships between age and kinematic variables during functional tasks: **(a)** scapular tipping, **(b)** scapular upward rotation, and **(c)** humeral elevation. Lines represent least-squares regression line.

humeral movements and stated that the measurement errors at the 95 percent confidence interval (CI) for scapular kinematics were less than 4° during arm elevations [21]. Ludewig et al. [27] and Lukasiewicz et al. [28] also investigated arm elevations and reported SEMs for scapular kinematics of less than 3° and 2°, respectively. Similar findings were observed in our study. The SEM and 95 percent CI for shoulder kinematics were ≤2° and 4°, respectively, in our study. Additionally, Pearson correlation values above 0.81 indicated good to excellent motion pattern similarity among the three trials. Although subjects are assumed to have more variability to perform functional tasks, the ICCs, SEM, and Pearson correlation values all indicate satisfactory reliability of the kinematic measures used to describe the four functional activities.

Characteristics of Four Functional Tasks

The 3-D shoulder complex movements observed in this study compare favorably with those reported by Ludewig et al. [27], McClure et al. [29], and Meskers et al. [16], whose studies focused on describing 3-D scapular movements during arm elevations in specified planes (**Table 3**). Notably less scapular upward rotation and more scapular protraction during the four functional tasks were found in our study, as compared to scapular plane abduction/flexion in previous studies [16,27,30]. These differences are important findings when considering kinematic abnormality in a patient population. During the evaluation of a patient with a shoulder dysfunction, the four functional tasks testing may be useful for observing abnormal scapular protraction components.

Previous studies demonstrated that inadequate scapular posterior tipping and scapular upward rotation during humeral elevations (decreased subacromial space presumably) are related to shoulder impingement and/or dysfunction [20,31–32]. That the largest demands on scapular posterior tipping and scapular upward rotation are in the overhead height task was demonstrated in our study. Our results suggest that an individual may increase the chances of subacromial impingement during the high demands of scapular posterior tipping and upward rotation in the overhead height task.

Between-subject variability in scapular motions has frequently been noted [17–18,27]. The magnitude of variability during the four functional tasks in our study, with SDs ranging from 2° to 7°, is consistent with the reported values during arm elevations in specified planes from previous studies [17–18,27]. Interestingly, the magnitude

Table 3.
Comparison between studies of 3-D scapular movements during tasks.

Tasks	Peak Scapular Upward Rotation (°)	Peak Scapular Posterior Tipping (°)	Peak Scapular Protraction (°)
A: Overhead Height Task (peak humeral elevation 135°)	25	25	23
B: Shoulder Height Task (peak humeral elevation 95°)	19	14	13
C: Sliding a Box Task (peak humeral elevation 118°)	20	20	19
D: Reaching for Salt Shaker Task (peak humeral elevation 105°)	17	15	16
Scapular Plane Abduction 140°*	34	15	13
Scapular Plane Abduction 130°†	35	15	9
Flexion 130°†	35	10	3
Flexion 150°‡	58	24	0

Note: Peak humeral elevation of tasks A to D was summation of peak scapular upward rotation and peak humeral elevation relative to scapula.
*Ludewig PM, Cook TM, Nawoczenski DA. Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. J Orthop Sports Phys Ther. 1996;24:57–65.
†McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J Shoulder Elbow Surg. 2001;10:269–77.
‡Meskers CG, Vermeulen HM, de Groot JH, van Der Helm FC, Rozing PM. 3D shoulder position measurements using a six-degree-of-freedom electromagnetic tracking device. Clin Biomech. 1998;13:280–92.

of between-subject variability of humeral rotation, with SDs ranging between 3° and 7°, is similar to the peak humeral rotation during the four functional tasks in our study, in which mean peak scapular rotation ranged between 2° and 11°. This suggests that humeral rotation during the four functional tasks is variable between subjects. The low magnitude and high variability of humeral rotation during the four functional tasks in our study indicate that other functional tasks related to personal care and requiring a large humeral rotation component, such as grooming, should be included in the battery of functional tasks investigating shoulder dysfunction in a patient population.

Relationships Between Age and Shoulder Complex Movements

Gibson et al. proposed that early scapular upward rotation during humeral elevation might occur as a result of a restricted capsule [30]. In our investigation, less peak humeral elevation in elderly individuals during the overhead height and sliding a box tasks (significant negative relationships between the age and peak humeral elevation) indicate that elderly individuals seem to have a tighter capsule. The increased scapular upward rotation (significant positive relationships between the age and peak scapular upward rotation during the overhead height and sliding a box tasks) might be the result of a tighter capsule pulling the scapula along during the two tasks. The relationships were considered to be mild to moderate ($0.2 < r < 0.6$) [26]. Hence, the assumed tighter capsule is likely in asymptomatic elderly subjects. Ludewig and Cook pointed out that serratus anterior muscle weakness would result in less scapular posterior tipping during arm elevations [20]. Subsequently, the decreased subacromial space occurs and results in an impingement syndrome. In our study, serratus anterior muscle weakness appears likely in the elderly subjects with regard to the less scapular posterior tipping during the two tasks ($r > 0.5$) Thus, strengthening exercises, such as push-up exercises, should be advocated in the elderly population to prevent shoulder impingement/dysfunction.

Limitations

Our study used a skin-based approach that involved digitizing bony landmarks and magnetic tracking sensors for measuring shoulder kinematics during the functional tasks. For definition of the longitudinal axis of the humerus, the glenohumeral joint rotation center was estimated from two digitalizing points (the anterior glenohumeral joint and posterior glenohumeral joint). These two points lacked discrete landmarks for palpation, which may have affected the accuracy of the data. To improve this accuracy, we defined and observed the two points on the humerus that moved the least with respect to the scapula when the humerus was moved into several mid-range glenohumeral positions. Although the definition of the axes was standardized and based on previous studies, errors may have existed in the digitizing of the bony landmarks. However, for a given subject, the axes definition was identical among trials and tasks. In addition, our ICC values suggest good consistency, and our data regarding the amount and general pattern of shoulder kinematics are similar to those of other studies, which validates our method.

Several factors regarding the subject sample should be considered. Since the population from our sample was obtained from the VA Medical Center (estimated to be 85% to 90% male), all the subjects participating in our study were males. Although no data exist identifying sex differences for the dependent variables of interest, the generalizability of the study results to women is uncertain.

CONCLUSIONS

Our results indicate that a 3-D electromagnetic tracking method can be used to consistently characterize four functional activities in asymptomatic subjects. The means of the three trials are better than those from a single measurement for reliably quantifying the functional activities. Additionally, the magnitudes of the identified differences in variables among the tasks are generally higher than the values of the SEM, which supports the method we used in our study to characterize the four functional tasks. Among the four functional tasks, the overhead height task was considered difficult in terms of scapular tipping, scapular upward rotation, and humeral elevation. The low magnitude and high variability of humeral rotation during the four functional tasks in our study indicate that other functional tasks related to personal care and requiring a large humeral rotation component, such as grooming, could be investigated in future studies. Additionally, elderly subjects exhibit a greater potential for serratus anterior muscle weakness as well as shoulder capsule tightness.

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