Journal of Chemical Health Risks

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JCHR (2025) 15(1), 661-668 | ISSN:2251-6727

Reliability and Validity of Shoulder Range of Motion Measurements using a Smartphone Tele-Assessment Solution among Healthy Adults: A Cross-Sectional Study

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(Received: 16 November 2024 Revised: 20 December 2024 Accepted: 04 January 2025)

KEYWORDS

Range of motion, Shoulder, Reliability, Validity, Protractor application.

ABSTRACT:

Introduction: Range of motion measurement is essential for clinical shoulder assessment. By utilizing the Protractor application on a smartphone, a healthcare practitioner has the capability to remotely connect to a patient's device and assess their shoulder range of motion in a live, real-time setting.

Objectives: The study aimed to determine the reliability and validity of the protractor mobile application (app) on shoulder flexion and abduction range of motion among healthy adults.

Methods: In a cross-sectional study, fifty subjects were examined; the protractor app was used to measure shoulder flexion and abduction ROM. To assess the reliability of the Protractor app, the intra-class correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC) were used. Pearson's correlation coefficients (r) were used to evaluate the Protractor application's validity against the digital inclinometer.

Results: The protractor app showed high inter-rater reliability, with ICCs for shoulder flexion and abduction of 0.950 and 0.977, respectively. With ICC values of 0.949 for shoulder flexion and 0.968 for shoulder abduction, the protractor app showed high intra-rater (between-session) reliability. The Protractor app demonstrated strong validity in shoulder flexion (r=0.91, ICC=0.947) and abduction (r=0.95, ICC=0.971) compared to the Digital Inclinometer.

Conclusions: The Protractor mobile application has demonstrated reliability and validity in measuring shoulder ROM, allowing for the utilization of app-captured photos for joint ROM assessment. This approach furnishes a convenient and precise tool for evaluating shoulder range of motion.

1. Introduction

Range of Motion (ROM) is the possible amount of motion that occurs at a joint. It was the most common method used for assessing the motion of the joint for therapeutic purposes. Clinically, the shoulder range of motion is used for diagnostic and treatment purposes. A goniometer is used to measure the shoulder ROM; it was used during the First World War. The Universal Goniometer (UG) is compact and cost-efficient [1]. The axis point would shift by using the universal goniometer for the shoulder ROM. It allows the examiner, using two hands, to make steadiness of the upper extremity to great

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JCHR (2025) 15(1), 661-668 | ISSN:2251-6727

challenging / trouble and therefore increase the exposure of error by measuring the instrument [2]. Following that, ROM has been assessed with digital goniometer, digital inclinometers, visual level, visual estimation, and additional tools like 3D gyroscopes, or Kinect systems. Currently, a digital inclinometer (DI) is used for ROM assessment due to its higher reliability when compared to the UG [3,4] the only disadvantage of the DI is that it is more expensive than the UG.

The advent of new technologies has popularized the notion of telerehabilitation as a contemporary substitute for conventional rehabilitation services, allowing for remote rehabilitation sessions conducted over the Internet. In addition to improving the standard of rehabilitation healthcare, this has several advantages for patients and healthcare providers [5–7]. Studies conducted in recent years have assessed the validity and reliability of smartphone applications for ROM measurement, with reported intra- and inter-rater reliabilities ranging from good to exceptional [8–10]. These findings highlight the dependability of such applications in assessing ROM [11–13]. The study conducted a comparison between the shoulder measurements performed using goniometers and smartphones. They observed a substantial to almost perfect agreement in inter-rater reliability (ICC 0.8) and found a significant correlation (r = 0.62–0.79) between the measurements obtained through goniometers and smartphones, indicating good criterion-related validity[14].

Concentrating on shoulder joint range of motion addresses a distinct void in current research, which predominantly centers on other joints. This emphasis aligns with the clinical significance of comprehending limitations in the shoulder, frequently implicated in musculoskeletal issues. Tailoring our approach to specific user needs in shoulder health monitoring serves as a specialized and precise contribution. This focus contributes significantly to advancing methods for assessing shoulder mobility, providing essential insights for both clinical practice and research.

2. Objectives

The study aims to evaluate the reliability and validity of the protractor mobile application on shoulder flexion and abduction range of motion among healthy adults.

3. Methods

Study design

In this cross-sectional study conducted from January to November 2021, we utilized purposive sampling to select participants and incorporated anthropometric independent variables, including aspects such as age, weight, height, and Body Mass Index (BMI).

Participants

Fifty healthy young adults (males) aged 18 to 25 years were recruited for the study. Participants with a documented history of musculoskeletal and neurological disorders, rheumatologic conditions, or prior surgeries affecting the shoulder joint were excluded from the study ***(Fig. 1)***. The study's protocol was reviewed and approved by the Institutional Ethical Committee of SRM Medical College Hospital & Research Centre, Chennai. Individuals meeting the inclusion criteria willingly provided written informed consent before participating in the study.

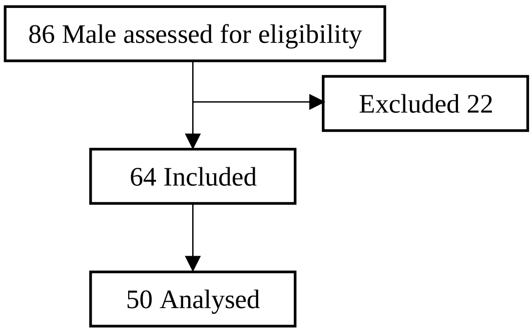

Fig. 1. **Flow diagram of the study.**

Instrumentation

The current study employed a design focused on validity and reliability to ascertain whether a smartphone application could be considered a valid and reliable tool for measuring shoulder range of motion (ROM). The assessment of the smartphone application's validity was conducted by comparing it to the baseline DI instrument (Model 12-1057, Fabrication Enterprises, Inc., NY), a validated and reliable tool for evaluating ROM.

In this study, we utilized the smartphone application called 'Protractor,' specifically version 1.7.0, available for free download on the Google Play store (https://play.google.com/store/apps/details?id=com.pan

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daz.protractor&pcampaignid=web_share). Additionally, the smartphone used was a Xiaomi Mi A3 running on the Android Pie 9 operating system.

Procedure

The study involves the novice (examiner 1) and expert (examiner 2) raters. Each participant was assessed by the novice and expert raters at the same time independently, without conferring during which documentation done. One week later for re-test for the intra rater reliability and the same day for inter rater reliability. The values obtained were compared with the standard measurement using digital inclinometer to determine the validity.

Participants were asked to stand on a mark placed on the floor, and another mark was positioned 2 meters away to ensure consistent spacing between subjects and investigators. The height of the shoulder was measured using an inch tape to position the smartphone at the same height. Double sided tape (suitable for skin) was used to mark three points around the shoulder region: one at the humerus head, another at the middle third of the humerus, and the third parallel to the centreline of the body. Photographs were taken from the lateral view during shoulder flexion and the frontal view during shoulder abduction. These photographs were later aligned with the three marked points on the shoulder and the corresponding points on the Protractor mobile application to measure the angle formed ***(Fig. 2)***. This angle was then compared with a digital inclinometer to assess reliability and validity.

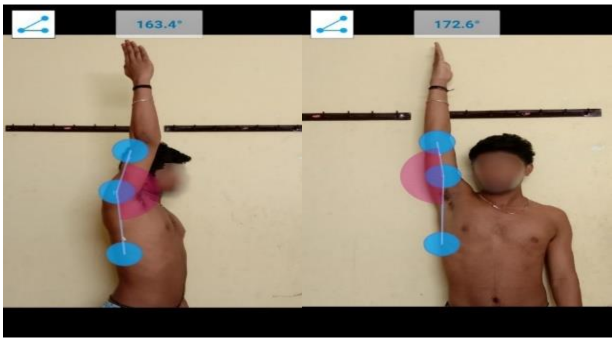

Fig. 2. **Shows the shoulder flexion and abduction range of motion (ROM) measurements used by protractor app.**

Sample size

Sample size calculation was based on validity, with an assumed two-tailed significance level (alpha) of 0.05, statistical power of 80%, and Pearson correlation coefficient (r) of 0.4 [15]; a minimum of 47 participants was required, rounded off to 50. Stata version 16 was used to calculate the sample size.

Ethical clearance

The study was approved by the Scientific Committee and the Institutional Ethics Committee (2384/IEC/2021) at SRM Medical College Hospital and Research Centre, Kattankulathur, Tamil Nadu.

Statistical analysis

The initial evaluation of normality assumptions for parametric statistical tests involved the utilization of the Shapiro-Wilk test, while variance homogeneity was examined through Levene's test. Pearson's correlation coefficients (r) were utilized to evaluate the correlation between ROM scores obtained from the Protractor application and Digital Inclinometer (DI) for the examined shoulder joint, establishing the validity of the Protractor application in comparison to the DI. The following correlation power standards were applied: [16] ($r < 0.19$) very weak, weak ($r = 0.2$–0.39), ($r = 0.40$–0.59) moderate, strong ($r = 0.6$–0.79), and ($r = 0.8$–1) very strong. A significance level of $p < 0.05$ was set.

Reliability (Inter- and intra-rater) of the Protractor application for shoulder ROM was assessed using the intra-class correlation coefficient (ICC). The interpretation of ICC values followed Landis and Koch's definitions: (0.00–0.20) slight, fair (0.21–0.40), (0.41–0.60) moderate, substantial (0.61–0.80), and almost perfect (0.81–1.00) correlation [17]. The standard error of measurement (SEM) was calculated for each measurement modality using the formula $SEM = SD\sqrt{(1 - ICC)}$, where SD is the standard deviation[18]. A decrease in SEM values suggests enhanced absolute validity and reliability. Additionally, the minimal detectable change (MDC) was computed to assess measurement error. MDC indicates the range within which measurement error is responsible for variation between two measured values from repeated measurements. True changes were defined as modifications exceeding the MDC. The formula used for MDC was $MDC = 1.96\sqrt{2}SEM$.

To visually compare measurements, the Bland-Altman Limits of Agreement (LOA) method was employed, predicting that 95% of future differences

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JCHR (2025) 15(1), 661-668 | ISSN:2251-6727

would fall within the established range. Consistency between devices was inferred if differences were minimal, and the mean of differences approached zero.

Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 23 and Excel 2016.

***Table 1*. Inter rater reliability-Comparison of Protractor measurements from examiner 1 and 2, (N=50).**

Measurement (ROM)	**Examiner 1 Mean ± SD (°)**	**Examiner 2 Mean ±SD (°)**	***P*-Value**	**ICC (95% CI)**	**SEM (°)**	**MDC (°)**
Shoulder Flexion	163.64±3.12	163.34±3.17	$<0.001^{***}$	0.950 (0.911-0.972)	1.37	3.25
Shoulder Abduction	170.88±3.48	170.76±3.63	$<0.001^{***}$	0.977 (0.959-0.987)	1.07	2.86

(***P<0.001), ROM: range of motion, SD: standard deviation, ICC: intraclass correlation coefficient, 95% CI: 95% confidence interval, SEM: standard error of the measurement, MDC: minimal detectable change.

***Table 2.* Intra rater reliability-Comparison of Protractor measurements from examiner 1; Ist and IInd measurement, (N=50).**

Measurement (ROM)	**Examiner 1 Ist Mean ± SD (°)**	**Examiner 1 IInd Mean ±SD (°)**	***P*-Value**	**ICC (95% CI)**	**SEM (°)**	**MDC (°)**
Shoulder Flexion	163.64±3.12	163.46±3.27	$<0.001^{***}$	0.949 (0.911-0.971)	1.41	3.32
Shoulder Abduction	170.88±3.48	170.36±3.38	$<0.001^{***}$	0.968 (0.931-0.984)	1.21	3.08

(***P<0.001), ROM: range of motion, SD: standard deviation, ICC: intraclass correlation coefficient, 95% CI: 95% confidence interval, SEM: standard error of the measurement, MDC: minimal detectable change.

***Table 3.* Validity-Comparison of Protractor measurements and gold standard (Digital Inclinometer) measurements, (N=50).**

Measurement (ROM)	**Protractor Mean ± SD (°)**	**Inclinometer Mean ±SD (°)**	***P*-Value**	**ICC (95% CI)**	**Bias ± SD (Lower–Upper LOA) (°)**	**SEM (°)**
Shoulder Flexion	163.64±3.12	163.72±2.67	$<0.001^{***}$	0.947 (0.907-0.970)	-0.08 ± 1.31 (-2.65 – 2.48)	1.30
Shoulder Abduction	170.88±3.48	170.54±3.45	$<0.001^{***}$	0.971 (0.947-0.984)	0.34±1.14 (-1.89-2.57)	1.17

(***P<0.001), ROM: range of motion, SD: standard deviation, ICC: intraclass correlation coefficient, 95% CI: 95% confidence interval, LOA: limit of agreement, SEM: standard error of the measurement.

4. Results

Out of the 64 individuals considered for eligibility, 14 eligible participants decided not to partake in the study. The participants had a mean age of 21.5 ± 3.3 years, a mean weight of 62.8 ± 11 kg, a mean height of 170.6 ± 8.7 cm, and a mean BMI of 21.6 ± 3.7 kg/m2. Bland-Altman plots illustrate agreement ***(Fig. 3)***.

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Inter-rater reliability

Table 1 shows the investigation of inter-rater reliability for shoulder range of motion, the study yielded statistically significant results (p < 0.001) for both shoulder flexion and abduction. The ICC for shoulder flexion and abduction were notably high, measuring 0.950 (95% CI: 0.911-0.972) and 0.977 (95% CI: 0.959-0.987), respectively. These values indicated a substantial to almost perfect agreement between the two examiners. The low P-values (P = 0.001) further affirmed the reliability of the measurements, suggesting that the observed agreement was unlikely to have occurred by chance alone. The SEM values, representing the precision of individual measurements, were 1.37° for shoulder flexion and 1.07° for shoulder abduction. Additionally, the MDC values were calculated at 3.25° for shoulder flexion and 2.86° for shoulder abduction, signifying the smallest change beyond measurement error.

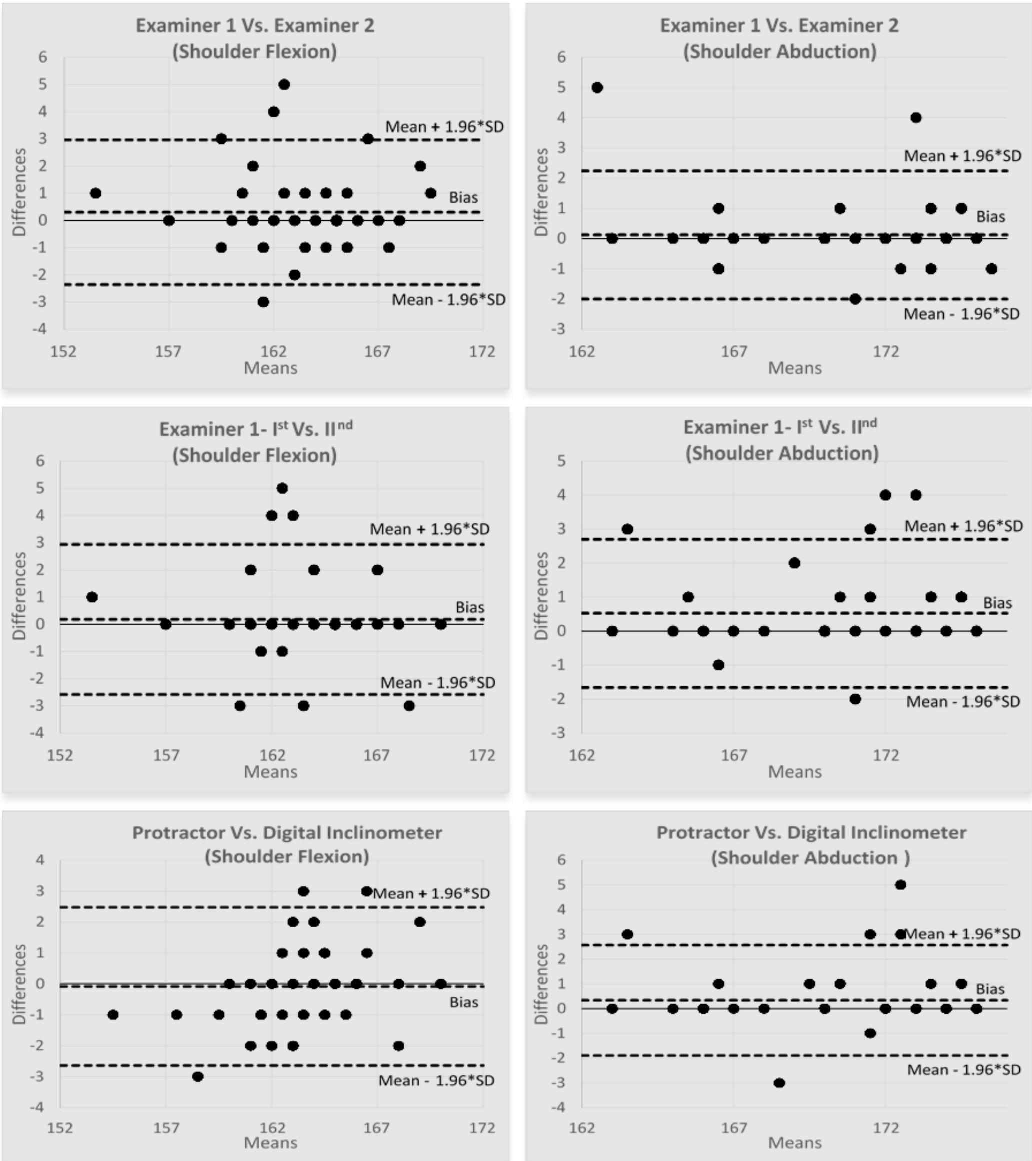

Fig. 3. **Bland-Altman plots illustrate agreement for inter rater, intra rater, and validity assessments. The y-axis shows degree differences, and the x-axis displays mean values in degrees. The solid black line at zero is a reference, the middle dash line signifies mean difference, and upper/lower dash lines represent the ±1.96 limits.**

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Intra rater reliability

Table 2 shows the intra-rater reliability, revealing statistically significant results (P < 0.001) for both shoulder flexion and abduction. The ICC for shoulder flexion and abduction were 0.949 (95% CI: 0.911-0.971) and 0.968 (95% CI: 0.931-0.984), respectively, indicating substantial to almost perfect agreement between measurements taken on two separate occasions by the same examiner. The SEM values for shoulder flexion and abduction mirrored those in the inter-rater reliability assessment, measuring 1.37° and 1.07°, respectively. The MDC values remained consistent at 3.25° for shoulder flexion and 2.86° for shoulder abduction.

Concurrent validity

Table 3 shows the evaluation of concurrent validity between the protractor and inclinometer measurements, the study revealed significant differences for both shoulder flexion and abduction (P < 0.001). Despite these differences, the Intraclass Correlation Coefficients (ICC) remained high at 0.947 (95% CI: 0.907-0.970) for shoulder flexion and 0.971 (95% CI: 0.947-0.984) for shoulder abduction. The bias analysis indicated minimal discrepancies, with a mean bias of -0.08° for shoulder flexion and 0.34° for shoulder abduction. Bland-Altman plots demonstrated acceptable agreement between the protractor and inclinometer measurements, as the majority of data points fell within the specified limits. The SEM values for concurrent validity were 1.30° for shoulder flexion and 1.17° for shoulder abduction, reflecting the precision of individual measurements. The Protractor app demonstrated strong validity in shoulder flexion (r=0.91) and abduction (r=0.95) when compared to the Digital inclinometer.

5. Discussion

The study aimed to assess the reliability and validity of cost-effective methods for assessing ROM in a clinical setting, comparing them to the gold standard. Specifically, the focus was on evaluating the accuracy of protractor assessment approaches for measuring shoulder flexion and abduction ROM in young adults. The investigation was prompted by the need to explore the validity of these methods. The findings indicate that mobile protractor tool exhibit excellent reliability and validity when compared to the gold standard, digital inclinometers.

Inter-rater reliability, with ICC values of 0.950 and 0.977 for shoulder flexion and abduction, respectively, showed significant results for both examiners. The ICC values for shoulder flexion and abduction were >0.9, indicating excellent inter-rater reliability. The protractor mobile application demonstrated even more significant inter-rater reliability. Cuesta-Vargas et al.,(2010)[19] suggested that a smartphone photography-based goniometer is a portable and cost-effective tool accessible to all. In a study on arm abduction angles measured on a smartphone (mROM) for a healthy group, the shoulder abduction inter-rater reliability (ICC) value was 0.492. In comparison, in the present study, the inter-rater reliability of mROM was lower than that of the protractor mobile application.

Pereira et al.,(2017)[20] demonstrated the good reliability of a smartphone-based accelerometer (App) for measuring knee joint ROM in a clinical position using a standard goniometer. The smartphone-based accelerometer showed inter-rater reliability (ICC) values of 0.02 (0.00–0.28) for active knee flexion and 0.22 (0.00–0.50) for extension in healthy subjects. In comparison, the protractor mobile app in the present study exhibited superior inter-rater reliability compared to the smartphone accelerometer. Shin et al.,(2012)[21] found that smartphone-based shoulder range of motion measurement showed good reliability for the same day. The inter-rater reliability of the smartphone inclinometer in the first and second sessions for shoulder flexion (ICC: 0.83 and 0.84) and abduction (ICC: 0.78 and 0.78) indicated good reliability. However, in comparison to the present study, the protractor mobile application demonstrated higher inter-rater reliability than the smartphone inclinometer.

Intra-rater reliability for shoulder flexion and abduction was excellent, with ICC values of 0.949 and 0.968, respectively, both exceeding 0.9. In conclusion, the protractor mobile application demonstrated highly reliable intra-rater results. Cuesta-Vargas et al., reported good intra-rater reliability (ICC: 0.780) for arm abduction angles measured on a smartphone (mROM) for a healthy group. In the present study, the ICC values for both shoulder flexion and abduction were >0.9,

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demonstrating excellent intra-rater reliability compared to the protractor mobile app. Pereira et al.,(2017) concluded that the smartphone-based accelerometer exhibited good to excellent intra-rater reliability for healthy subjects' active knee flexion and extension, with ICC values of 0.75 and 0.96, and passive flexion and extension, with ICC values of 0.82 and 0.98. However, the protractor mobile app in the present study showed even higher intra-rater reliability. Shin et al.,(2012) assessed within-day intra-rater reliability using a smartphone inclinometer for shoulder flexion, with ICC values of 0.99, 0.97, and 0.97 for three observers. This indicated excellent intra-rater reliability, but the protractor mobile application in the present study demonstrated lower reliability than the smartphone inclinometer.

As indicated by Hamersma et al.,(2020)[22] the %MDC is considered a more effective metric for assessing the reliability of a measuring tool. %MDC values below 20% are regarded as acceptable, and the calculation involves dividing the MDC by the measured value. In this study, the Protractor app's assessment of Shoulder flexion and abduction ROM revealed an MDC less than 3.32°, and the %MDC value was found to be less than 2%. Consequently, the measurement methods employed by the Protractor application can be considered acceptable.

Validity was assessed, revealing Pearson correlation (r) values of 0.91 for shoulder flexion and 0.95 for abduction. Both the examiner's and inclinometer values exceeded 0.9, signifying a perfect positive correlation. This indicates that the protractor mobile application in the current study exhibited strong validity. Cuesta-Vargas et al., suggested that a smartphone photography-based goniometer was a portable tool accessible to all. In their study, smartphone shoulder abduction values were compared to a universal goniometer, resulting in an r value of 0.400. In the present study, mROM had less validity compared to the protractor mobile application. Kolber and Hanney, (2012)[23] concluded that shoulder mobility measurement using a digital inclinometer and goniometer through the substitution method showed good validity, with values of ≥0.85.

The use of the protractor mobile application offers several advantages for assessing the ROM in patients, eliminating the need to invest in expensive devices. The Protractor application provides a straightforward approach for clinicians to remotely measure their patients ROM, fostering a convenient and accessible method of evaluation. The benefits encompass its compact nature, universal accessibility and non-invasiveness for both clinicians and patients. Additionally, the platform holds the potential to empower patients to conduct self-assessments and monitor their condition independently.

The limitation of the study includes the fact that participants utilized various personal smartphone devices, potentially introducing errors in data sampling due to differences in smartphone models and operating software platforms. Additionally, the study focused exclusively on healthy young adults, highlighting the necessity for future research to expand participant inclusion across diverse age groups, genders, and linguistic backgrounds. Furthermore, the testing methodology involved active movements initiated by the participants for shoulder ROM, neglecting passive range of movement, which holds clinical significance. Moreover, the assessment failed to incorporate rotational movements of the shoulder, which are crucial for comprehensive evaluation.

In Conclusion, the utilization of a smartphone protractor application for assessing shoulder flexion and abduction range of motion demonstrates outstanding reliability and validity. This approach offers a straightforward and readily accessible tool for assessing patients, as the app is available at no cost. In terms of clinical implications, this application has the potential to aid medical professionals in delivering follow-up treatments by providing reliable measurements of shoulder range of motion.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Funding: None

Acknowledgments

The authors are grateful to the volunteers for their participation.

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JCHR (2025) 15(1), 661-668 | ISSN:2251-6727

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