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Reliability and Validity of a Clinical Assessment Tool for Measuring Scapular Motion in All 3 Anatomical Planes

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The Reliability and Validity of a Clinical Assessment Tool to Measure Scapular Motion in All Three Anatomical Planes

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The Reliability and Validity of a Clinical Assessment Tool to Measure Scapular Motion in All Three Anatomical Planes

Context: A single clinical assessment device that objectively measures scapular motion in each anatomical plane is not currently available. The development of a novel electric goniometer affords the ability to quantify scapular motion in all three anatomical planes.

Objective: Investigate the reliability and validity of an electric goniometer to measure scapular motion in each anatomical plane during arm elevation.

Design: Cross-sectional.

Setting: Laboratory setting.

Patients or Other Participants: Sixty participants (29 females, 31 males) were recruited from the general population.

Intervention(s): An electric goniometer was used to record clinical measurements of scapular position at rest and total arc of motion (excursion) during active arm elevation in two testing sessions separated by several days. Measurements were recorded independently by two examiners. In one session, scapular motion was recorded simultaneously with a 14-camera three-dimensional optical motion capture system.

Main Outcome Measures: Reliability analysis included examination of clinical measurements for scapular position at rest and excursion during each condition. Both the intra-rater reliability between testing sessions and the inter-rater reliability recorded within the same session were assessed using Intraclass Correlation Coefficients ($ICC_{2,3}$). The criterion-validity was examined by

comparing the mean excursion values of each condition recorded by the electric goniometer to the 3D optical motion capture system. Validity was assessed by evaluating the average difference and root mean square error (RMSE).

Results: The between session intra-rater reliability was moderate to good ($ICC_{2,3}$: 0.628-0.874). The within session inter-rater reliability was moderate to excellent ($ICC_{2,3}$: 0.545-0.912). The average difference between the electric goniometer and 3D optical motion capture system ranged from -7° to 4° and the RMSE was between 7-10°.

Conclusions: The reliability of scapular measurements is best when a standard operating procedure is used. The electric goniometer provides an accurate measurement of scapular excursions in all three anatomical planes during arm elevation.

Key words: Scapula, reliability, validity, measurement, shoulder

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Key Points:

- This electric goniometer provides clinicians and researchers with a simple tool to objectively measure scapular position and motion in all three anatomical planes.
- There was moderate to excellent intra-rater and inter-rater reliability for measuring scapular rest position and total excursion within and between testing sessions using the electric goniometer.
- The electric goniometer proved to be a valid device to measure scapular motion in the transverse plane.

Motion of the shoulder complex consists of a combination of movement from the glenohumeral, acromioclavicular, and sternoclavicular joints, as well as the scapulothoracic articulation.[1,2] Moving in multiple anatomical planes during humeral motion, scapula motion is integral to provide optimal function to the upper extremity.[1–3] Alterations in scapular motion have been attributed to pathologies such as multi-directional instability, impingement, nerve palsies, rotator cuff tears, and biceps tendinopathy.[4–6]

In order to understand how scapular motion contributes to upper extremity function, clinicians must be able to accurately quantify scapular motion. Currently, the gold-standard for evaluating multiplanar scapular motion includes bone pins, radiography, and magnetic resonance imaging.[2,7–9] Non-invasive reference-standards for tracking scapular kinematics such as video-based three-dimensional (3D) motion analysis and 3D electromagnetic tracking have been validated to the gold-standard methods.[8,10] Though proven to be accurate for measuring scapular motion, these techniques have their drawbacks such as the lack of availability to clinicians, invasive nature, complex computation, expense, and restriction to a laboratory setting.

To overcome the limitations of laboratory-based methods highlighted above, clinical assessment techniques are necessary to measure scapular motion in the clinical setting. Further, reliable and precise objective scapular measurement can guide treatment plans and rehabilitation efforts of upper extremity pathologies. The objective assessment of scapular motion has been examined in previous literature.[11–14] Both observation and palpation-based techniques have been examined, however, the observational approach lacks objective measurement values, thus rendering the method as a subjective screening tool.[11] The gravity-

referenced digital inclinometer, first investigated by Johnson et al.,[13] demonstrated good to excellent intra-rater reliability ($ICC_{3,1}$: 0.89-0.96) and moderate to good validity (r= 0.59-0.73) for measuring the scapular motions of upward and downward rotation in the frontal plane during arm elevation.[15] Subsequent research by Scibek and Carcia[14] further investigated the gravity-referenced digital inclinometer to measure the scapular motions of anterior and posterior tilt in the sagittal plane during arm elevation and reported excellent intra-rater reliability ($ICC_{3,1}$: 0.97-0.99) and moderate to good excellent validity (r= 0.63-0.86).[15] These findings, supported by subsequent studies, serves as grounds to demonstrate the use of gravity-referenced digital inclinometers as reliable and valid for measuring scapular motion in the frontal and sagittal planes.[13,14,16–19]

While a digital inclinometer is a non-invasive and portable clinical assessment tool to objectively measure scapular motion in the frontal and sagittal plane, it is not capable of measuring the scapular motions of internal and external rotation in the transverse plane due to their reliance on gravity-referenced sensors. However, new advancements in the development of a novel electric goniometer, equipped with an inertial measurement unit (IMU), affords the ability to clinically measure scapular motion in the transverse plane. Similar to the angular rotation recorded by the accelerometer internal to the gravity-referenced inclinometer, the IMU captures angular rotations relative to a reference position created and stored by a tri-axial gyroscope and magnetometer. The additional two sensors allow the system to calculate angular rotations relative to any defined calibration position, which does not have to be in the line of gravity, therefore overcoming the limitations faced by gravity-referenced inclinometers.

Currently, the ability to easily and accurately quantify scapular motion in all three anatomical planes with a single clinical device is not available. Although, a new electric goniometer, equipped with an IMU, has the capability to overcome this limitation, we do not know if this novel device is reliable or valid for measuring scapular motion in each anatomical plane. Therefore, the purpose of this study was to investigate the reliability and validity of an IMU-based electric goniometer to measure scapular motion during arm elevation. Reliability analyses sought to investigate the intra- and inter-rater reliability by examining the reliability characteristics of measurements across days and between examiners. Validity analyses sought to establish criterion-validity by comparing the measurements recorded by the electric goniometer to a validated reference-standard of 3D optical motion capture. We hypothesized that the measurements recorded from the electric goniometer would not exceed 10° of error compared to the 3D optical motion capture system, and the intra-rater reliability of each examiner between two days of testing would exceed an intraclass correlation coefficient (ICC) value of 0.80 while the inter-rater reliability between two examiners on a single day of testing would exceed an ICC value of 0.70. Establishing the reliability and validity characteristics of the electric goniometer will provide critical evidence regarding the utility of these IMU-based devices to measure scapular motion. If valid and reliable, these types of devices will provide clinicians with the ability to objectively measure scapular motion in the clinical setting.

Methods:

Participants:

A sample of convenience generated a total of 67 inquiries from the general population within [redacted]. All volunteers were screened for eligibility based on the inclusion

criteria that required participants to: be between 18-99 years of age, willing to attend two testing sessions separated by at least 24 hours, have the ability to lift their right arm to at least 120° in the scapular plane, and have no current self-reported current medical restrictions relating to their upper extremity or spine. An *a priori* power analysis conducted using Nquery V8.1 software (Statistical Solutions, Boston, MA, United States) prior to data collection indicated a sample size of 60 participants will have 90% power to detect a difference in means of 3° in scapular motion and minimize chance of creating a type II error.

We identified and enrolled 60 participants (29 females, 31 males, mean age: 30 $\pm$ 14 years, height: 1.73 $\pm$ 0.10 m, mass: 75.32 $\pm$ 16.90 kg) who met inclusion criteria. All participants completed two testing sessions with an average time between sessions being 9 days. All participants were provided verbal and written descriptions of the study and signed informed consent forms prior to data collection. This study protocol was approved the University [redacted] institutional review board (IRB #XXX).

Materials:

The EasyAngle electric goniometer (Meloq AB, Stockholm, Sweden) was used to perform clinical measurements of scapular motion (Figure 1C). Prior to data collection, an upright homemade PVC pole was placed at 30° anterior to the frontal plane relative to the participant's sitting location, marking the scapular plane. The participant was instructed to actively raise their arm with their wrist touching the PVC pole until they reached 120°, confirmed with a standard goniometer. When the participant reached 120° of arm elevation, a quick-grip mini bar clamp (Irwin, Huntersville, NC, United States) was used to mark and physically limit 120° of arm elevation the PVC pole (Figure 2). An I-beam square bubble level (Model #7724, Johnson

Level and Tool Manufacturing, Inc, Mequon, WI, United States) was used to calibrate the electric goniometer for measurements taken in the sagittal plane as described below.

Three-dimensional motion capture was recorded with a Nexus 14-camera high-speed infrared video-based optical motion capture system (Vicon, Oxford, United Kingdom). Raw marker trajectory data was stored and reconstructed in Vicon Nexus software (Vicon, Oxford, United Kingdom). Reconstructed kinematic data were exported and analyzed in Visual 3D (v9 Professional, C-Motion, Germantown, MD, USA).

Procedures:

Clinical measurements were recorded with the electric goniometer independently by each examiner during arm elevation in the frontal, transverse, and sagittal planes. To facilitate consistency of clinical measurements between examiners, and to accommodate the placement of retroreflective markers used for 3D optical motion capture, a standard operating procedure was implemented. Specific to each anatomical plane in which measurement occurred, the standard operating procedure specified a calibration technique and the specific placement location for the electric goniometer based on several scapular landmarks. To measure scapular motion in the frontal plane, the electric goniometer was calibrated to the floor directly beneath the participant to represent zero degrees. The electric goniometer was placed on the scapular spine at the location of one third of the distance between the root of the scapular spine and the posterior acromion angle, as measured and marked with a cloth tape measure (Figure 1A), and oriented posteriorly (Figure 1B). To measure scapular motion in the transverse plane, the electric goniometer was calibrated using a perpendicular edge of a floor tile beneath the participant to represent zero degrees. The electric goniometer was placed at the same location

on the scapular spine as described for frontal plane motion but oriented superiorly (Figure 1C). To record scapular motion in the sagittal plane, the electric goniometer was calibrated to the vertical I-beam square level to represent zero degrees and placed on the most prominent portion of the medial scapular border oriented laterally (Figure 1D).

All participants began each trial seated in an upright position on a 35-cm tall stool with their feet flat on the floor. The motion of arm elevation was explained and demonstrated for the participant. The participant was able to practice the motion several times and ask questions prior to data collection. To begin each trial, the examiner applied the electric goniometer to the specified scapular landmark and asked the participant to assume an upright and relaxed sitting posture. The scapular rest position was recorded and then the participant was prompted to perform the desired condition. Upon completion of active movement, the participant held their final position for several seconds while the examiner measured the end scapular position. Total excursion values were calculated by subtracting the initial scapular position (rest) from the final scapular position (end) observed upon completion of motion. Three trials of active arm elevation were recorded for each scapular condition, totaling nine trials of motion for data collection. A constant pressure and contact were maintained with the scapular landmark during each movement. The order of anatomical planes was randomized prior to testing and the same order was used on both days of testing. Clinical measurements of scapular motion were interpreted following the guidelines set by the International Society of Biomechanics[20] where positive scapular motion in the frontal, transverse, and sagittal planes occurs as downward rotation, internal rotation, and posterior tilt, respectively.

On one day of testing, 3D optical motion capture was recorded simultaneously as the clinical measurements. Surface reflective markers were attached to the participant using two-sided tape following the procedures outlined by Chu et al[8] (Figure 3) in a validation study of the marker-based motion capture model of scapular motion. A scapular acromial marker cluster (AMC) was created using a rigid triangular body and was applied to the posterior acromion process and medial to the posterior acromion calibration marker (Figure 1B). Recording scapular motion using and AMC has been found to have excellent within-session reliability (Intraclass correlation coefficient (ICC): 0.90-0.98) and a standard error of measurement (SEM) of 2.25° for active arm elevation, protraction, and retraction and has been validated against gold-standard technique such as dynamic radiography.[8,21] Raw kinematic camera data was collected at 200Hz and smoothed using a lowpass Butterworth filter with a cut off frequency of 6Hz. Joint coordinate systems and segment parameters for the trunk, pelvis, and scapula were oriented with the X axis pointed anteriorly, the Y axis oriented superiorly, and the Z axis oriented laterally (Figure 3).[20] A Euler rotation sequence for scapular motion in the frontal and transverse planes was resolved as Y-X-Z and calculated relative to the thorax per the ISB guidelines.[20]

Analysis:

A test-retest design was used to examine the intra-rater reliability of the same examiner between testing sessions and the inter-rater reliability of two examiners within the same testing session for clinical measurements recorded with the electric goniometer. Both the intra-rater and the inter-rater reliability of scapular measurements recorded during rest and excursion for anatomical plane were assessed with ICC ($ICC_{2,3}$) using the average of three trials

of motion. Intraclass correlation coefficients were interpreted as: <0.5 as poor, 0.5-0.75 as moderate, 0.75-0.90 as good, and >0.90 as excellent reliability.[15] Measurement precision was determined by calculating the SEM and the minimal detectable change score at the 90% confidence interval (MDC_{90}).[22]

The criterion-validity of the electric goniometer to measure total scapular excursion in each anatomical plane compared to the reference standard of 3D optical motion capture system was completed using several approaches. First, a paired t-test was used to compare the average excursion of three trials of motion between the electric goniometer and the 3D optical motion capture. Alpha was set *a priori* ≤ 0.05, although a Bonferroni correction was applied to account for the three total comparisons of each condition in each plane. This correction reduced alpha to ≤ 0.017. Second, the root mean square error (RMSE) was calculated to determine error associated with electric goniometer compared to the 3D optical motion capture for each condition. Third, we calculated Bland-Altman plots to observe for the average difference and limits of agreement (LOA) between the electric goniometer and the 3D optical motion capture. The LOA was calculated by multiplying the standard deviation of the average difference by 1.96 to observe the 95% confidence interval.[23] During analysis of the Bland-Altman plots, a systematic average difference of -7° was observed for scapular excursions recorded by the electric goniometer compared to the 3D optical motion capture for scapular motion measured in the frontal plane. Therefore, a correction of adding 7° to the mean scapular excursion in the frontal plane was applied to the clinical data.

Results:

Reliability:

We observed moderate to good intra-rater reliability for determining scapular rest position and scapular excursion between testing sessions (Table 1). We observed good to excellent inter-rater reliability for measuring scapular rest position and moderate to good inter-rater reliability for measuring scapular excursion within a testing session (Table 2).

Validity:

Validity results are presented in Table 3. The Bland-Altman plots are provided as supplemental figures. Statistical significance was found between the mean scapular excursions recorded by electric goniometer and the 3D optical motion capture for in the frontal ($p<0.001$), transverse ($p=0.015$), and the sagittal plane ($p<0.001$). The RMSE ranged from 7-10°, the average difference between -7° and 4° (Table 3).

Discussion:

The present study sought to investigate the reliability and validity of the novel electric goniometer to measure scapular motion in each anatomical plane during arm elevation. The reliability aim was designed to investigate the intra- and inter-rater reliability of clinical scapular measurements across days and between examiners. The validity aim was designed to examine the criterion-validity of measurements recorded by the clinical assessment device compared to the reference-standard of 3D optical motion capture. The results from this study indicate the electric goniometer is a reliable device for measuring scapular rest positions and total excursions in each anatomical plane when a standard operating procedure is used. Further, the findings from this study indicate the electric goniometer has moderate validity to measure scapular excursions in all three anatomical planes in a clinical setting.

Prior to data collection, we hypothesized that the measurements recorded from the electric goniometer would not exceed 10° of error compared to the 3D optical motion capture system. Though the resultant p-values evaluating for significant differences in mean values of scapular excursions were significant for each anatomical plane, the comparison of means alone is not sufficient for a complete validity analysis.[24] Therefore, the we used a multistep approach to assess validity using statistics such as RMSE, average difference, and LOA.[23] The threshold of RMSE was rooted in the notion that 10° of error would exceed both measurement error and minimal detectable change, such that error over 10° would indicate an invalid measurement of scapular motion. Additionally, previous literature has indicated that RMSE values above 10° is indicative of inaccurate measures of true scapular motion.[8,25,26] In the current study, RMSE values were 10° or less for all planes of motion. Further, the average difference between the electric goniometer and the 3D motion capture system ranged from -7° to 4° across the three anatomical planes. Taken together, these results suggest that the electric goniometer is capable of measuring scapular motion in each anatomical plane during arm elevation with a moderate degree of accuracy.

The RMSE associated with arm elevation in the frontal plane highlights a limitation with the use of a 3D optical motion capture using an AMC to capture scapular motion. The AMC represents the scapula and its motion is recorded by the 14-camera 3D optical motion capture system to represent scapular movement. A difficulty of the AMC is its placement on the posterior acromion limiting access to the scapular spine. In Figure's 1B & 1C, the placement of the electric goniometer is limited to being placed on the medial aspect of the scapular spine due to the AMC position on the acromion. Thus, the correction applied to frontal plane data,

the plane of motion most affected by the AMC, was conducted to reduce the limitations of the AMC. The correction reduced the RMSE value from 10° to 7° and increased the associated *p*-value to 0.957, indicating no significant difference between the electric goniometer and the 3D optical system when measuring scapular motion in the frontal plane during arm elevation.

There was similar error between the measurement methods during motion in the sagittal plane. The fact that there was a significant difference between methods, despite an RMSE of 9° and an average difference of 4°, we suspect that accessory motion from spinal flexion and extension contributed to the overall differences in scapular measurement. Although participants were verbally instructed to not move their spine during each trial, and were closely observed during testing, it was not possible to completely eliminate the inherent motion from the spine. This concept highlights a limitation of calibrating the electric goniometer to a stand-alone vertical surface (I-beam square level). To overcome this limitation in the future, we suggest that the electric goniometer be calibrated to the participant's spine prior to measuring sagittal plane motions. This adjustment in calibration will ideally capture the inherent trunk position of the participant and account for any initial spinal offset in the sagittal plane.

While each measurement recorded by the electric goniometer introduces a specific limitation, the comparison between mean excursion values recorded by the device and previous literature is encouraging. Specifically, the average scapular external rotation observed in the current study in the transverse plane (-8°) is identical to the average scapular external rotation recorded by the AMC investigated by Chu et al.[8] (-8°) and closely similar to the value observed by McClure et al[3] using bone pins (-6°). In addition, the average total excursion value of scapular posterior tilt recorded by the electric goniometer (18°) agreed with the average

excursion values using intracortical measurement techniques previously reported by Ludewig et al[2] (18°). These comparisons to previous literature using gold-standard techniques of measurement demonstrates promising capabilities of scapular measurement in each anatomical plane during arm elevation.

A strength of this study is the examination of both the between examiner and between day reliability. Previous studies examining the clinical assessment of scapular motion have been limited to single examiner within the same day analyses, separated by 30 minutes or less[27,28] or are absent from reports.[13,29] This study examined the both the intra-rater reliability of the electric goniometer across two testing sessions and the inter-rater reliability within a single testing session. The average rest position and the average excursion values from the three trials of motion were analyzed for reliability. To minimize the risk of error between measurement techniques, the use of a standardized placement procedures was implemented as described in the methods section. Our results were consistent with previous investigations of digital goniometer measurement in finding that there is higher intra-rater reliability than inter-rater reliability even when a standard procedure is used.[30]

In the present study, the electric goniometer was found to be reliable for determining both scapular rest position ($ICC_{2,3}$: 0.692-0.874) and total excursion ($ICC_{2,3}$: 0.628-0.790) across an average of 9 days. There was less associated error when measuring rest position (SEM: 2-3º) than during the measurement of scapular excursions (SEM: 2-4°). The decrease in ICC values and increase in SEM between rest and excursion measurement could be linked to variations in movement patterns of individuals across days. Further, the inter-rater reliability on the same day of testing to determine scapular rest position ($ICC_{2,3}$: 0.833-0.912) across all three

anatomical planes was higher than those reported by Watson et al. (ICC: 0.21-0.52).[28] Reliability for total scapular excursion ($ICC_{2,3}$: 0.545-0.724) in the present study was also higher than reported by Watson et al. (ICC: 0.23) during arm elevation.[28] These results demonstrating increased of inter-rater reliability facilitate the concept that the electric goniometer is reliable when used by multiple raters within a single testing session.

This study is not without limitations. First, the electric goniometer serves as a surface-based assessment approach which is affected by soft tissue obstruction and movement. As reported in the literature, scapular clinical assessment is limited by the presence of soft tissue and skin movement artifact.[18,21,31] This limitation was apparent during the measurement of scapular motion in the frontal plane during the condition of arm elevation, where a correction was necessary to account for an average difference of -7°. Additionally, attempting to measure the scapula during sagittal plane motion may be inhibited by soft tissues bunching posteriorly during active movement. Conversely, scapular motion in the sagittal plane introduces the difficulty in palpating the scapula as it wraps around the thorax, making the prominent bony aspects on the scapula difficult to discern. As a result of this difficulty, the authors feel that either teaching videos or hands-on training with the device prior to implementation to practice or research may be necessary. Another limitation in the present study was the sample population. Participants in the current study were asymptomatic and did not have any current shoulder pathology. This highlights a constraint to the clinical application of the electric goniometer as a screening tool versus a diagnostic device based on this study. Future research should include patients with pathological shoulders to determine if scapular motion measured with the electric goniometer can discriminant between healthy and pathological states.

Ultimately, the results from this investigation demonstrate that the IMU equipped electric goniometer is a reliable and moderately valid device to measure scapular motion in each anatomical plane during arm elevation in a healthy population. The degree of error associated with the device when measuring scapular motion excursions is dependent on the presence of soft-tissue and palpation restrictions. The authors recommend that a clear and defined standard operating procedure be used when scapular measurements are taken between examiners. This information provides evidence of a clinically portable and consistent device to objectively measure scapular motion in the clinical setting.

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Legends to figures:

Figure 1:

1A: Identification of one third of the distance between the root of the scapular spine and the posterior acromial angle.

1B: Orientation of the electric goniometer to measure scapular motion in the frontal plane.

1C: Orientation of the electric goniometer to measure scapular motion in the transverse plane.

1D: Orientation of the electric g.oniometer to measure scapular motion in the sagittal plane. Inset: calibration to sagittal plane

Figure 2: Measurement of scapular motion in the frontal plane during arm elevation to 120° in the scapular plane.

Figure 3: Standardized marker set up for 3D optical motion capture. Scapular and thorax joint coordinate system with positive motion in the direction of the arrows.

Supplemental Figure 1: Bland-Altman plot depicting the average difference and limits of agreement (LOA) of the electric goniometer to measure scapular excursion in the frontal plane. Dotted line: average difference (-7°) ; solid lines: LOA (7° & -21°).

Supplemental Figure 2: Bland-Altman plot depicting the average difference and limits of agreement (LOA) of the electric goniometer to measure scapular excursion in the transverse plane. Dotted line: average difference (2°) ; solid lines: LOA (15° & -11°).

454 Supplemental Figure 3: Bland-Altman plot depicting the average difference and limits of

455 agreement (LOA) of the electric goniometer to measure scapular excursion in the frontal plane.

456 Dotted line: average difference (4°) ; solid lines: LOA (20° & -12°).

Table 1: Intra-Rater Reliability Results of a Single Rater Between Two Testing Sessions

Anatomical plane	Day 1 mean ± SD[a]	Day 2 mean ± SD[a]	$ICC_{2,3}$[b]	SEM[c]	MDC_{90}[d]
Rest position					
Frontal *(Downward rotation +)*	-3 ± 6	-2 ± 5	0.692	3	7
Transverse *(Internal rotation +)*	30 ± 7	30 ± 7	0.805	3	7
Sagittal *(Posterior tilt +)*	-26 ± 7	-28 ± 7	0.874	3	6
Total excursion					
Frontal *(Downward rotation +)*	-19 ± 7	-19 ± 6	0.701	4	9
Transverse *(Internal rotation +)*	-5 ± 4	-5 ± 3	0.628	2	5
Sagittal *(Posterior tilt +)*	18 ± 6	20 ± 6	0.790	3	7

All units are in degrees with exception of ICC values.
[a] SD: Standard Deviation
[b] ICC: Intraclass Correlation Coefficient
[c] SEM: Standard Error of Measure
[d] MDC_{90}: Minimal Detectable Change at a 90% confidence interval

Table 2: Inter-Rater Reliability Between Two Raters in a Single Testing Session

Anatomical plane	Rater 1 mean ± SD[a]	Rater 2 mean ± SD[a]	$ICC_{2,3}$[b]	SEM[c]	MDC_{90}[d]
Rest position					
Frontal *(Downward rotation +)*	-1 ± 5	-2 ± 5	0.833	3	8
Transverse *(Internal rotation +)*	30 ± 7	30 ± 7	0.912	4	9
Sagittal *(Posterior tilt +)*	-24 ± 6	-28 ± 7	0.841	3	7
Total excursion					
Frontal *(Downward rotation +)*	-22 ± 7	-19 ± 6	0.724	4	9
Transverse *(Internal rotation +)*	-6 ± 4	-5 ± 3	0.545	4	8
Sagittal *(Posterior tilt +)*	19 ± 6	20 ± 6	0.703	5	11

All units are in degrees with exception of ICC values.
[a] SD: Standard Deviation
[b] ICC: Intraclass Correlation Coefficient
[c] SEM: Standard Error of Measure
[d] MDC_{90}: Minimal Detectable Change at a 90% confidence interval

Table 3: Comparison Between Total Excursion Values Recorded by the EasyAngle and the 3D Optical Motion Capture System

Anatomical plane	EasyAngle mean ± SD[a]	3D system mean ± SD[a]	Average difference	RMSE[b]	Sig.[c] *(p ≤ 0.017)*
Frontal *(Downward rotation +)*	-23 ± 6	-30 ± 7	-7	10	<0.001
Corrected Frontal[d] *(Downward rotation +)*	-30 ± 6	-30 ± 7	0	7	0.960
Transverse *(Internal rotation +)*	-8 ± 5	-6 ± 7	2	7	0.015
Sagittal *(Posterior tilt +)*	18 ± 7	22 ±7	4	9	<0.001

All units are in degrees with exception of significance values.
[a] SD: Standard Deviation
[b] RMSE: Root Mean Square Error
[c] Sig: Significance level accounting for the Bonferroni correction (Alpha ≤ 0.017)
[d] Corrected Frontal: A correction of -7º added to the mean scapular excursion recorded by the EasyAngle in the frontal plane