

Reliability and Psychometric Properties of the Hand Behind Back Test in Young Healthy Adults: A Cross-sectional Study

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ABSTRACT

Introduction: The Hand Behind Back (HBB) test is often used in clinical practice to evaluate shoulder internal rotation; yet, additional clarification regarding its measurement reliability using a tape measure is required.

Aim: To identify the HBB test's intra-rater and inter-rater reliability and its psychometric qualities such as Standard Error of Measurement (SEM), Minimum Detectable Changes (MDC) at the 95% Confidence level (MDC_{95}), Coefficient of Variation (CV%) and Smallest Worthwhile Change (SWC) using tape measurement in healthy adults.

Materials and Methods: A prospective observational cross-sectional test-retest study was conducted at the Outpatient Physiotherapy Department of Maharishi Markandeshwar Deemed to be University, Ambala, Haryana, India, between March 2025 to November 2025 on total of 60 healthy individuals which were evaluated by two physiotherapists. Each rater completed two measurement sessions under uniform conditions. The inter-rater and intra-rater reliability were assessed by analysing Cronbach's alpha and interclass correlation coefficients. Cohen's Kappa was

used to assess agreement for the categorical variable of gender. SEM, MDC_{95} , CV%, and SWC were analysed for evaluation of absolute reliability and psychometric qualities. Bland-Altman analysis was further used to investigate the agreement.

Results: Both raters showed excellent intra-rater reliability, with ICC values of 0.988 and 0.953, respectively. With an ICC of 0.967, it showed excellent inter-rater reliability. Cohen's Kappa showed excellent agreement for gender classification with a value of $\kappa=1.00$, while Cronbach's alpha values revealed high internal consistency (≥ 0.97). The MDC_{95} value was 0.69 cm, and the SEM values were low (0.25 cm). The SWC (0.46 cm) was higher than the SEM, and the CV% was 5.92%. There was no indication of proportional bias, and Bland-Altman plots showed narrow Limits of Agreement (LoA) and small mean biases.

Conclusion: In healthy adults, the tape measure hand behind the back test showed good psychometric qualities with low measurement error, and excellent intra-rater and inter-rater reliability. The results obtained indicate that it can be applied as a sensitive and trustworthy clinical outcome measure for evaluating internal rotation of the shoulder joint.

Keywords: Articular, Healthcare, Outcome assessment, Range of motion, Reproducibility of results, Shoulder joint, Young adult

INTRODUCTION

One of the most complicated biomechanical systems in the human body is the shoulder complex. It consists of four separate articulations that function together to provide a wide Range Of Motion (ROM) while preserving dynamic stability [1]. Shoulder internal rotation is a basic movement pattern that combines coordinated scapulothoracic motion with glenohumeral rotation within this complex system [2]. Because it represents the functional integrity of the glenohumeral joint and its periarticular structures, shoulder internal rotation ROM is a necessary clinical criterion for evaluating, diagnosing, and tracking shoulder disorders [3]. Many important daily tasks, such as clothing, personal hygiene, reaching behind the back, and a range of functional and vocational tasks, depend on this coordinated action [4].

Shoulder internal rotation can be evaluated through goniometry, inclinometers, visual estimation, digital imaging, and functional testing, each having different accuracy, examiner dependency and clinical practicality. Conventional goniometry is a practitioner-dependent because it depends on precise landmark identification and scapular and trunkal stabilisation. Advanced technical procedures show good reliability, but they frequently necessitate specialised equipment and experience, restricting normal clinical application. Therefore, simple, low-cost, quick, and reproducible functional measurements continue to be therapeutically useful [4].

Subjective observation in the clinical assessment of shoulder internal rotation has been replaced by standardised methods [5]. The American Shoulder and Elbow Surgeons and the American

Academy of Orthopaedic Surgeons support the HBB test as a widely used functional measurement method that combines internal rotation, extension, and adduction in a movement pattern that represents our everyday activities [6].

Traditionally, the HBB test records the highest-vertebral level that can be reached by the thumb by the individual. However, this approach can be challenging due to the difficulty of accurately palpating landmarks and significant reliance on the examiner's skill. As a result, especially with the less experienced clinicians, recording at the vertebral level shows lower consistency among different raters and also limits the ability to reproduce results [7].

To address these limitations, a flexible tape to measure the vertical upward distance between the thumb tip and the midpoint of the horizontal line through the Posterior Superior Iliac Spine (PSIS) is needed. This method uses stable, easy-to-identify markers, which makes the HBB assessment less dependent on the examiner and more objective and consistent [8]. Comparative studies have shown that tape measurement methods are generally more accurate and reliable than vertebral levels measurements. Furthermore, linear measures provide continuous data, which improves statistical precision, sensitivity to change, and suitability for longitudinal outcome assessments [7,9,10].

Although reasonable reliability of the HBB test has been documented [8,10], more data based on standardised protocols and extensive reporting of relative and absolute reliability and psychometric properties are required to improve clinical interpretability. Most known data comes from Western populations, emphasising the importance

of population-specific estimates for gender generalisability [10]. Moreover, variability in reported population MDC values due to methodological and procedural differences underscores the need for replication studies using standardised approaches.

Therefore, the present research aims to examine the relative and absolute reliability and psychometric properties when using the HBB test in healthy adults using a standardised PSIS-based tape measurement protocol. The present study is a part of a larger project evaluating reference value, relative and absolute reliability of HBB test for dominant and non dominant hand in healthy adults.

MATERIALS AND METHODS

A prospective observational cross-sectional test-retest study was conducted at the Outpatient Physiotherapy Department of Maharishi Markandeshwar Deemed to be University, Ambala, Haryana, India between March 2025 to November 2025 to determine the reliability and psychometric properties of the tape measure HBB test in young healthy adults. This study was evaluated and approved by the Institutional Ethics Committee (Ref. No. IEC-3104) and registered with the Clinical Trial Registry of India (CTRI) number: CTRI/2025/04/084638. The registration details are available at: <https://ctri.nic.in/Clinicaltrials/pmaindet2.php?EncHid=MTI4NDI0&Enc=&userName=>. A study protocol abstract was published previously to enhance methodological transparency [11].

Inclusion and Exclusion criteria: Eligibility criteria for the current study were healthy adults aged from 18 to 25 years with absence of current or prior shoulder, cervical or upper limb musculoskeletal pathology within the preceding six months; no history of neurological or systemic conditions affecting movement and the capacity to provide informed consent [8]. The exclusion criteria were pain associated with shoulder instability, inflammatory or neoplastic disorder [7], recent upper extremities surgery or fracture, neurological or musculoskeletal problems affecting the upper extremities and any restriction in active shoulder flexion, extension, abduction or internal rotation [12,13].

Sample size calculation: A sample size estimation was guided by methodological recommendation by Lynn MR, 1986 and Walter SD et al., 1998 [14,15]. A minimum of 50 samples is required to obtain stable reliability estimation as per Walter SD et al., 1998 [15]. To further increase the statistical precision and reduce sampling variability, 60 asymptomatic healthy young adults were recruited, 30 males and 30 females.

Study Procedure

Raters: Rater 1 and Rater 2 are both licensed physiotherapists from the Department of Physiotherapy with over two years of clinical experience in musculoskeletal rehabilitation. Pilot measurements trial was conducted on 15 participants prior to the study to ensure procedural consistency. The raters were blinded to each other's measurements as well as previous tests. To reduce the possibility of bias, an independent third rater who was not participating in the assessments recorded all measurements.

Instruments: During the HBB test, the vertical distance (in centimetres) from the tip of the participant's thumb to the midpoint between the PSIS was measured using a standard flexible measuring tape (non elastic 150 cm length, 1 mm accuracy) [7]. The body weight was taken using a digital weighing scale, and standing height was recorded with a wall-mounted stadiometer. All equipment was calibrated before the data collection to ensure accuracy [16].

All assessments were carried out in a peaceful clinical setting at the Institute's Physiotherapy Department. Participants stood straight in a neutral stance with their feet shoulder-width apart. In the HBB test, each subject was directed to reach their dominant hand behind the back as high as possible, with the palm facing outward

and the elbow bent, without assistance from the other arm [10]. The dominant hand was defined as the hand used for writing.

A flexible measuring tape was used to measure the vertical distance from the tip of the thumb to the midpoint between the PSIS. Each rater took three consecutive measurements, with a 30-second rest interval between trials. Rater 1 completed all evaluations in the morning session, followed by Rater 2 in the afternoon to reduce recollection bias, as shown in [Table/Fig-1,2]. To assess intra-rater reliability, both raters repeated the same procedure after 48 hours under identical settings [17].



[Table/Fig-1]: HBB testing position by Rater 1.



[Table/Fig-2]: HBB testing position by Rater 2.

Participants were instructed to avoid any strenuous upper limb activity between sessions. Measurements were recorded by an independent observer who was not involved in performing the tests at the same time as when the test was conducted.

STATISTICAL ANALYSIS

Descriptive data, including means and Standard Deviation (SD), were calculated for all the measurements. Relative reliability was assessed using Intraclass Correlation Coefficients (ICCs) with 95% Confidence Intervals (CIs). An ICC (2,1), two-way random-effect model for absolute agreement was used for intra-rater reliability, while ICC (2,2), a two-way mixed-effect model, was used for inter-rater reliability. Interpretation of ICC values followed Portney LG and Watkins MP criteria, where ICC values greater than 0.90 were considered excellent, 0.75-0.90 were considered good, and those below 0.75 were considered moderate to poor reliability [17,18].

The internal consistency of the repeated measures was evaluated using Cronbach's alpha, with values greater than 0.90 considered excellent [19, 20]. For categorical variables, specifically agreement in participant gender classification (male vs female), Cohen's Kappa was calculated, with values interpreted using the Landis and Koch benchmarks. Since ICC values can be influenced by inter-subject variability, absolute measures of reliability were also calculated. The SEM, reflecting the amount of measurement error, was calculated using the formula $SEM = SD \times \sqrt{1 - ICC}$ [21]. The MDC is the smallest change that can be noticed, and it was calculated with the equation: $MDC = SEM \times 1.96 \times \sqrt{2}$ [17]. To further assess measurement accuracy, we evaluated the SWC defined as $0.2 \times SD$ [22], which reflects a small effect size. The CV% was additionally calculated using the formula: $CV\% = \left(\frac{SD}{Mean}\right) \times 100$, to assess relative variability. To visualise both inter-rater and intra-rater agreement, Bland-Altman plots were created and calculated the 95% LoA using following equation: $95\% \text{ LoA} = \text{mean difference} \pm 2SD$ [23].

RESULTS

A 60 asymptomatic/healthy people (30 males and 30 females) with pain-free functioning of the upper limb were recruited. Participants were aged from 18 to 25 years with a full, unrestricted active shoulder ROM. The demographic baseline characteristics of the participants has been depicted in [Table/Fig-3].

Characteristics	Values
Age (years) (Mean±SD)	21.91 (2.11)
BMI (kg/m ²) (Mean±SD)	23.35 (3.81)
Gender n (%)	
Male	30 (50%)
Female	30 (50%)

[Table/Fig-3]: Baseline demographic characteristics of participants (N= 60). BMI: Body mass index; SD: Standard deviation; n (%)

Intra-rater Reliability

The intra-rater reliability of the HBB test was examined separately for both raters and is presented in [Table/Fig-4,5]. Rater 1 showed excellent intra-rater reliability, with an ICC value of 0.988 (95% CI: 0.914-0.996). With a Cronbach's alpha of "0.997", the internal consistency of repeated measurements was high. Also, for the categorical variable of gender, the intra-rater agreement was good, with a Cohen's Kappa value of "1.00".

Reliability type	ICC (single measures)	95% CI	Cronbach's alpha	Cohen's Kappa (gender)
Intra-rater reliability (Rater 1)	0.988	0.914 - 0.996	0.997	1.00

[Table/Fig-4]: Intra-rater reliability (Rater 1) of the HBB test (n=60). "ICC: Intraclass Correlation Coefficient"; "CI: Confidence interval"

Reliability type	ICC (single measures)	95% CI	Cronbach's alpha	Cohen's Kappa (gender)
Intra-rater reliability (Rater 2)	0.953	0.923 - 0.972	0.976	1.00

[Table/Fig-5]: Intra-rater reliability (Rater 2) of the HBB test (n=60). ICC: Intraclass correlation coefficient; CI: Confidence interval

Rater 2 similarly showed excellent intra-rater reliability for the repeated HBB measurements, with an ICC of 0.953 (95% CI: 0.923-0.972). Cronbach's alpha for Rater B was 0.976, which shows a strong internal consistency across different sessions. As for intra-rater agreement in gender classification, Cohen's Kappa was 1.00, indicating there was a perfect consistency between the repeated assessments.

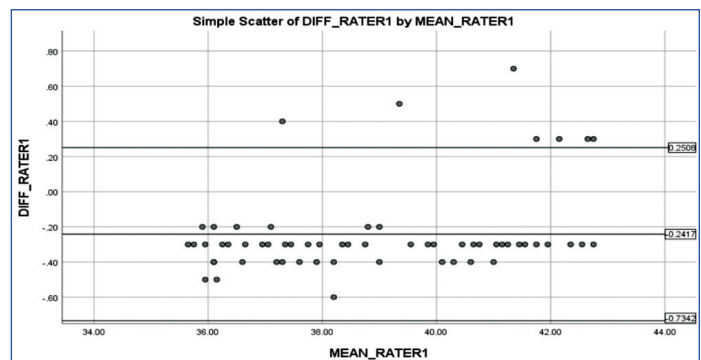
The SEM value was 0.25 cm. Accordingly, the MDC_{95} was calculated to be 0.69 cm. This indicates a small absolute measurement error. On the other hand, the SWC was 0.46 cm, and the CV% was

5.92%. Since the SEM is smaller than the SWC, the HBB test demonstrates excellent sensitivity in detecting clinically meaningful changes. The psychometric properties of the HBB test are displayed in [Table/Fig-6].

Psychometric property	SEM	MDC_{95}	SWC	CV%
Value	0.25	0.69	0.46	5.92

[Table/Fig-6]: Psychometric properties of the HBB test. SEM: Standard error of measurement; MDC_{95} : Minimum detectable change; SWC: Smallest worthwhile change; CV%: Coefficient of variation

To visually assess the agreement between raters and repeated measurements, authors used Bland-Altman plots. For the inter-rater analysis, the mean difference between the two sessions conducted by Rater 1 was -0.24 cm, indicating minimal systematic bias. The 95% LoA ranged from -0.73 cm to 0.25 cm, as shown in [Table/Fig-7]. The differences were systematically distributed around the mean, with no evidence of systematic measurement bias or proportional error across the range of measurements.



[Table/Fig-7]: Bland-Altman plot illustrating intra-rater agreement. The central horizontal line represents the mean difference, while the upper and lower lines indicate the 95% LoA (mean ± 1.96 SD).

Inter-rater Reliability

Inter-rater reliability between Rater 1 and Rater 2 for the HBB test is summarised in [Table/Fig-8]. The inter-rater ICC was excellent 0.967 (95% CI: 0.071-0.993), demonstrating that there was a great agreement across raters. Internal consistency with Cronbach's alpha of 0.998 shows remarkable result.

Reliability type	ICC (single measures)	95% CI	Cronbach's alpha	Cohen's Kappa (gender)
Inter-rater reliability	0.967	0.071-0.993	0.998	1.00

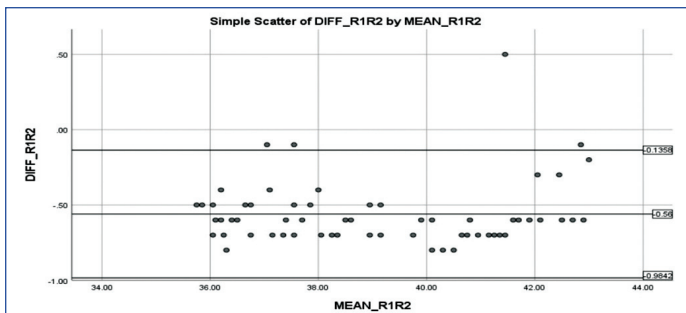
[Table/Fig-8]: Inter-rater reliability of the HBB test (n=60). ICC: Intraclass correlation coefficient; CI: Confidence interval

For the categorical variable of gender, Cohen's Kappa value was 1.00, which shows perfect the agreement among raters. These results reveal that HBB measurements made by different raters are not only very consistent but also reproducible when applying a standardised measurement technique.

When creating a Bland-Altman plot to see the agreement between Rater 1 and Rater 2. The findings showed a small average bias of -0.56 cm, and the 95% LoA were between -0.98 cm to -0.14 cm, as shown in [Table/Fig-9]. The differences were widely spread around the mean, and there was no proportional bias throughout the measurement range, which indicates that the inter-rater agreement is excellent.

DISCUSSION

The present study investigated how reliable the HBB test is and its psychometric features, all while applying a standard tape measure on a group of young, healthy adults. The study's result indicates that the HBB test demonstrates high reliability and negligible measurement error when administered by proficient physiotherapists adhering to a specified methodology. Both inter-rater and intra-rater evaluations



[Table/Fig-9]: Bland-Altman plot showing inter-rater agreement between Rater 1 and Rater 2. The central horizontal line shows the average difference, while the upper and lower lines represent the 95% LoA (mean \pm 1.96 SD).

confirmed the efficacy of this measurement technique, illustrating its applicability in both clinical and research contexts.

When it comes to relative reliability, both raters demonstrated excellent intra-rater reliability, and inter-rater reliability was similarly high, which suggests a constant dedication to the standardised measurement procedure. These findings confirm that the tape-measure HBB distance is a highly reproducible metric in asymptomatic individuals [19].

These findings are appropriate with and improve on the existing research on the reliability of HBB measurement. Beshara P et al., showed strong intra- and inter-rater reliability for tape-measured HBB in healthy adults, which confirms the reproducibility of linear measurement techniques [7]. Similarly, another author, Satpute K et al., showed remarkably great reliability for an inclinometer-based HBB approach, which suggests that other instrumented methodologies can also generate valid and reliable estimates of shoulder internal rotation [10].

Absolute reliability measures used in the present study further enhance these findings by presenting psychometric properties of the HBB test. The SEM value was 0.25 cm, which suggests that there is a very little random measurement error. Following were the MDC₉₅ value, which was 0.69 cm, demonstrating that the test is a sensitive tool. The relative reliability of the test was also quite low, which was proved by the CV% of 5.92%, showing that the measurements taken were stable. The SEM value was even lower than the SWC value, which shows even more that the HBB test can find clinically important changes instead of just random changes when we use the tape-measured method. These results confirm that the HBB test is accurate and responsive.

The Bland-Altman analyses confirmed the ICC findings regarding both intra-rater and inter-rater reliability comparisons, indicating a minimal mean difference and restricted LoA. After looking at both plots, it found that most of the results were within the 95% agreement ranges. This shows that there is a strong agreement and makes the HBB measuring process more reliable and repeatable [24]. The validity of the test was not evaluated as adequate reliability must be established before the validity of the measurement can be meaningfully interpreted [17,25]. So, the current study was purposefully created as a preliminary psychometric investigation with an emphasis on measurement stability and error quantification.

From a clinical standpoint, the reliability demonstrated in present study suggests that the HBB test is an effective and practical instrument for assessment of internal rotation in various shoulder joint conditions like adhesive capsulitis and rotator cuff tear. Because the SEM is low, healthcare professionals can trust this test in their clinicals and research work. Rather than being slight variations in the measurement of the internal rotation of the shoulder, changes over the MDC value indicate the real improvements.

Limitation(s)

There are a few limitations that need to be recognised. Firstly, the present study was conducted in a group of healthy adults aged 18-25

years-old, so the results might vary for patients experiencing shoulder issues related to pain or compensatory movement mechanisms. Additionally, the second limitation, which can be acknowledged in this research, is that it only looked at one measurement method, that is tape-measured linear distance method, which means that the results might not be directly compared to other techniques that use angular or ratio-based HBB assessments. Furthermore, the third limitation of the study was that the validity of the HBB test was not investigated despite the study's strong relative and absolute reliability. The validity of the test was not evaluated as adequate reliability must be established before the validity of the measurement can be meaningfully interpreted [17,25]. So, the current study was purposefully created as a preliminary psychometric investigation with an emphasis on measurement stability and error quantification. The future research should establish convergent and criterion validity by comparing tape-measured HBB with goniometry, inclinometry or motion-analysis methods, which will further offer valuable insights into the best ways to measure shoulder internal rotation in healthy and pathological shoulders.

CONCLUSION(S)

The tape-measured hand behind the back test demonstrated excellent reliability both within the same raters and between the raters, along with positive psychometric qualities in healthy adults. The results of present study indicate that the HBB distance test is a dependable, accurate, and clinically significant measure. Further research is required to establish its validity and responsiveness in individuals with shoulder pathology.

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