[RESEARCH REPORT]

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Reliability and Minimal Detectable Change of 3-Dimensional Scapular Orientation in Individuals With and Without Shoulder Impingement

Scapulothoracic movement results from a complex interaction of sternoclavicular and acromioclavicular joint motion.[12,21] There is evidence that alterations of this motion pattern are associated with shoulder pathologies, such as shoulder impingement and rotator cuff disease.[20,22,23,25] However, there are some inconsistencies and discrepancies regarding scapular orientation alterations across studies.[22]

Electromagnetic devices are commonly used to measure 3-D scapular orientation during shoulder movements in healthy subjects and individuals with different shoulder conditions.[19-21,23-25,31,37,38] The use of a skin-based sensor attached to the scapula has previously been shown to be a valid method to measure scapular orientation and motion when compared to a bone-based technique.[14] Despite the wide use of surface sensors to assess 3-D scapular orientation in different shoulder conditions, limited data are available concerning reliability of these methods.

Only 1 study[32] has specifically evaluated the reliability of measurement of scapular orientation and showed that the within-day was better than the between-day reliability in young, healthy subjects. The authors[32] also recommended the use of arm elevation in the sagittal plane when the most repeatable scapular pattern is desired. Although Thigpen et al[32] have contributed to the literature, their results cannot be generalized, as they only evaluated healthy subjects and elevation of the arm. It is also important to measure scapular orientation in people with shoulder dysfunction and when lowering the arm. Most importantly, a number of recent studies have investigated the efficacy of therapeutic interventions by making kinematic evaluations of subjects on different days without a clear knowledge of between-day reliability.[10,24,34] Better documentation of the reliability of 3-D

STUDY DESIGN: Clinical measurement.

OBJECTIVE: To establish trial-to-trial within-day and between-day reliability, standard error of measurement, and minimal detectable change of scapular orientation during elevation and lowering of the arm, and with the arm relaxed at the side, in individuals with and without shoulder impingement.

BACKGROUND: Electromagnetic devices are commonly used to measure 3-D scapular kinematics during arm elevation in different conditions and for intervention studies. However, there is a lack of studies that evaluate within- and between-day reliability of these measurements.

METHODS: The subjects were allocated to either a control group or an impingement group. Kinematic data were collected using the Flock of Birds electromagnetic device during elevation and lowering of the arm in the sagittal plane on 2 different occasions, separated by 3 to 5 days. Forty-nine subjects were tested for within-day reliability. Forty-three subjects were reassessed for between-day reliability.

RESULTS: Intraclass correlation coefficients for within- and between-day assessment of scapular orientation during elevation and lowering of the arm in both groups ranged from 0.92 to 0.99 and from 0.54 to 0.88, respectively. Intraclass correlation coefficients for assessment of scapular orientation with the arms relaxed at the side in both groups ranged from 0.66 to 0.95. The standard error of measurement for between-day measurements ranged from 3.37° to 7.44° for both groups. The minimal detectable change for between-day measurements increased from 7.81° at the lower to 17.27° at the higher humerothoracic elevation angles.

CONCLUSION: These results support the use of Flock of Birds to measure scapular orientations in subjects with and without impingement symptoms. The measurements showed excellent within-day reliability but were not highly reliable over time.

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scapular orientation measurements using an electromagnetic system, quantified using intraclass correlation coefficients (ICCs), standard errors of measurement (SEMs), and minimal detectable change (MDC), is important for future research and clinical decision making. This information will improve the ability to interpret differences in scapular orientation between trials and between days. Considering that scapular dyskinesia is commonly observed in individuals with shoulder impingement,[16,20] and that it can vary from day to day due to fatigue or intensity of symptoms,[15] scapular kinematics could be less reliable in these individuals compared to healthy controls.

The purpose of this study was to determine trial-to-trial within-day and between-day reliability of surface-sensor measurement of scapular orientation during elevation and lowering of the arm, and with the arm relaxed at the side, in healthy subjects and subjects with shoulder impingement symptoms. A secondary objective was to establish SEM and MDC values to facilitate clinical interpretation of scapular kinematic change over time.

METHODS

Subjects

Of the 49 individuals who participated in the study, 23 were in the control group and 26 were in the impingement group. The symptomatic participants in the impingement group were recruited with flyers posted on the university premises, in orthopaedic clinics, and in community public places. Participants in the control group, who had no shoulder symptoms or impairments, were recruited from the university and surrounding community, as well as through personal contacts of the investigators. The basic descriptive characteristics of the subjects are given in **TABLE 1**.

TABLE 1 DEMOGRAPHIC CHARACTERISTICS OF THE SUBJECTS*

	Within-Day Reliability (n = 49)		Between-Day Reliability (n = 43)	
	Control Group (n = 23)	Impingement Group (n = 26)	Control Group (n = 19)	Impingement Group (n = 24)
Age, y	27.77 ± 6.84	29.65 ± 9.09	28.11 ± 7.29	29.92 ± 9.40
Weight, kg	62.66 ± 11.22	76.50 ± 13.55	62.66 ± 11.89	75.92 ± 13.96
Height, m	1.67 ± 0.09	1.73 ± 0.10	1.66 ± 0.09	1.73 ± 0.10
BMI, kg/m^2	22.33 ± 2.65	25.42 ± 3.45	22.59 ± 2.76	25.39 ± 3.55
Evaluated shoulder	7 dominant, 16 nondominant	16 dominant, 10 nondominant	4 dominant, 15 nondominant	16 dominant, 8 nondominant
Duration of pain, mo	...	41.62 ± 64.82	...	42.04 ± 66.85
Duration between evaluations, d	...	...	3.24 ± 1.17	3.42 ± 0.71

Abbreviation: BMI, body mass index.
**Values are mean ± SD except for evaluated shoulder.*

The diagnosis of shoulder impingement was based on a clinical screening examination and self-reported orthopaedic history. To be classified as having shoulder impingement, subjects had to present with at least 3 of the following: positive Neer impingement test,[26] positive Hawkins-Kennedy impingement test,[8] pain with isometric resisted shoulder abduction,[13] pain with passive[9] or isometric resisted shoulder lateral rotation,[27,30] pain with active shoulder elevation,[11] pain with palpation of rotator cuff tendons, and pain in the C5 or C6 dermatome region.[25] All subjects had to achieve 150° of active arm elevation. Exclusion criteria were pregnancy, systemic illnesses, physical therapy treatment within 6 months prior to the evaluation, signs of a complete rotator cuff tear (positive drop-arm test[1]), cervical spine–related symptoms, glenohumeral instability (positive apprehension, anterior drawer, or sulcus test[25]), or previous upper extremity fracture or shoulder surgery. Control subjects were excluded if they presented with any complaints of cervical or shoulder pain, any positive test for shoulder impingement[8,13,26] or instability,[25] history of upper extremity fractures, pregnancy, or systemic illnesses. This study was approved by the Ethics Committee of the Federal University of São Carlos (465/2011). The subjects gave their written and informed consent to participate in this study, which was conducted according to the Helsinki Declaration.

Only the shoulder on the symptomatic side was evaluated in subjects with shoulder impingement, and the side evaluated in the asymptomatic group was randomly determined with a computer-randomized list.

Three-Dimensional Kinematics

Kinematic data were collected on 2 different occasions, separated by 3 to 5 days. On the first day, 49 subjects were tested to determine trial-to-trial within-day reliability of 3 trials of elevation and lowering of the arm. Forty-three of the 49 subjects were reassessed on a second day to determine between-day reliability of the mean of 3 trials on each testing day. The examiner was blinded to the initial-day measures at the time of retesting. All within- and between-day testing was completed by the same examiner, who was a physical therapist with 4 years of experience in manual therapy and palpation techniques.

For 3-D measurements, data capture and analysis were completed using Flock of Birds hardware (miniBIRD; Ascension Technology Corporation, Shelburne, VT) integrated with MotionMonitor software (Innovative Sports Training, Inc, Chicago, IL). The Flock of Birds is a direct-current electromagnetic tracking device able to locate multiple sensors relative to a source transmitter. The transmitter produces an electromagnetic field that induces current into the sensors with 3 embedded orthogonal coils. The 3-D position and orientation of each sensor were tracked simultaneously at sampling rates of 100 Hz. The sensors are small (1.8 × 0.8 × 0.8 cm) and lightweight. In a metal-free environment up to a 76-cm distance from the transmitter, the root-mean-square accuracy of the system is 0.5° for orientation and 0.18 cm for position, as reported by the manufacturer. One of the sensors is attached to a stylus with known offsets to digitize anatomical landmarks for building the joint coordinate systems.

The electromagnetic sensors were attached with double-sided adhesive tape to the sternum, to the acromion of the scapula, and to a thermoplastic cuff that was secured to the distal humerus to track humeral motion. These surface-sensor placements have been previously used.[5,19,20,25,31] Bony landmarks on the thorax, scapula, and humerus were palpated and digitized to allow transformation of the sensor data to local anatomically based coordinate systems. Digitizing involves bringing a stylus with an embedded electromagnetic sensor and known tip offsets to the palpated landmark location and digitally recording the 3-D coordinate locations relative to the respective segment sensor. Thorax landmarks included the sternal notch, C7 spinous process, T8 spinous process, and xiphoid process. Scapular landmarks included the root of the spine, the posterolateral acromion, and the inferior angle of the scapula. Humerus landmarks included the lateral and medial epicondyles. The center of the humeral head was estimated by moving the arm passively through short arcs (less than 45°) to define the pivot point.[3]

Local coordinate systems were established for the trunk, scapula, and humerus using the digitized landmarks, following the International Society of Biomechanics' recommended protocol.[36] The z-axis was pointing laterally, the x-axis anteriorly, and the y-axis superiorly for the right-side data analysis for all segments. The axis orientation for the left side was changed such that the z-axis pointed laterally, the x-axis posteriorly, and the y-axis superiorly. These 3 axes defined the cardinal planes for the trunk. The y-axis was formed by the vector joining the midpoints between the C7 spinous process and the sternal notch and between the T8 spinous process and the xiphoid process. The z-axis was directed perpendicular to the sagittal plane. The x-axis was perpendicular to the z-axis and y-axis. To define the axes of the scapula, the z-axis was defined in the plane of the scapula from the root of the scapular spine to the posterolateral acromion. The x-axis was perpendicular to the plane of the scapula. The y-axis was perpendicular to the z-axis and x-axis.

The y-x-z sequence was used to describe the scapular orientation relative to the trunk. For the scapula, the orientations were described in the order of internal/external rotation, upward/downward rotation, and anterior/posterior tilt. The humeral position with reference to the trunk was determined using the y-x'-y'' sequence. The first rotation defined the plane of elevation, the second defined the humeral elevation angle, and the third defined internal/external rotation.

Data were collected with the subjects standing in front of the transmitter, with their feet a comfortable width apart and the arm relaxed at the side of the body. This position was maintained throughout the digitization and testing procedures. After mounting of the receivers and digitization of landmarks, data were collected with the arms relaxed at the side, and then arm elevation and lowering in the sagittal plane were performed. The sagittal plane was determined with a flat planar surface in 90° of arm elevation to ensure the proper plane of elevation during active flexion. During elevation, subjects were instructed to keep their thumb pointing up, to slide their hand on the board, and to elevate their arm at a rate of approximately 3 seconds to complete the movement. Lowering was performed at the same rate. Three complete cycles of movement were completed.

Pain was monitored immediately after each trial of elevation and lowering of the arm with the numeric pain rating scale. Subjects were asked to rate their pain with performing the full movement on a scale ranging from 0 (no pain) to 10 (worst pain).

Data Analysis

Data analysis for scapular orientation was performed for selected angles of humerothoracic elevation (30°, 60°, 90°, and 120°) and lowering (120°, 90°, 60°, and 30°). Descriptive statistics (mean and standard error) were calculated for all scapular orientation angles (internal/external rotation, upward/downward rotation, and posterior/anterior tilt). The relative reliability for the measurements of each scapular orientation was determined by calculating ICCs for trial-to-trial within-day reliability ($ICC_{2,1}$) and between-day reliability ($ICC_{2,3}$).[29] Within-day reliability was calculated based on data from 3 trials performed on the first day, and between-day reliability was estimated using the mean of 3 trials performed on 2 separate days. For all analyses, the ICC values were considered poor when below 0.20, fair from 0.21 to 0.40, moderate from 0.41 to 0.60, good from 0.61 to 0.80, and very good from 0.81 to 1.00.[2] All analyses were performed using SPSS Version 17 (SPSS Inc, Chicago, IL). The absolute reliability was determined by calculating the SEM and the MDC_{90} for each humeral angle: $SEM = \sqrt{WMS}$, where WMS is the within-subject mean square error term from 1-way analysis of variance[18]; and $MDC_{90} = SEM \times \sqrt{2} \times 1.64$ at the 90% confidence level.[4,33]

The SEM provides a value for random measurement error in the same unit as the measurement itself, quantifies within-subject variability, and reflects the amount of measurement error for any given trial (within-day reliability) and for any test occasion (between-day reli-

TABLE 2 Trial-to-Trial Within-Day Reliability for Measurements of Scapular Orientation During Arm Elevation and Lowering at 4 Angles of Humerothoracic Elevation in the Sagittal Plane

	Control Group (n = 23)		Impingement Group (n = 26)	
	ICC*	SEM, deg	ICC*	SEM, deg
Scapular internal rotation				
Elevation				
30°	0.97 (0.95, 0.99)	1.23	0.98 (0.98, 0.99)	1.38
60°	0.97 (0.94, 0.98)	1.43	0.98 (0.96, 0.99)	1.57
90°	0.96 (0.92, 0.98)	1.85	0.98 (0.96, 0.99)	2.02
120°	0.98 (0.97, 0.99)	1.64	0.98 (0.97, 0.99)	2.53
Lowering				
120°	0.99 (0.98, 0.99)	1.40	0.98 (0.97, 0.99)	2.68
90°	0.98 (0.96, 0.99)	1.63	0.99 (0.98, 0.99)	1.92
60°	0.97 (0.94, 0.98)	1.46	0.98 (0.97, 0.99)	1.86
30°	0.97 (0.95, 0.99)	1.24	0.98 (0.96, 0.99)	1.61
Scapular upward rotation				
Elevation				
30°	0.97 (0.95, 0.99)	1.58	0.97 (0.94, 0.98)	1.72
60°	0.95 (0.89, 0.97)	2.27	0.95 (0.91, 0.97)	2.50
90°	0.94 (0.87, 0.97)	2.60	0.95 (0.90, 0.97)	3.01
120°	0.96 (0.92, 0.98)	1.91	0.97 (0.95, 0.98)	2.48
Lowering				
120°	0.94 (0.89, 0.97)	2.16	0.96 (0.92, 0.98)	2.79
90°	0.93 (0.85, 0.96)	3.07	0.92 (0.86, 0.96)	3.17
60°	0.95 (0.91, 0.98)	2.86	0.95 (0.91, 0.98)	2.69
30°	0.97 (0.94, 0.99)	2.20	0.98 (0.96, 0.99)	1.93
Scapular tilt				
Elevation				
30°	0.99 (0.98, 0.99)	0.86	0.97 (0.95, 0.99)	1.43
60°	0.99 (0.98, 0.99)	0.92	0.98 (0.97, 0.99)	1.23
90°	0.99 (0.98, 1.00)	1.02	0.98 (0.96, 0.99)	1.67
120°	0.99 (0.98, 0.99)	1.20	0.99 (0.98, 0.99)	1.78
Lowering				
120°	0.99 (0.98, 0.99)	1.16	0.99 (0.98, 0.99)	1.74
90°	0.98 (0.97, 0.99)	1.42	0.98 (0.97, 0.99)	1.61
60°	0.98 (0.97, 0.99)	1.49	0.97 (0.95, 0.98)	1.79
30°	0.98 (0.96, 0.99)	1.40	0.98 (0.97, 0.99)	1.31

Abbreviations: ICC, intraclass correlation coefficient; SEM, standard error of measurement.
**Values in parentheses are 95% confidence interval.*

ability).[7,18] This type of reliability is more clinically applicable on a day-to-day basis than the relative reliability coefficient.[7] The MDC is an estimate of the smallest amount of change between separate measures that can be detected objectively as true change outside of the measurement error.[7,33,35] This calculation helps clinical decision making as to whether the change score in individual performance represents real change.[4,35] The MDC_{90} is frequently used when the outcomes aid decisions regarding effectiveness of an intervention.[35]

RESULTS

Asymptomatic subjects experienced no pain, whereas the average pain rating in the symptomatic group was 2.3 on day 1 and 2.0 on day 2.

Within-Day Reliability

ICC and SEM values for trial-to-trial within-day reliability ranged from 0.92 to 0.99 and from 0.86° to 3.17°, respectively, for all scapular orientation measurements in both groups (**TABLE 2**).

Between-Day Reliability

FIGURES 1 and **2** show the scapular orientations for the control and impingement groups during arm elevation and lowering for both evaluation days. In general, the scapula demonstrated increased internal and upward rotation, progressed from anterior to posterior tilt during elevation of the arm, and returned to the initial position during lowering of the arm.

TABLE 3 shows between-day reliability data (ICC, SEM, and MDC values) for scapular internal rotation, upward rotation, and tilt for both groups at each humerothoracic angle. ICCs ranged from 0.58 to 0.88 and from 0.54 to 0.85 for the control group and impingement group, respectively. SEM values ranged from 3.37° to 6.79° for the control group and from 3.62° to 7.44° for the impingement group. MDC values ranged from 7.81° to 15.76° for the control group and from 8.41° to 17.27° for the impingement group. For assessing scapular orientation with the arms relaxed at the side, ICCs ranged from 0.66 to 0.95, SEM values from 2.77° to 4.95°, and MDC values from 6.43° to 11.50° in both groups (**TABLE 3**).

DISCUSSION

Three-dimensional scapular evaluation has been widely used to evaluate shoulder movement in asymptomatic subjects[19,21,31,37,38] and in different shoulder conditions.[20,23-25] Measurements of scapular orientations must be reliable to determine alterations over

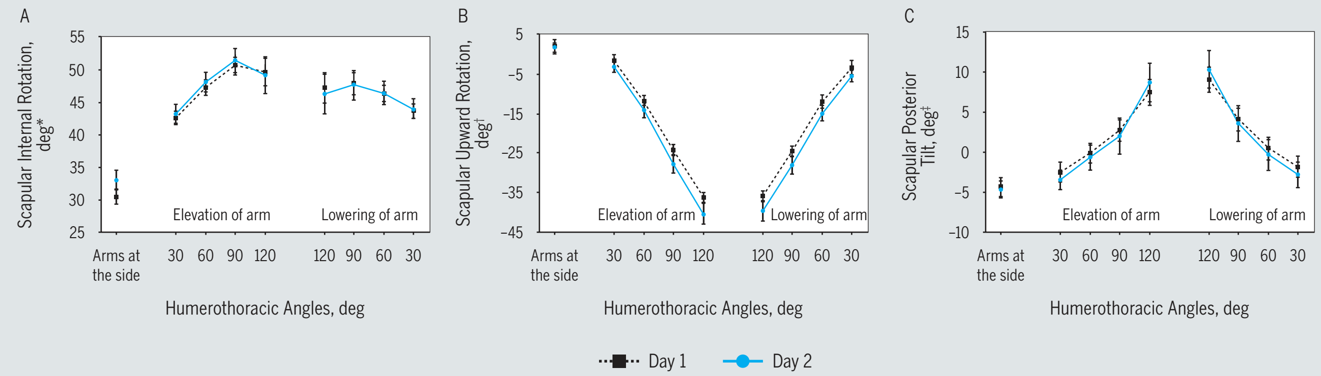

FIGURE 1. Means (standard errors) for scapular internal/external rotation (A), upward/downward rotation (B), and anterior/posterior tilt (C) during elevation and lowering of the arm and with the arms relaxed at the side for the control group for both days of evaluation. *Higher values indicate greater internal rotation. †Lower values indicate greater upward rotation. ‡Higher values indicate greater posterior tilt.

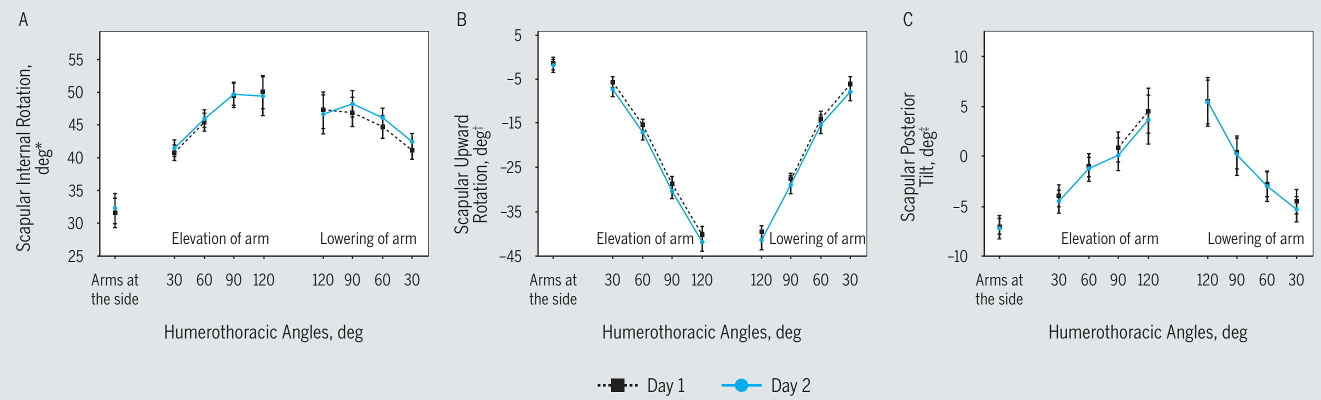

FIGURE 2. Means (standard errors) for scapular internal/external rotation (A), upward/downward rotation (B), and anterior/posterior tilt (C) during elevation and lowering of the arm and with the arms relaxed at the side for the impingement group for both days of evaluation. *Higher values indicate greater internal rotation. †Lower values indicate greater upward rotation. ‡Higher values indicate greater posterior tilt.

time and the efficacy of injury-prevention and rehabilitation programs prescribed to restore shoulder kinematics. This study shows that trial-to-trial within-day reliability is generally present to 3° or less during arm elevation and lowering in the sagittal plane for both asymptomatic subjects and individuals with shoulder pain consistent with shoulder impingement. With regard to between-day reliability, it is questionable, as measurement errors for scapular orientation can reach 7°, depending on the humeral angle during elevation and lowering of the arm, for both populations.

Limited information about within-day reliability of scapular orientations assessed with surface sensors is available in the literature. Ludewig and Cook[20] found very good trial-to-trial reliability of the FASTRAK system (Polhemus, Colchester, VT) for all scapular orientations (ICC = 0.93-0.99) in subjects with impingement symptoms under different load conditions during arm elevation. Thigpen et al[32] demonstrated good reliability of scapular measures for 3 trials of arm elevation in the scapular, frontal, and sagittal planes with the Flock of Birds system (Ascension Technology Corporation) in asymptomatic subjects. Because the tools used to measure reliability in the previous study[32] were different from those in the current study (coefficients of multiple correlation and ICC, respectively), direct comparisons are limited, as the ICC values reflect the reliability of the scapular orientation for defined angles and the coefficients of multiple correlation throughout the range of humeral elevation. These past investigations showed trial-to-trial reliability only for arm elevation,[20,32] whereas the current study also reports trial-to-trial within-day reliability for lowering of the arm, with ICC values ranging from 0.92 to 0.99 for all scapular orientations in symptomatic and asymptomatic subjects.

Considering trial-to-trial errors of 3-D measurements of scapular orientations with surface sensors, Thigpen et al[32] showed good reliability with low root-mean-square errors (ranging from 1.35° to 1.74°) during elevation of the arm in all planes evaluated. Our trial-to-trial with-

TABLE 3 Between-Day Reliability for Measurements of Scapular Orientation During Arm Elevation and Lowering at 4 Angles of Humerothoracic Elevation in the Sagittal Plane and With the Arm Relaxed at the Side

	Control Group (n = 23)			Impingement Group (n = 26)		
	ICC*	SEM, deg	MDC_{90}, deg	ICC*	SEM, deg	MDC_{90}, deg
Scapular internal rotation						
Elevation						
30°	0.71 (0.26, 0.89)	3.64	8.44	0.77 (0.48, 0.90)	3.62	8.41
60°	0.71 (0.26, 0.89)	3.81	8.84	0.75 (0.43, 0.89)	4.16	9.66
90°	0.77 (0.40, 0.91)	4.29	9.95	0.76 (0.44, 0.96)	5.37	12.47
120°	0.82 (0.53, 0.93)	5.79	13.43	0.84 (0.63, 0.93)	7.02	16.28
Lowering						
120°	0.84 (0.58, 0.93)	6.07	14.08	0.85 (0.65, 0.93)	7.09	16.44
90°	0.81 (0.51, 0.93)	4.79	11.10	0.83 (0.61, 0.92)	5.60	13.00
60°	0.71 (0.24, 0.89)	4.36	10.11	0.82 (0.59, 0.92)	4.38	10.16
30°	0.58 (−0.08, 0.84)	4.33	10.04	0.80 (0.54, 0.91)	3.83	8.89
Arms relaxed at the side	0.95 (0.87, 0.98)	4.95	11.50	0.83 (0.60, 0.92)	3.09	7.17
Scapular upward rotation						
Elevation						
30°	0.72 (0.27, 0.89)	4.21	9.76	0.83 (0.60, 0.92)	4.04	9.37
60°	0.79 (0.46, 0.92)	4.50	10.43	0.79 (0.52, 0.91)	4.45	10.32
90°	0.78 (0.42, 0.91)	5.31	12.31	0.66 (0.22, 0.85)	5.98	13.87
120°	0.70 (0.22, 0.88)	6.79	15.76	0.59 (0.05, 0.82)	7.23	16.78
Lowering						
120°	0.75 (0.36, 0.90)	6.10	14.16	0.64 (0.16, 0.84)	6.53	15.15
90°	0.84 (0.58, 0.94)	4.88	11.33	0.73 (0.37, 0.88)	5.61	13.02
60°	0.88 (0.70, 0.95)	4.11	9.54	0.83 (0.60, 0.92)	4.96	11.51
30°	0.78 (0.43, 0.91)	4.42	10.25	0.85 (0.65, 0.93)	4.70	10.90
Arms relaxed at the side	0.80 (0.47, 0.92)	3.74	8.69	0.82 (0.59, 0.92)	3.78	8.78
Scapular tilt						
Elevation						
30°	0.73 (0.27, 0.90)	3.37	7.81	0.61 (0.11, 0.83)	4.05	9.40
60°	0.77 (0.39, 0.91)	3.53	8.20	0.66 (0.21, 0.85)	4.12	9.57
90°	0.74 (0.31, 0.90)	4.90	11.37	0.55 (−0.02, 0.81)	5.99	13.89
120°	0.74 (0.30, 0.90)	5.51	12.77	0.69 (0.30, 0.87)	7.44	17.27
Lowering						
120°	0.64 (0.06, 0.87)	6.01	13.94	0.73 (0.37, 0.88)	7.20	16.71
90°	0.72 (0.25, 0.89)	5.16	11.97	0.54 (−0.06, 0.80)	6.96	16.15
60°	0.77 (0.39, 0.91)	4.37	10.13	0.54 (−0.05, 0.80)	5.36	12.43
30°	0.79 (0.45, 0.92)	3.60	8.34	0.61 (0.10, 0.83)	4.49	10.41
Arms relaxed at the side	0.81 (0.48, 0.93)	2.77	6.43	0.66 (0.21, 0.85)	3.38	7.85

Abbreviations: ICC, intraclass correlation coefficient; MDC, minimal detectable change; SEM, standard error of measurement.
**Values in parentheses are 95% confidence interval.*

in-day SEM values (from 0.86° to 2.60°) during arm elevation for asymptomatic subjects compare favorably with those of the previous investigation. In the current study, SEM values during arm elevation in subjects with impingement symptoms (from 1.23° to 3.01°) and during lowering of the arm in both symptomatic and asymptomatic subjects (from 1.16° to 3.17°) were also calculated.

Thigpen et al[32] also reported good between-day reliability for the scapular orientations during arm elevation in the sagittal plane in asymptomatic subjects and found the sagittal plane to be more repeatable between days than the coronal and scapular planes. In the current investigation, only arm elevation in the sagittal plane was evaluated, and the between-day reliability ranged from poor to very good (ICC confidence intervals from −0.08 to 0.96), depending on the scapular orientation and on the humeral angle during elevation and lowering of the arm, for both groups of subjects.

Ludewig and Cook[20] calculated the SEM for between-day comparison for 5 of their subjects (with and without shoulder impingement symptoms) for all angular variables and reported 3.3° or less for all phases and load conditions. Our data show higher SEM values (from 2.77° to 7.44°) than those of the previous investigation. This difference may be due to the fact that Ludewig and Cook[20] used only a subset of their subjects to calculate errors of measurement, whereas the sample size of the present study was significantly bigger. A qualitative analysis of SEM values shows that most of them are higher during lowering of the arm and at higher angles of humeral elevation. It is important to consider that the amount of error is dependent on the range of elevation,[14] where less error is likely to appear at lower angles of arm elevation.

In this study, the symptomatic subjects appeared to have higher body mass index than the asymptomatic subjects (**TABLE 1**). This condition could have contributed to more difficulty when palpating or digitizing anatomical landmarks, or greater skin-motion artifact during movement, leading to higher SEM values when descriptively comparing the symptomatic group to the asymptomatic group for the between-day reliability in almost all conditions.

The wide confidence intervals of the ICCs, together with the moderate values of the ICCs for between-day reliability observed in all scapular orientations, result in uncertainty about the point estimate, with the true reliability potentially being anywhere within the confidence interval in both directions. Thus, these results should be interpreted with caution when aiming to measure alterations in 3-D scapular orientations over time in asymptomatic subjects and subjects with impingement symptoms. Also, it is important to consider the magnitude of each scapular orientation when interpreting the reliability. Considering the SEM as a percentage of the mean at each humeral angle, the relative reliability was low (8%-15%) for scapular internal rotation, very high (greater than 100%) for scapular tilt, and lower (16%-35%) at higher humeral angles than lower angles of arm elevation for scapular upward rotation. This suggests that it may be more difficult to identify meaningful change for scapular tilt, for instance, as the actual values are low in magnitude compared to the magnitude of reliability.

The current investigation also provides the MDC_{90} values for scapular orientation, ranging approximately from 9° to 17°, depending on the humeral angle, where descriptively higher MDC values were generally observed as humeral elevation angles increased (**TABLE 3**). Changes exceeding the MDC represent the amount by which a subject's measure needs to change to be sure the change is greater than measurement error.[7,33,35] Our data show that the MDC is 20% or greater of the respective mean value for each position tested. As such, individual subject changes after intervention are not likely to exceed the MDC in many cases. Subsequently, the measurements are not highly reliable over time when considered on an individual-subject basis.

On the other hand, in group samples, effects could be detected with the device dependent on the sample size. Although the amount of change that is meaningful and beneficial for the patient is yet to be determined, it does not mean that angular changes below MDC values are not clinically important. Recent studies have used 5° of difference between groups for all scapular orientations as clinically meaningful angular differences,[6,20] but it is important to consider that between-day differences of 5° or less may be due to measurement errors and to the effects of the study interventions. Researchers should be cautious when assessing 3-D scapular orientation once it is known that many factors can influence the measurement, such as skin-slip errors, placement of the scapular sensor, digitizing variations, and difficulty in palpating the bony landmarks.[28,32] More studies are necessary to determine the detectable and minimal clinically important difference for scapular orientations.

Wide confidence intervals were also demonstrated for assessing orientation of the scapula relative to the thorax with the arms relaxed at the side. Asymptomatic individuals presented ICC values from 0.80 to 0.95. The upward rotation and scapular tilt confidence intervals went as low as 0.47 and 0.48, respectively. Moreover, SEM values for internal rotation were the largest, reaching 5°. For the impingement group, fair to very good between-day reliability was observed, and SEM values were around 3.4° for all scapular orientations. However, the confidence intervals went as low as 0.21 for scapular tilt and as low as 0.59 for the internal and upward rotation. MDC_{90} values for scapular orientation with the arms relaxed at the side ranged from 6.43° to 11.50° for both groups. Again, this fact deserves attention because measures after intervention are not likely to exceed the MDC in many cases, as discussed above.

The current study has some limitations. Collecting scapular orientation with surface sensors results in errors associated with skin motion during data collection. These skin-motion artifacts can be highly reliable. The reliability measures of this investigation do not account for systematic skin-motion errors that are generally larger and typically result in underrepresentation of underlying bone motion. Such errors can only be identified with a validity study. This study also involved a short time duration of data collection, without many repetitions. Within-day reliability values may not be generalized to long time durations of data collection, as sensor movements due to sweating, gravity, or pull on the sensor cord may not be accounted for. Between-day reliability of scapular measures with skin-based sensors could have been influenced by digitizing variations and difficulty of palpating scapular bone landmarks. The results of this study can be generalizable to asymptomatic subjects and individuals with shoulder impingement symptoms, but not necessarily for other shoulder pathologies. Although Thigpen et al[32] recommended elevation in the sagittal plane as the most reliable, the present study evaluated only elevation and lowering of the arm in the sagittal plane performed at a relatively slow speed. As such, reliability of other motions or for higher speeds of different movements, such as throwing or wheelchair propelling, may be less. Further investigations should determine whether the experience of the evaluator may influence the measurements. Finally, additional studies should determine the sensitivity to change and minimal clinically important difference[17,18] for scapular orientations to aid in the interpretation of interventional study results.

CONCLUSION

This study provides new knowledge of within- and between-day reliability for scapular orientation in individuals with and without shoulder impingement symptoms. These results support the use of the Flock of Birds (Ascension Technology Corporation) to measure scapular orientations, with excellent within-day reliability. Although some measurements may present acceptable reliability over time, depending on the angle of humeral elevation, caution should be taken when interpreting these results, as wide confidence intervals and relatively high SEM and MDC values were present. ◉

KEY POINTS

FINDINGS: The measurement of 3-D scapular orientation in individuals with and without impingement symptoms, using the Flock of Birds electromagnetic device (Ascension Technology Corporation), shows adequate within-day reliability and questionable between-day reliability.

IMPLICATIONS: The information contained in this study may be used by clinicians to determine whether change observed between testing sessions reflects true change or random error.

CAUTION: These results are not generalizable to other shoulder pathologies, other movements of the arm, and measures with multiple raters. The between-day reliability of the device should be interpreted with caution because of the wide ICC confidence intervals and limitations described in this study.

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