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J Sport Rehabil. 2006, 15, 125-143

Reliability and Precision of in Vivo Scapular Kinematic Measurements Using an Electromagnetic Tracking Device

Joseph Myers, John Jolly, Takashi Nagai, and Scott Lephart

Context: In vivo scapular kinematics during humeral movements are commonly assessed with electromagnetic tracking devices despite few published data related to reliability and precision of these measurements. ***Objective:*** To determine the intrasession reliability and precision of assessing scapular kinematics using an electromagnetic tracking device. ***Design:*** Scapular position and orientation were measured with an electromagnetic tracking device during humeral elevation/depression in several planes. Intrasession reliability and precision were established by comparing 2 trials performed in succession. ***Setting:*** A human-movement research laboratory. ***Participants:*** 15 healthy individuals. ***Main Outcome Measures:*** Intrasession intraclass correlation coefficients and standard error of measurement of all scapular variables were established. ***Results:*** The mean intrasession reliability for all variables was ICC = .97 ± .03. The mean intrasession precision was .99° ± .36°. ***Conclusions:*** In vivo scapular kinematics can be measured with high reliability and precision during intrasession research designs. ***Key Words:*** shoulder, biomechanics, motion analysis

During upper extremity movement, the scapula must act as the stable base of support between the humerus and trunk while still allowing for the high degree of movement needed from the upper extremity. This is accomplished by the scapula's ability to move in 3 dimensions (3D) about the trunk while still maintaining glenohumeral alignment and proper angulation of the humerus with the trunk.[1-3] In order to maintain joint congruency, the scapula has a high degree of mobility that includes its ability to upwardly and downwardly rotate, internally and externally rotate, tilt anteroposteriorly, and translate both superoinferiorly and anteroposteriorly.[4,5] In addition, proper 3D position of the scapula relative to the humerus and trunk is also important for muscle function because the scapula acts as a common point of attachment of the rotator cuff and primary humeral movers such as the biceps, deltoid, and triceps, as well as several scapular stabilizers. Poor position and movement of the scapula is suggested to lead to alterations to the length–tension relationship of each muscle, thus adversely affecting muscle-force generation.[6]

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If movement of the scapula is not coordinated, the integrity of the glenohumeral joint can be compromised and the risk of injury increased.[2] Numerous studies have identified altered scapular positions and orientations in various shoulder pathologies such as instability, subacromial impingement, internal impingement, and rotator-cuff lesions.[7-11] In addition, fatigue has been demonstrated to negatively affect scapular motion, which can have serious implications for overuse injury in both overhead athletes and individuals who perform repetitive overhead occupational tasks.[12-14]

Given the important role that the scapula plays in shoulder function, clinicians and researchers alike seek to effectively quantify scapular motion. For example, radiography has been used to quantify scapular motion.[15-18] The main limitations of this assessment are the invasiveness and cost of using radiography and the fact that it only is able to measure 2-dimensional movements. Others have used less invasive but costly magnetic resonance imaging to measure scapular and humeral motion.[19,20] To overcome the difficulties related to the invasive methods, several investigators have used electromechanical, electromagnetic, or optoelectronic devices to palpate and digitize scapular landmarks when the upper extremity is placed in static positions.[9,21-24] From the digitized data, scapular position can be quantified. The recognized limitation of this palpation method is that measurements cannot be made during dynamic movement of the upper extremity but only during static positioning. Inclinometers have been used to perform similar static assessments by measuring scapular upward rotation.[25,26] These techniques are limited to assessing only 1 degree of freedom of scapular movement in static upper extremity positions. Recently, Karduna et al[4] validated 2 noninvasive methods of measuring in vivo scapular motion using an electromagnetic tracking device during dynamic upper extremity movement. One method consists of simply fixing a sensor directly to the skin over the acromion, and the other consisted of mounting a sensor to an adjustable plastic jig that fits over the scapular spine and acromion. The validity of both methods was assessed by comparing the data collected with data simultaneously collected from pins drilled directly into the scapula. The results indicated that both noninvasive methods might offer reasonably accurate representations of scapular motion.

Several research groups have used this 3D scapular kinematic assessment to answer clinical questions related to shoulder-injury assessment, rehabilitation, and prevention.[7,11-13,27-31] Nonetheless, there is very little published research that specifically reports the reliability and precision of such scapular kinematic assessments. The purpose of this study was to determine the intrasession reliability and precision of assessing scapular kinematics using an electromagnetic tracking device during dynamic humeral elevation and depression movements.

Methods

Subjects

Fifteen volunteers, 12 men and 3 women (height 1.7 ± 0.1 m, mass 69.1 ± 11.0 kg, age 29.2 ± 5.9 years), participated in this study. All were free of upper extremity injury history (ie, no history of physician examination for upper extremity injury). All subjects provided informed consent before participation, as required by the university's institutional review board.

Instrumentation

Scapular and humeral kinematic data were collected using the Motion Star (Ascension Technology Corp, Burlington, Vt) electromagnetic tracking device integrated with MotionMonitor (Innovative Sports Training, Inc, Chicago, Ill) motion-capture software. The MotionMonitor software uses data conveyed by electromagnetic receivers for the calculation of receiver position and orientation relative to an electromagnetic transmitter. The specific hardware used in this investigation consisted of an extended-range direct-current transmitter with a maximum range of 3 m (according to manufacturer specifications) and 4 receivers. The instrumentation sampling frequency used for all kinematic assessments in the current study was 100 Hz. In a pilot study, we determined the accuracy of our electromagnetic instrumentation and the optimal location within our measurement space for subject positioning and testing. Initially, the root mean square errors for both position and orientation were calculated for the 8 ft × 8 ft (2.44 × 2.44 m) measurement space allocated for our electromagnetic tracking device. The overall position error for the 64-ft^2 (17.87-m^2) measurement was 3.3 millimeters, and the orientation error was 0.57°. Given that electromagnetic accuracy is compromised when measurements are taken too close to or too far from the transmitter, we determined the area within that measurement space that yielded the lowest amount of error. It was determined that the region of the measurement space that is between 3 ft (0.91 m) and 4 ft (01.2 m) directly in front of the transmitter demonstrated the least amount of position (0.7 millimeters) and orientation (0.27°) error. Thus, all kinematic assessments in the current study were performed with the subjects standing with their heels 3 ft away from the transmitter.

Procedures

Before data collection, each subject had 3 electromagnetic receivers secured to various anatomical landmarks for kinematic analysis of the scapula and humerus (Figure 1[A]). Two electromagnetic receivers were secured with double-sided adhesive disks (3M Health Care, St Paul, Minn) and hypoallergenic tape (to further reduce receiver-to-skin movement), with 1 receiver attached superficial to the seventh cervical vertebra and 1 receiver attached on the flat, broad portion of the acromion on the scapula at a point one third of the distance from the angulus acromialis to the acromioclavicular joint. A third electromagnetic receiver was secured on the humerus using a neoprene cuff at the midpoint between the angulus acromialis and the lateral humeral epicondyle. The receiver positions of the scapula were previously validated using bone-fixed markers and shown to accurately represent movement of their respective segments.[4,30] A fourth receiver was attached to a stylus that was used for the digitization of landmarks described in the next paragraph.[22,23]

While the subjects stood with their arms at their sides, several bony landmarks on the thorax, scapula, and humerus of the dominant limb were palpated, marked with a skin pen, and digitized with the stylus. The digitized landmarks appear in Table 1. Digitization of the bony landmarks allowed for transformation of the receiver data from a global coordinate system to anatomically based local coordinate systems (Figure 2). Data collection consisted of each subject performing humeral-elevation and -depression tasks in the sagittal, scapular, and frontal planes while

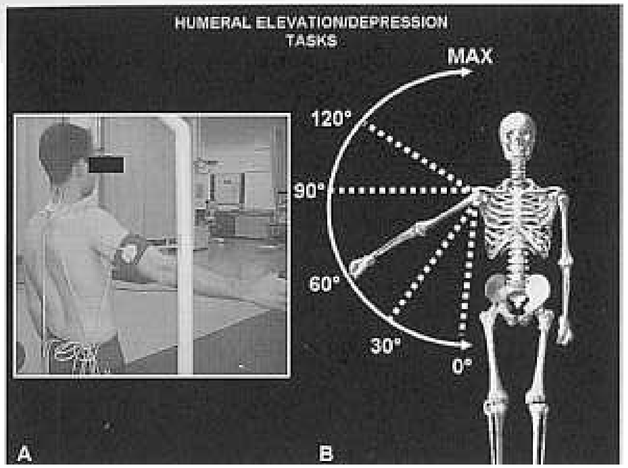

Figure 1 — (A) A participant performing humeral elevation/depression during data collection. **(B)** Portions of the elevation/depression tasks analyzed for each scapular kinematic variable.

Table 1 Description of Bony Landmarks

Bony landmark	Description of palpation point
Thorax	
8th thoracic spinous process (T8)	Most dorsal point
processus xiphoideus (PX)	Most caudal point of the sternum
7th cervical spinous process (C7)	Most dorsal point
incisura jugularis (IJ)	Most cranial point of the sternum (suprasternal notch)
Scapula	
angulus acromialis (AA)	Most laterodorsal point of the scapula
trigonum spinae (TS)	Midpoint of the triangular surface on the medial border of the scapula in line with the scapular spine
angulus inferior (AI)	Most caudal point of the scapula
Humerus	
medial epicondyle (ME)	Most medial point on the medial epicondyle
lateral epicondyle (LE)	Most lateral point on the lateral epicondyle
glenohumeral-joint center (GH)	*

*The glenohumeral-joint center was not palpated but rather estimated with a least-squares algorithm for the point on the humerus that moves the least during several short-arc humeral movements.[32,33]

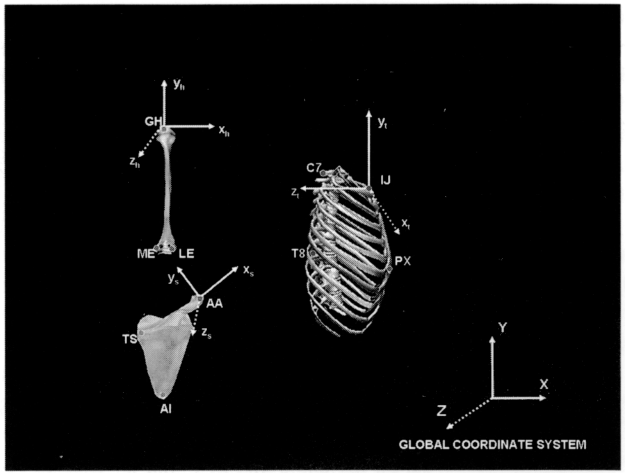

Figure 2 — Bony landmarks and local coordinate system of the trunk, scapula, and humerus.

humeral and scapular kinematic data were collected. All humeral-elevation and -depression tasks began with the arm in the resting position at the subject's side (referred to as 0° of elevation throughout this article), progressing toward full elevation (maximum amount of elevation each subject could obtain), and then returning to the resting position (Figure 1[B]). The plane of motion for the humeral-elevation and -depression tasks was maintained through the use of a guide tube placed in the sagittal plane, frontal plane, or scapular plane (30° anterior to the frontal plane). One trial consisted of each subject performing 10 continuous repetitions lasting 4 seconds (2 seconds to reach maximum elevation and 2 seconds to return to the starting position) with assistance from a metronome.

The elevation and depression task used in the current study was chosen because it is a noninvasive, in vivo, validated means of assessing scapular kinematics[4]; it replicates a substantial amount of previously published research that has assessed scapular position and orientation, making comparison with previous work feasible; it is sensitive enough to show changes associated with shoulder pathology[7,11,30] and scapular-stabilizer muscle fatigue[12]; and it mimics how clinicians typically observe scapular dyskinesis during shoulder-injury evaluation.[34] For each of the 3 humeral-motion tasks, each subject performed 2 trials separated by approximately 20 seconds.

Data Reduction and Analysis

Raw kinematic data were filtered with a low-pass fourth-order zero-phase shift filter with a cutoff frequency of 10 Hz. Receiver position and orientation data of the thoracic, scapular, and humeral receivers were transformed into a local coordinate system for each of the respective segments. Definitions of the local coordinate systems can be obtained from Table 2 and observed in Figure 2. The coordinate systems used were in accordance with recommendations from the International Shoulder Group

Table 2 Definitions of Local Coordinate Systems*

Local coordinate system	Axis	Definition
Thorax	y_t	Vector from the midpoint of PX and T8 to the midpoint between IJ and C7
	x_t	Vector perpendicular to the plane fitted by midpoint of PX and T8, the midpoint of IJ and C7, and IJ
	z_t	Vector perpendicular to x_t and y_t
	origin	IJ
Scapula	x_s	Vector from TS to AA
	y_s	Vector perpendicular to the plane fitted by TS, AA, and AI (scapular plane)
	z_s	Vector perpendicular to x_s and y_s
	origin	AA
Humerus	y_h	Vector from midpoint of ME and LE to GH
	x_h	Vector perpendicular to the plane fitted by GH, ME, and LE
	z_h	Perpendicular to y_h and x_h
	origin	GH

*PX indicates processus xiphoideus; T8, 8th thoracic spinous process; C7, 7th cervical spinous process; IJ, incisura jugularis; TS, trigonum spinae; AA, angulus acromialis; AI, angulus inferior; ME, medial epicondyle; LE, lateral epicondyle; and GH, glenohumeral-joint center.

of the International Society of Biomechanics.[21] In general, 2 points first described the longitudinal axis of a segment, and a third point defined the plane. A second axis is defined perpendicular to the plane, and the third axis is defined as perpendicular to both of the first 2 axes. When standing in a neutral stance, the orthogonal coordinate system for each segment is vertical (y-axis), horizontal to the right (x-axis), and posterior (z-axis). Matrix transformations for each of the segments were used to move from the global to local coordinate systems, producing a 4×4 position and orientation matrix.

Euler-angle decompositions were used to determine scapular and humeral orientation with respect to the thorax. Orientation of the scapula was determined as rotation about the y-axis of the scapula (internal/external rotation), rotation about the z-axis of the scapula (upward/downward rotation), and rotation about the x-axis of the scapula (anteroposterior tilting). Humeral orientation was determined as rotation about the y-axis of the humerus (plane of elevation), rotation about the z-axis of the humerus (elevation), and rotation about the y-axis of the humerus (axial rotation). Each of these rotations was chosen based on the recommendations of the International Shoulder Group.[21] The Euler-angle sequences were used to most closely represent clinical definitions of movements and to decrease mathematical inconsistencies (ie, gimble lock).[35]

Position of the scapula was also described. Scapulothoracic movement does not involve any bone–bone contact, and the scapula does not attach via a direct contact to the thorax. The only attachment of these 2 segments is via the clavicle, a rigid body with a fixed length. As such, the position of the scapula can be described by 2 degrees of freedom as if in spherical space, by both anteroposterior and superoinferior translation.[4,5] The positions of the angulus acromialis and incisura jugularis (IJ) points with respect to the global coordinate system (tracked by the scapular and thoracic receivers, respectively) were used to calculate a vector from the IJ point to the angulus acromialis point. The angle of this vector relative to the transverse plane that bisects the IJ point represents superoinferior translation of the scapula. For anteroposterior translation, this vector was projected onto the transverse plane bisecting IJ and is calculated as the angle between this projection and the frontal plane that bisects IJ.

For each humeral-elevation and -depression trial, the mean position and orientation of the scapula for the middle 8 repetitions were analyzed at the initiation of movement (0°), 30°, 60°, 90°, and 120° of humeral elevation and 120°, 90°, 60°, and 30° of depression (Figure 1[B]). The degrees of humeral elevation and depression were identified from the humeral-elevation and -depression Euler-angle data collected with the electromagnetic tracking device (humeral elevation = rotation about the z'-axis [$yz'y''$ Euler-angle sequence]). No data above 120° of elevation were analyzed because of the lack of accuracy that can occur when measuring scapular kinematics with an electromagnetic tracking device, as demonstrated in the literature.[4]

Reliability for each scapular variable at each phase of the 3 humeral movements was calculated using the (2,k) intraclass correlation coefficient (ICC) model described by Shrout and Fleiss.[36] Intrasession reliability was determined by calculating the ICC between trials 1 and 2. From the obtained ICCs and the standard deviation of each variable, intrasession (trial 1 vs trial 2) precision was established by calculating the standard error of measurement (SEM) for each scapular variable at each phase of the 3 humeral movements.

Results

The descriptive statistics (mean ± SD), intrasession reliability (ICC), and precision (SEM) for each of the 5 scapular kinematic variables during each phase of the 3 humeral movements for each of the 3 trials appear in Tables 3–8.

Comments

As the use of scapular kinematic assessment increases in clinical research,[7,11-13,27-31] in order to evaluate the effectiveness of specific interventions for altering measurable impairments, it is important to establish both the reliability and the precision of such assessments. This study established both the intrasession reliability and the precision of assessing scapular kinematics using an electromagnetic tracking device during dynamic humeral movements. These results provide important considerations for clinical researchers as they decide whether to use electromagnetic tracking to assess scapular motion in their clinical research.

Table 3 Scapular Kinematics Descriptive Statistics, Reliability, and Precision During Sagittal-Plane Elevation

	Trial 1		Trial 2			
Variable	Mean	SD	Mean	SD	Intrasession ICC	SEM
0° ER	32.37	7.74	32.39	8.32	.990	0.80
0° UP	4.92	6.82	5.18	7.03	.975	1.09
0° PT	–12.00	5.11	–12.35	4.87	.977	0.76
0° AP	–18.13	5.14	–18.44	5.40	.962	1.03
0° SI	–3.33	4.12	–2.86	3.95	.981	0.56
0° ER	34.33	7.84	33.84	8.26	.993	0.67
30° UP	10.10	6.79	10.25	6.91	.984	0.87
30° PT	–8.38	5.79	–8.75	5.67	.991	0.54
30° AP	–18.83	5.62	–18.81	5.77	.980	0.81
30° SI	–2.10	4.21	–1.72	3.94	.981	0.56
60° ER	37.82	8.41	37.22	9.05	.996	0.55
60° UP	19.63	6.92	19.85	6.88	.980	0.98
60° PT	–4.46	6.43	–4.90	6.24	.992	0.57
60° AP	–19.56	6.34	–19.69	7.05	.971	1.14
60° SI	2.21	4.68	2.90	4.39	.981	0.63
90° ER	38.60	11.11	37.47	11.71	.996	0.72
90° UP	29.51	7.15	29.34	7.28	.983	0.94
90° PT	–1.03	7.92	–1.49	7.72	.993	0.65
90° AP	–23.92	6.29	–24.02	7.43	.967	1.25
90° SI	7.09	4.70	7.58	4.67	.976	0.73
120° ER	34.92	15.84	33.56	15.91	.994	1.35
120° UP	34.57	13.45	33.86	12.94	.981	1.82
120° PT	7.52	12.00	6.64	11.95	.969	2.11
120° AP	–31.49	6.94	–31.29	7.42	.933	1.86
120° SI	8.21	5.54	7.96	5.44	.975	0.87

*ICC indicates intraclass correlation coefficient; SEM, standard error of measurement; ER, scapular internal/external rotation; UP, scapular upward/downward rotation; PT, scapular anterior/posterior tilting; AP, scapular anterior/posterior translation; and SI, scapular superior/inferior translation.

Table 4 Scapular Kinematics Descriptive Statistics (°), Reliability, and Precision During Sagittal-Plane Depression

	Trial 1		Trial 2			
Variable	Mean	SD	Mean	SD	Intrasession ICC	SEM
30° ER	36.94	8.47	37.02	8.72	.989	0.90
30° UP	9.67	8.12	9.22	7.79	.990	0.80
30° PT	–7.65	5.48	–8.49	5.47	.993	0.46
30° AP	–18.28	6.02	–18.22	6.34	.974	1.00
30° SI	–0.43	4.22	0.10	4.18	.972	0.70
60° ER	40.49	8.97	40.15	9.63	.991	0.88
60° UP	21.16	8.00	21.01	8.12	.986	0.95
60° PT	–3.62	6.37	–4.09	6.26	.994	0.49
60° AP	–22.29	6.85	–22.38	7.12	.981	0.96
60° SI	4.76	4.78	5.39	4.72	.972	0.79
90° ER	40.42	11.42	39.64	11.99	.994	0.91
90° UP	31.01	9.33	30.27	9.11	.994	0.71
90° PT	1.32	8.07	1.02	7.73	.996	0.50
90° AP	–27.47	6.10	–27.38	6.61	.982	0.85
90° SI	9.04	5.41	9.12	5.29	.985	0.66
120° ER	34.16	15.49	33.47	15.50	.995	1.10
120° UP	35.37	13.90	34.13	13.15	.982	1.81
120° PT	9.46	11.98	8.37	11.75	.964	2.25
120° AP	–33.19	6.46	–32.72	7.00	.923	1.87
120° SI	9.16	5.93	8.78	5.96	.975	0.94

*ICC indicates intraclass correlation coefficient; SEM, standard error of measurement; ER, scapular internal/external rotation; UP, scapular upward/downward rotation; PT, scapular anterior/posterior tilting; AP, scapular anterior/posterior translation; and SI, scapular superior/inferior translation.

Reliability for all scapular kinematic variables during humeral movements was established with the use of ICCs. ICCs provide a numeric means of assessing the agreement between 2 trials, thus providing an indication of the repeatability. As a general guideline, Portney and Watkins[37] suggest that ICC values above .75 are indicative of good reliability and those below .75 indicate moderate to poor reliability. Clinical measurements should exceed .90 to ensure reasonable validity.[37] In

Table 5 Scapular Kinematics Descriptive Statistics (°), Reliability, and Precision During Scapular-Plane Elevation

	Trial 1		Trial 2			
Variable	Mean	SD	Mean	SD	Intrasession ICC	SEM
0° ER	27.11	6.98	27.01	7.59	.991	0.69
0° UP	2.50	6.40	2.10	5.73	.986	0.70
0° PT	−15.29	6.56	−15.07	6.74	.963	1.25
0° AP	−28.08	4.91	−27.12	4.57	.961	0.91
0° SI	−4.39	4.56	−4.01	4.16	.969	0.76
0° ER	26.62	7.46	26.39	7.45	.992	0.67
30° UP	8.25	5.70	7.92	5.52	.994	0.43
30° PT	−11.32	7.20	−11.69	7.05	.953	1.51
30° AP	−31.32	4.53	−30.35	4.94	.982	0.61
30° SI	−2.47	4.11	−2.02	3.93	.893	1.29
60° ER	26.78	8.41	26.14	8.45	.982	1.09
60° UP	17.85	5.86	17.88	5.51	.919	1.60
60° PT	−8.16	7.58	−8.52	7.31	.964	1.38
60° AP	−34.61	4.90	−33.75	4.79	.950	1.06
60° SI	2.50	3.99	3.29	4.26	.859	1.53
90° ER	26.92	11.14	26.69	11.07	.996	0.72
90° UP	27.26	6.39	27.19	6.06	.991	0.58
90° PT	−3.37	8.13	−4.11	7.73	.987	0.89
90° AP	−38.96	4.57	−38.11	4.40	.950	0.99
90° SI	7.16	4.61	7.94	4.76	.982	0.62
120° ER	27.05	16.31	27.53	16.36	.995	1.18
120° UP	35.78	8.74	35.59	8.59	.997	0.48
120° PT	6.56	11.73	5.74	11.36	.993	0.93
120° AP	−45.68	4.04	−44.54	4.15	.937	1.01
120° SI	9.47	5.60	10.69	6.06	.986	0.67

*ICC indicates intraclass correlation coefficient; SEM, standard error of measurement; ER, scapular internal/external rotation; UP, scapular upward/downward rotation; PT, scapular anterior/posterior tilting; AP, scapular anterior/posterior translation; and SI, scapular superior/inferior translation.

Table 6 Scapular Kinematics Descriptive Statistics (°), Reliability, and Precision During Scapular-Plane Depression

	Trial 1		Trial 2			
Variable	Mean	SD	Mean	SD	Intrasession ICC	SEM
30° ER	28.50	8.12	28.13	8.61	.989	0.81
UP	7.47	6.88	7.21	6.14	.968	1.08
30° PT	−10.85	6.13	−10.91	6.21	.968	1.02
30° AP	−31.20	5.09	−30.46	5.37	.930	1.28
30° SI	−2.14	4.48	−1.51	4.33	.965	0.76
60° ER	29.00	8.78	28.52	9.38	.990	0.84
60° UP	18.85	6.77	18.71	6.72	.981	0.86
60° PT	−5.82	6.37	−5.87	6.74	.970	1.05
60° AP	−36.33	5.39	−35.61	5.71	.933	1.33
60° SI	3.22	4.16	3.95	4.42	.958	0.81
90° ER	30.31	11.68	29.88	11.74	.994	0.84
90° UP	28.23	7.04	28.01	6.92	.995	0.46
90° PT	−0.14	7.43	−0.12	7.18	.974	1.09
90° AP	−40.99	4.86	−40.13	4.83	.941	1.09
90° SI	7.61	4.54	8.31	4.62	.972	0.71
120° ER	29.56	16.35	30.14	16.39	.989	1.59
120° UP	36.15	8.54	35.69	8.88	.998	0.36
120° PT	8.39	11.51	7.70	11.21	.989	1.10
120° AP	−46.62	3.86	−45.37	4.02	.933	0.94
120° SI	10.66	5.59	11.53	5.92	.989	0.56

*ICC indicates intraclass correlation coefficient; SEM, standard error of measurement; ER, scapular internal/external rotation; UP, scapular upward/downward rotation; PT, scapular anterior/posterior tilting; AP, scapular anterior/posterior translation; and SI, scapular superior/inferior translation.

the current study, the intrasession reliability for most scapular kinematic variables assessed exceeded .90, thus indicating that one can expect high levels of reliability when comparing data between trials within testing sessions. Given the high intrasession reliability (mean ICC = .97 ± .03), the results of this study suggest that in vivo scapular kinematics can be assessed with an electromagnetic tracking device with reasonable reliability.

Table 7 Scapular Kinematics Descriptive Statistics (°), Reliability, and Precision During Frontal-Plane Elevation

	Trial 1		Trial 2			
Variable	Mean	SD	Mean	SD	Intrasession ICC	SEM
0° ER	22.19	5.83	23.28	6.55	.930	1.61
0° UP	7.32	6.30	6.17	4.84	.919	1.59
0° PT	−14.34	6.77	−14.48	6.67	.982	0.87
0° AP	−33.77	4.50	−32.56	4.33	.879	1.56
0° SI	−3.72	4.65	−4.08	4.68	.953	1.00
0° ER	20.63	6.28	21.36	6.62	.946	1.49
30° UP	11.78	5.15	10.61	4.44	.917	1.74
30° PT	−10.76	6.94	−11.20	7.14	.985	0.83
30° AP	−36.22	4.06	−35.67	4.10	.897	1.34
30° SI	−1.81	4.50	−2.15	4.71	.977	0.68
60° ER	19.04	7.09	19.63	7.88	.969	1.35
60° UP	20.77	4.81	20.30	4.54	.949	1.06
60° PT	−6.78	7.43	−7.21	7.74	.982	0.99
60° AP	−40.07	3.78	−40.07	4.56	.933	1.10
60° SI	3.24	4.35	3.27	4.50	.973	0.71
90° ER	19.79	9.45	20.31	10.48	.985	1.24
90° UP	29.54	4.78	28.51	5.60	.967	0.85
90° PT	−2.22	8.25	−2.63	8.86	.983	1.08
90° AP	−43.58	3.60	−43.66	4.26	.952	0.92
90° SI	7.21	4.73	7.47	4.90	.956	1.00
120° ER	21.64	12.62	22.70	15.13	.986	1.63
120° UP	35.98	7.60	36.23	8.31	.985	0.97
120° PT	5.76	11.09	5.72	11.79	.992	0.52
120° AP	−47.92	3.36	−48.29	3.72	.924	1.21
120° SI	9.73	4.70	10.58	5.43	.959	1.07

*ICC indicates intraclass correlation coefficient; SEM, standard error of measurement; ER, scapular internal/external rotation; UP, scapular upward/downward rotation; PT, scapular anterior/posterior tilting; AP, scapular anterior/posterior translation; and SI, scapular superior/inferior translation.

Table 8 Scapular Kinematics Descriptive Statistics (°), Reliability, and Precision During Frontal-Plane Depression*

	Trial 1		Trial 2			
Variable	Mean	SD	Mean	SD		SEM
30° ER	20.77	5.63	21.63	6.61	.946	1.46
30° UP	13.32	5.63	11.72	5.01	.962	1.04
30° PT	−8.99	6.24	−9.26	6.46	.979	0.89
30° AP	−37.15	4.09	−36.83	4.26	.943	1.04
30° SI	−1.05	4.18	−1.36	4.21	.976	0.64
60° ER	20.25	6.57	20.72	7.19	.967	1.34
60° UP	22.87	4.96	22.36	4.53	.975	0.75
60° PT	−2.65	6.83	−2.73	7.08	.977	1.02
60° AP	−41.83	4.03	−41.95	4.19	.952	0.94
60° SI	3.92	3.88	4.19	4.30	.967	0.74
90° ER	22.35	9.50	22.86	10.03	.988	1.10
90° UP	30.26	6.28	29.68	6.09	.987	0.71
90° PT	3.01	8.04	3.04	8.08	.982	1.04
90° AP	−45.34	3.40	−45.41	3.89	.943	0.99
90° SI	7.51	4.64	8.08	4.59	.957	0.98
120° ER	24.63	12.49	25.97	13.73	.989	1.37
120° UP	36.36	7.85	36.53	8.48	.990	0.82
120° PT	8.23	11.16	8.48	11.42	.994	0.84
120° AP	−48.67	3.20	−48.79	3.53	.932	1.10
120° SI	10.21	4.78	11.30	5.17	.963	0.57

*ICC indicates intraclass correlation coefficient; SEM, standard error of measurement; ER, scapular internal/external rotation; UP, scapular upward/downward rotation; PT, scapular anteroposterior tilting; AP, scapular anteroposterior translation; and SI, scapular superoinferior translation.

Other investigators have reported intrasession ICCs comparable to those of the current study. Ludewig et al[7] reported ICC values ranging from .93 to .98 for scapular kinematics variables assessed during humeral elevation in the scapular plane. Padua et al[38] reported good intrasession reliability of ICC = .89 to 99 for scapulohumeral rhythm in a group of baseball players. Thigpen et al[31] reported both the intrasession and intersession reliability of scapular tilting during humeral rotation and demonstrated excellent between-trials reliability (ICC = .99), moderate between-sessions reliability (ICC = .67), and good between-days reliability (ICC = .79). From the results of the current study, as well as other published results, assessment of scapular kinematics using an electromagnetic tracking device can be performed with good reliability.

ICCs provide a unitless estimate of reliability of measurement but do not provide an estimate of the precision one can expect from the measurement.[39] SEM provides an indication of precision and represents the expected unit-based standard deviation for the particular measurement. In the current study we calculated the intrasession for each scapular kinematic variable during each humeral movement. We calculated the intrasession SEM, which appears to be low, indicating that one can expect good precision. In most cases, the intrasession SEMs were below 2° of error (mean = 0.99° ± 0.36°). In addition, there appears to be no appreciable difference in reliability and precision between humeral elevation and depression, planes of humeral motion, or scapular variables assessed (Figures 3–6). All reliability coefficients were greater than .93, with less than 0.5° of error. Given the high reliability and precision, the results suggest that scapular kinematics can be assessed during any of the 3 humeral-elevation and -depression tasks used in the current study, accurately when an intrasession research design is used.

From visual interpretation of Tables 3–8 and Figures 3–6, the SEM tended to center around 1°, with the exception of sagittal-plane motions at 120° of elevation, where the error was closer to and even exceeded 2°. These findings are important when interpreting previous work that used similar methodology, as well as considerations for use of electromagnetic tracking of the scapular in future research. For example, in recent work that used electromagnetic tracking to assess scapular motion, the effect size associated with subacromial impingement,[7,40] shoulder

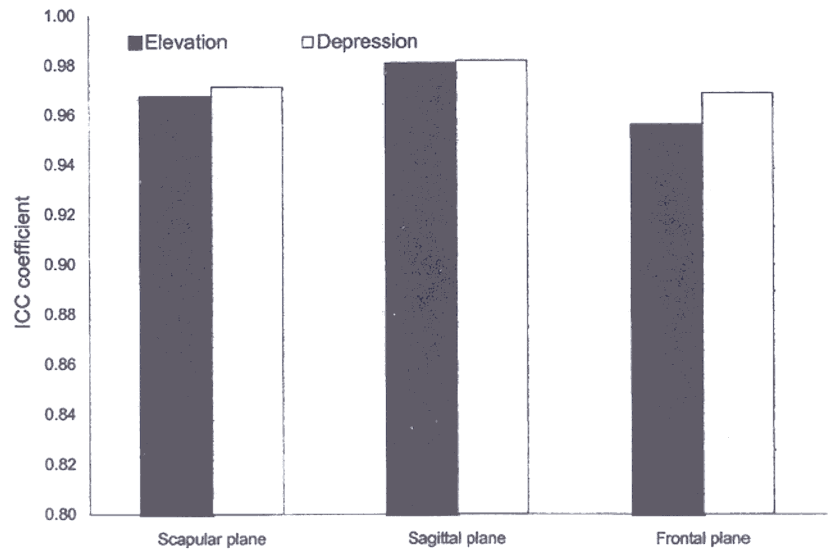

Figure 3 — Intrasession reliability for the 3 planes of humeral elevation and depression.

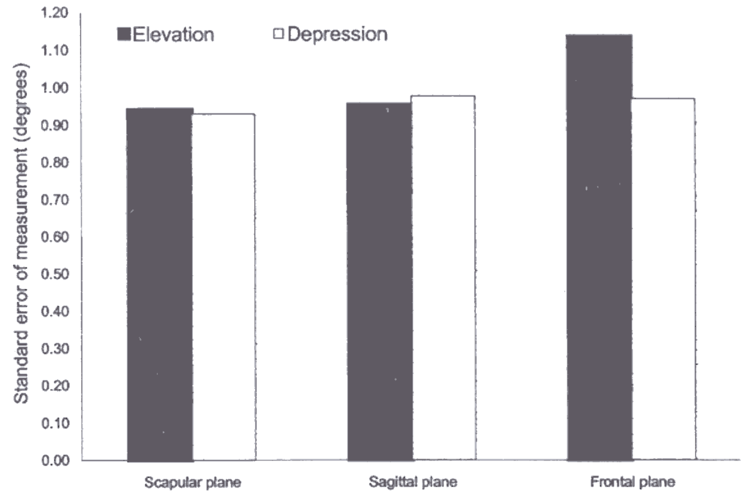

Figure 4 — Intrasession precision for the 3 planes of humeral elevation and depression.

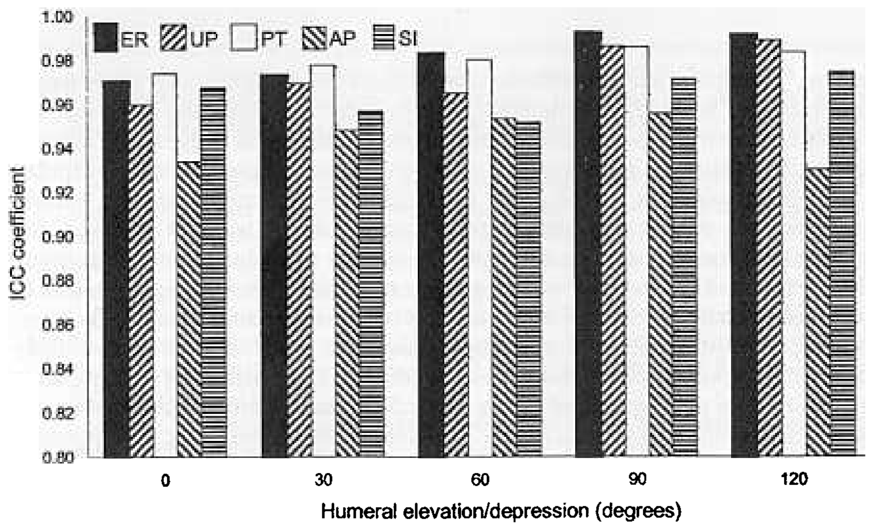

Figure 5 — Intrasession reliability for the 5 scapular movements assessed at the 5 levels of humeral elevation/depression. ER indicates scapular internal/external rotation; UP, scapular upward/downward rotation; PT, scapular anterior/posterior tilting; AP, scapular anterior/posterior translation; and SI, scapular superior/inferior translation.

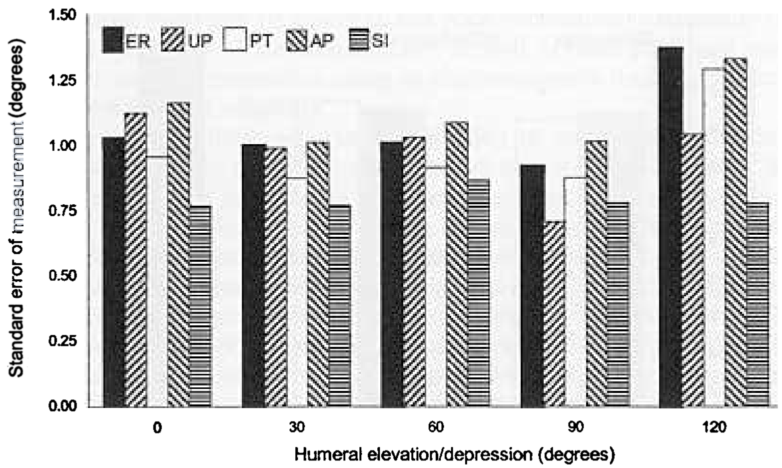

Figure 6 — Intrasession precision for the 5 scapular movements assessed at the 5 levels of humeral elevation/depression. ER indicates scapular internal/external rotation; UP, scapular upward/downward rotation; PT, scapular anterior/posterior tilting; AP, scapular anterior/posterior translation; and SI, scapular superior/inferior translation.

fatigue,[12,13] scapular adaptations associated with throwing,[27] pectoralis minor length and posture,[29,4] and pathologic internal impingement[11] were typically larger than the measurement error reported in the current study. This would suggest that electromagnetic tracking has the necessary precision for use in research on the scapula.

The investigators in this study recognize several limitations that warrant discussion. In the current study, intersession reliability was not assessed, but intersession research designs are typically needed to evaluate the effectiveness of interventions for shoulder pathology. For example, if an investigator wants to determine the effectiveness of some treatment or rehabilitation technique for treating scapular dysfunction in a pathological shoulder, he or she would most likely use a pretest–posttest intersession research design. Establishment of intersession reliability is an area in need of future research. A second limitation that warrants acknowledgment was the exclusion of humeral movements that incorporate a substantial amount of humeral rotation. In the current study, the humerus was in a position of neutral rotation. Unlike Thigpen et al,[31] we were unable to accurately measure humeral rotation during tasks that involve humeral-rotation movement using an electromagnetic tracking device during pilot testing. This difficulty in measuring humeral rotation is consistent with the work of Ludewig et al[42] in that humeral rotation might be underestimated by as much as 15° when assessed with surface-based electromagnetic tracking, because of soft-tissue movement that occurs relative to the electromagnetic receiver. Finally, the sample size was limited to 15 participants. This subject group consisted of normal, healthy individuals and did not represent an injured population. We studied a normal, healthy group so that true reliability and precision of scapular motion could be assessed without any influence that injury might have on scapular motion.

Conclusion

The results of this study suggest that in vivo scapular kinematics can be measured with high reliability and precision with intrasession research designs using an electromagnetic tracking device. Ultimately, the methods used in the current study can be mimicked to reliably and precisely measure scapular kinematics in clinical research on the shoulder.

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