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Original Article

Physiotherapy Section

Reliability and Measurement Precision of a Low-cost Head-mounted Laser Device for Cervical Joint Position Error Assessment: A Reproducibility Study

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ABSTRACT

Introduction: Sensorimotor control and postural stability heavily rely on cervical proprioception. A head-mounted laser pointer is often used in a clinical practice as it is a simple and inexpensive head-to-neutral Joint Position Error (JPE) test. Its test-retest reliability and measurement precision need to be established.

Aim: To find out the test-retest reliability and measurement error of an indigenously developed low-cost head-mounted laser pointer instrument to measure cervical JPE in healthy adults.

Materials and Methods: This was an observational repeated-measures reliability test conducted in the Department of Physiotherapy, Maharishi Markandeshwar Institute of Physiotherapy and Rehabilitation, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India, from November 2025 to December 2025. This study employed a test-retest reliability design with repeated measures involving 51 healthy adults aged 18-45 years of age. Cervical JPE was measured in flexion, right rotation, left rotation and right lateral flexion and left lateral flexion using a laser device mounted on the head placed 90 cm away against a board. The protocol was repeated again after 72 hours under the same conditions. The Intraclass Correlation Coefficient (ICC 2,1) was used to assess test-retest reliability. The measure of absolute reliability was determined by computing the Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC) at the 95% confidence level (MDC_{95}). Intersession comparison was analysed through Bland Altman analysis.

Results: High reliability of all movements with ICC values of between 0.98 and 0.99 were exhibited. The range of SEM was between 0.03° and 0.04°, and the range of MDC was between 0.08° and 0.12°. Bland Altman analysis revealed that there were small mean bias and close Limits of Agreement (LoA).

Conclusion: The test-retest reliability of the device showed excellent performance and low measurement error among the healthy adults. The findings support its potential utility as a low-cost clinical assessment tool on cervical proprioception.

Keywords: Proprioception, Reproducibility of results, Test-retest reliability, Young adults

INTRODUCTION

Cervical proprioception supports sensorimotor control and postural stability by providing afferent information to cervical mechanoreceptors combined with visual and vestibular information [1,2]. Neck pain, dizziness, as well as further motor control has been linked to impairment of cervical proprioception as indicators of sensorimotor disturbances in cervical spine disorders [3,4]. One of the most popular tests to assess cervical joint position sense is the head-to-neutral JPE test which is regarded as a practical clinical measure of cervical proprioception [5,6]. When using this test, people are expected to actively move the head and then return it as accurately as possible to a predefined neutral starting position [7].

A head-mounted laser pointer device is also widely used in clinical practice as it is simple, affordable, and easy to implement [8]. Even though the use of advanced technologies (inertial measurement unit and motion capture systems) can offer detailed kinematic data, their practical applicability in the clinical setting might be limited in the routine practice setting [9]. While previous studies have used commercially available laser pointer devices for cervical JPE assessment, the present study utilised an indigenously developed low-cost head-mounted device. Unlike earlier devices, the current apparatus was fabricated using a lightweight PVC frame with adjustable Velcro straps to ensure consistent positioning and improved stability during repeated measurements. This design enhances accessibility in low-resource clinical settings while maintaining measurement precision [8,10]. Thus, before it can be widely used in clinical practice, it is important to determine test-retest reliability and measurement precision.

Measurement consistency of a repeated measurement is associated with test-retest reliability, which is often measured using statistical indicators such as the ICC, along with indices of absolute reliability including the SEM and MDC, which give estimates of measurement precision and changes of clinical importance [11]. Other researchers who have conducted previous research on the reliability of laser-based JPE have noted inconsistent results in the various movement directions and testing procedures. The ICC values are reported to be moderate to excellent (ICC=0.50-0.90) and they are dependent on a range of factors including target angle, repositioning technique, and the nature of the participants [7,8,12]. Besides, relative inconsistency of the absolute reliability indices, such as the SEM and the MDC, has also been reported, which suggests differences in measurement precision between studies [7,8]. Such discrepancy in reported measurement properties suggests the need to conduct further inquiry with standardised protocols.

Hence, the present study aimed to establish the test-retest reliability and measurement error of an indigenously developed low-cost head-mounted laser pointer device to evaluate cervical JPE in healthy adults within a period of 72 hours.

MATERIALS AND METHODS

This was an observational repeated-measures reliability test conducted in the Department of Physiotherapy, Maharishi

Markandeshwar Institute of Physiotherapy and Rehabilitation, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India from November 2025 to December 2025. The research received the approval of the Institutional Ethics Committee (IEC-3457), and written informed consent was obtained. It was a study that was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki [13].

The device comprised of a lightweight PVC frame with adjustable Velcro straps and a centrally aligned low-intensity laser module, for evaluating cervical JPE. The device was refined through iterative modifications to ensure consistent positioning and reliable measurements. The authors have also developed an advanced version incorporating sensors and camera-based tracking, for which a patent application has been filed (Application No.: 202511071035 A).

Sample size: Convenience sampling was used to recruit 51 healthy adults aged 18-45 years of age. The amount of sample involved was calculated according to the methodology requirements of reliability study based on the SEM. Sample size estimation was based on ICC reliability methodology assuming an expected ICC of 0.90, minimum acceptable ICC of 0.75, α=0.05, and power=80%. A total of 51 participants were included to improve precision. Also, it is recommended that a minimum of 30 participants is sufficient when conducting reliability studies, and statistical guidelines indicate that samples of over 50 enhance precision and consistency of ICC estimates [11].

Inclusion and Exclusion criteria: The study population consisted of participants who had no record of chronic neck pain, cervical dysfunction, neurological conditions and vertigo, or recent cervical trauma. Those who reported neck pain in the last three months or some systemic musculoskeletal disorders were excluded.

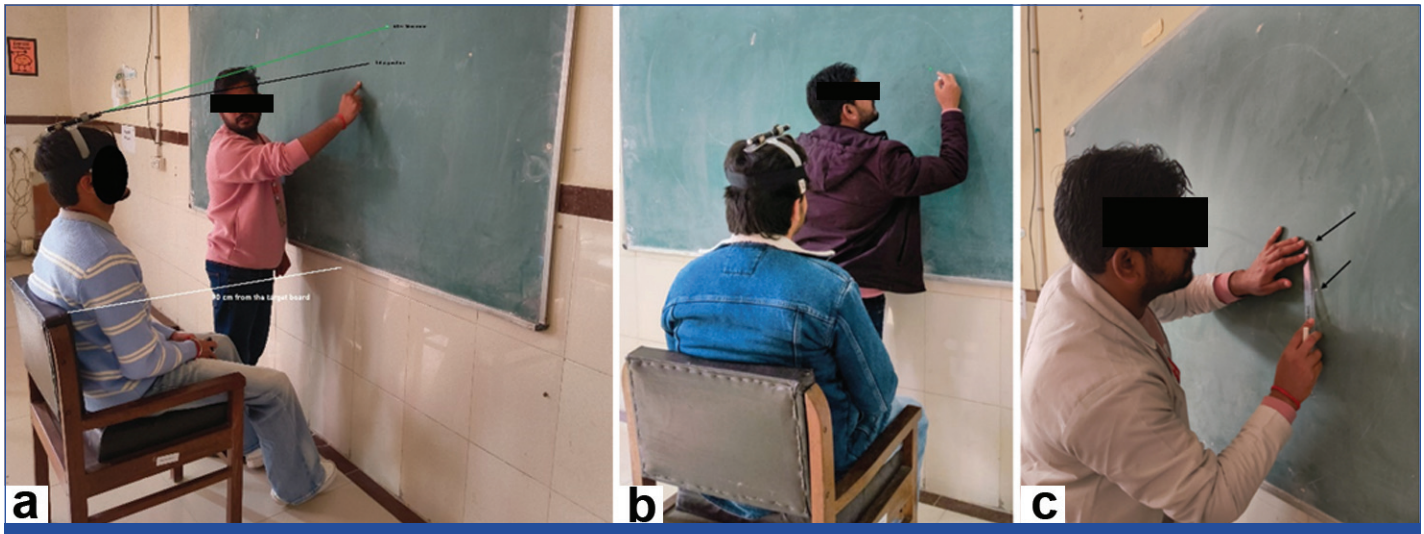
Study Procedure

Instrument used outcome measure: The error of cervical joint position measurement was carried out by means of a laser pointer shaped and mounted on the head which had been designed by the authors. The apparatus was a lightweight Polyvinyl Chloride (PVC) frame that was attached to the head of the participant with adjustable Velcro belts so that the sensor would be positioned in the same place consistently every time. The low intensity laser module was centrally guided over the forehead to bring about steady and repeatable projection of the beam. The calibration test was done before a collection of the data, so that the laser beam was perfectly aligned to the target grid A standardised distance of 90 cm was selected based on previous cervical proprioception studies to optimise angular measurement accuracy while maintaining participant comfort [8,12]. To maximise the accuracy of measurements and minimise possible bias, all tests were performed by the same examiner and under the same testing conditions and the participant given familiarisation tests prior to data collection. The position was kept standardised and in alignment with anatomical position to reduce the variation during the examination as manipulated by the examiners and movement of the participants. A representative image of the device setup and measurement procedure has been included [Table/Fig-1a].

Experimental procedures: The test-retest reliability of cervical proprioception was evaluated by administering the JPE tests in two testing sessions 72 hours apart. The participants were positioned upright comfortably sitting in a standardised posture with hips and knees flexed to 90°, feet placed flat on the floor and the trunk against the chair back [9]. There was a green target board that was positioned at a constant distance of 90 cm in front of the participant. In the repositioning tests, a blindfold was used to block visual feedback so that the vision was lost.

Head-to-neutral repositioning test: In each trial, subjects were made to take a natural relaxed Neutral Head Position (NHP). The location where the laser beam hit the target was used as the reference position. The examiner would then passively move the head of the participant in one of the following positions: flexion, right rotation, left rotation, right-side flexion, and left-side flexion. It was based on these positions that the participants were asked to actively resume what they considered the NHP. Before the data collection procedure was done, the testing procedure was outlined and demonstrated to every participant, and a trial of familiarisation was given to make sure that they understand what is required. No further formal practice trials and washouts were introduced, since repositioning exercise was simple, not fatiguing, and had associated with minimal learning effects, which is congruent with the existing literature [Table/Fig-1b] [8,9]. Participant wearing device during repositioning task marking of the new laser point location was made and the error in joint position was the distance between the new laser point and the reference point. [Table/Fig-1c]. All cervical movements in directions (flexion, right rotation, left rotation, right lateral flexion, and left lateral flexion) were measured in a predetermined order by all the participants to make processes consistent. A rest interval of 30 seconds between consecutive movement was allowed to reduce the possible fatigue and order effect. Moreover, the repositioning task had low physical and cognitive loads hence eliminating chances of cumulative fatigue or learning impact on performance. The movements were repeated three times and the average was taken to analyse it.

The calculation of Joint Position Error (JPE): Linear movements between the reference point (position of the neutral head) and the repositioned point were displayed in centimeters for each trial.



[Table/Fig-1]: a) Testing of cervical joint position (A) device and calibration on target board; b) Participant wearing device during repositioning task; c) Measurement of Joint Position Error (JPE).

Because the individuals were situated at the same distance (90 cm) of the target board, a trigonometric conversion involving the inverse tangent function was made to compute the error of the angular joint position in degrees: JPE (°)=$\tan^{-1}$ (error distance/90) [8,12]. In this approach, linear movement is transformed into angular movement deviation and has been widely utilised in cervical proprioception testing based on laser source [8]. The analysis of mean values of three movements using each direction of movement was taken.

Test-retest reliability test: To minimise the possible recall and learning effects and keep cervical proprioception physiological stability, a 72-hour period between testing sessions was chosen. Shorter intervals, such as 24 hours, may allow participants to remember their previous performance, which can increase reliability artificially [7]. Conversely, extended periods, e.g., one week, could cause real differences in proprioception performance because of everyday exercises or neuromuscular changes [9]. To reduce the effect of raters, all measurements were tried by one examiner to achieve consistency in the testing procedure. The measurement results were not concealed, and the examiner was aware of the results of the first session, resulting in a possible source of bias. Nevertheless, to reduce it, the standardised testing measures were adhered to in both sessions and measurements were taken after every trial. Also, laser-based measurement is objective, which will minimise the chances of examiner-related bias. Relative reliability was analysed using the ICC (2,1), based on a two-way random effects model with absolute agreement. ICC is an indicator of the consistency of repeated measures made in different sessions [11].

The measure of absolute reliability involved tracking the calculation of the SEM, which is chosen as the measure of the error of measurement that is purely random and is provided in the same unit as the outcome variable [14]. The SEM was calculated by using the equation SEM=SD×√(1-ICC). This is one of the recommended methods of estimating the precision of measurement in the study of reliability [15]. Minimum significance changes at 95% confidence level (MDC_{95}) to ascertain the minimum change needed to surpass measurement error was determined, MDC_{95} (MDC_{95}=SEM×√2×1.96). The basic error dimension is transformed into MDC which is usually employed to interpret clinically significant change that is not due to random variability [16]. SEM and MDC values should be interpreted to determine whether observed changes reflect true physiological changes or measurement error [15,16].

STATISTICAL ANALYSIS

All statistical procedure was performed using IBM SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA). All variables were computed using descriptive statistics. Data distribution was assessed for normality using the Kolmogorov-Smirnov test [17].

Test-retest reliability of the cervical JPE over the 72-hour interval was evaluated using the ICC (2,1) based on a two-way random effects model with the absolute agreement [11]. The ICC model has been chosen based on the reflection of both random effects of subjects and measures occasions. 95% CI has been computed to all ICC estimates. The SEM and MDC at the 95% confidence interval (MDC_{95}) were carried out to determine the level of absolute reliability. These indices give a guide of the level of precision in measurement and the minimal level of change that can be detected over random error [15]. Bland-Altman analysis was also performed to investigate agreement between sessions. To assess systematic differences between the testing sessions, the mean bias and 95% LoA were determined [18]. All the analyses considered a $p<0.05$ statistically significant.

RESULTS

A total of 51 participants were included in this investigation. Participant characteristics were reported using descriptive statistics based on data distribution. Age and weight were not normally distributed and are expressed as median {Interquartile Range (IQR)}, while height and BMI are expressed as mean±SD [Table/Fig-2].

Variables	Mean±SD	Median (IQR)	p-value[a]
Age (in years)	-	23.00 (4)	0.012
Height (cm)	170.55±7.50	-	0.073
Weight (kg)	-	65.00 (12)	0.022
BMI (kg/m²)	22.72±2.41	-	0.200

[Table/Fig-2]: Demographic characteristics of participants.
[a]Represents the values of the Kolmogorov-Smirnov test for normality, $p<0.05$ was considered significant

Test-retest reliability: Test-retest reliability of cervical JPE measurements over a 72-hour interval was assessed using the ICC. Excellent reliability was observed across all cervical movements.

Mean cervical JPE values for all movements were comparable between day 0 and the 72-hour assessment, indicating stability of measurements across testing sessions. Descriptive statistics for each cervical movement are presented in [Table/Fig-3].

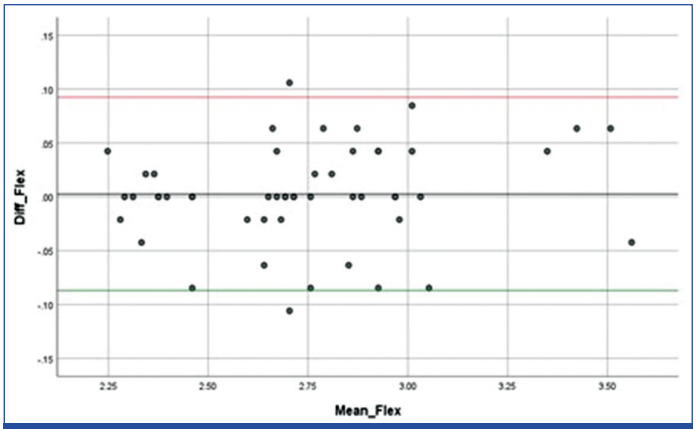
Movement	Session 1 Mean±SD (°)	Session 2 Mean±SD (°)	ICC (95% CI)	SEM (°)	MDC_{95} (°)
Neck flexion	2.75±0.31	2.73±0.30	0.98 (0.98-0.99)	0.04	0.12
Right rotation	2.75±0.22	2.74±0.23	0.98 (0.97-0.99)	0.03	0.08
Left rotation	2.75±0.22	2.76±0.21	0.98 (0.97-0.99)	0.03	0.08
Right lateral flexion	2.82±0.30	2.80±0.29	0.98 (0.96-0.99)	0.04	0.12
Left lateral flexion	2.74±0.33	2.73±0.32	0.99 (0.993-0.998)	0.03	0.09

[Table/Fig-3]: Test-retest reliability of cervical Joint Position Error (JPE) measurements. ICC calculated using a two-way random-effects models with absolute agreement {ICC (2,1)}.

Cervical flexion demonstrated excellent reliability, with an ICC (2,1) of 0.98, indicating high measurement stability between day 0- and 72-hour assessments. The SEM for flexion was 0.04°, resulting in a MDC at the 95% confidence level (MDC_{95}) of 0.12°. Right and left cervical rotation also exhibited excellent reliability, each demonstrating ICC values of 0.98. Measurement error for rotation was minimum with SEM value of 0.03 and MDC_{95} of 0.08° for both sides. Cervical side flexion movements showed high reliability of 0.98 ICC, SEM 0.04° and MDC_{95} of 0.12° for right-side and reliability of 0.99 ICC, SEM of 0.03° and MDC_{95} of 0.09° for left-side. Overall, the low SEM and MDC_{95} values across all movements indicate minimal measurement error and high consistency of the device across repeated testing sessions.

Agreement analysis: Agreement between two reliability measures was evaluated using Bland-Altman analysis for all cervical movements. Bland-Altman analysis was used to measure agreement between test and retest measurements of all cervical movements. The interpretation presented low systematic bias between movements. The means of the bias and 95% LoA of each movement were as follows: cervical flexion (mean bias: 0.0025°, LoA: -0.087 to 0.092°), right rotation (mean bias: -0.0112°, LoA: -0.079 to 0.056°), left rotation (mean bias: 0.0083°, LoA: -0.058 to 0.075°), right lateral flexion (mean bias: 0.0054°, LoA: -0.105 to 0.116°), and left lateral flexion (mean bias: 0.0050°, LoA: -0.054 to 0.064°). These results suggest that there was good consistency between the two occasions of measurement and most of the values were within the LoA.

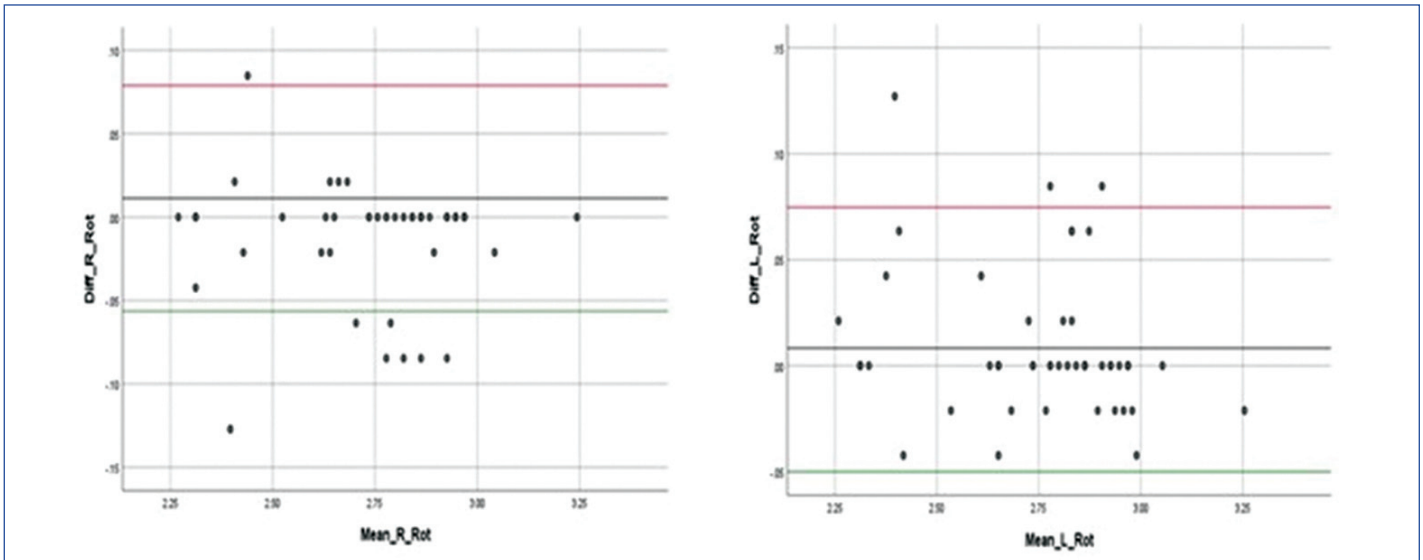
For cervical flexion, the plot represented negligible mean bias with narrow limit of agreement, indicating good agreement between two testing sessions [Table/Fig-4]. Right and left cervical rotation also demonstrated minimal bias and narrow LoA with most data points lying within the 95% limits [Table/Fig-5]. Right and left cervical side flexion showed very small average differences and restricted LoA, reflecting stable measurement performance between sessions [Table/Fig-6]. Overall, the Bland-Altman analyses support the



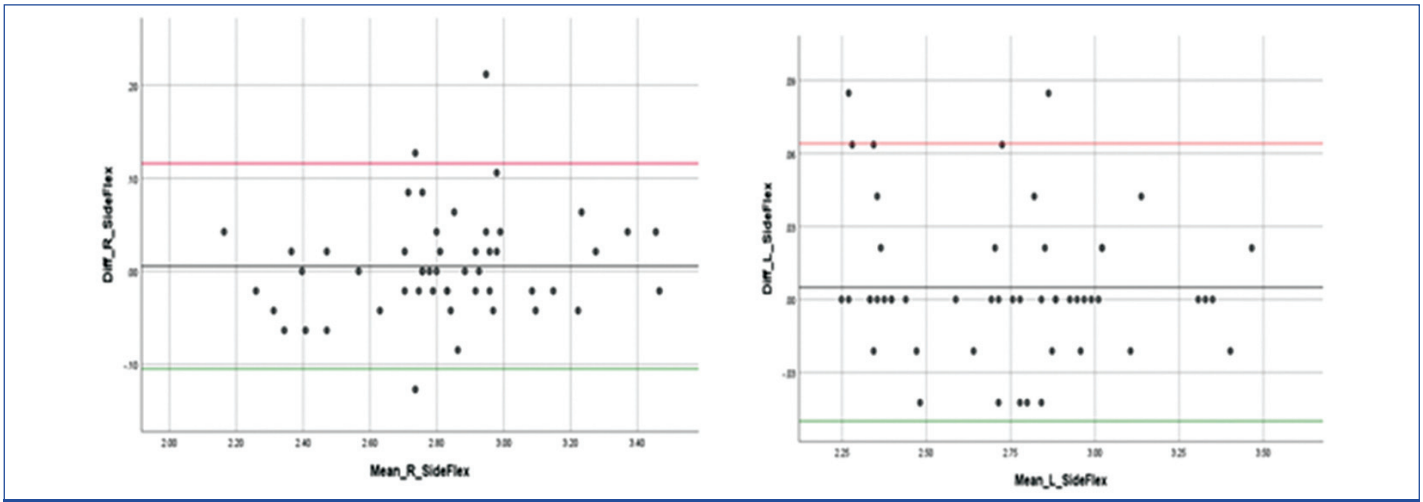
[Table/Fig-4]: Bland-Altman plot showing agreement between Day 0 and 72-hour cervical flexion Joint Position Error (JPE) measurements. The solid horizontal line represents the mean difference (bias), and the dashed lines represent the 95% LoA.

Therefore, accurate assessment of cervical proprioception requires robust measurement properties, as reliable tools are essential for the distinction of sensorimotor deficit from measurement error and to monitor meaningful changes over time [11]. The present study examined the test-retest reliability of a laser pointer-based device for assessing cervical JPE over a 72-hour interval. The findings suggest that the instrument gives reliable and consistent measurements under standardised conditions on healthy adults.

The ICC values used in this study are consistent with previous studies reporting good to excellent reliability in cervical JPE by using both laser-based and sensor-based repositioning techniques, with ICC values of about 0.77 to 0.95 usually associated with the various cervical movements [8,12,19]. Such differences could be explained by the differences in testing procedures, the features of the subjects, and intervals of retests. By contrast, the current research showed high reliability with ICC values of 0.98 to 0.99, which indicated a



[Table/Fig-5]: Bland-Altman plots showing agreement between Day 0 and 72-hour cervical rotation Joint Position Error (JPE) measurements: (A) Right rotation and (B) Left rotation. The solid horizontal lines represent the mean differences (bias), and the dashed lines represent the 95% LoA.



[Table/Fig-6]: Bland-Altman plots showing agreement between Day 0 and 72-hour cervical side flexion Joint Position Error (JPE) measurements: (a) right-side flexion and (b) left-side flexion. The solid horizontal lines represent the mean differences (bias), and the dashed lines represent the 95% LoA. Images from left to right.

excellent test-retest agreement of the device and confirm JPE measurements over a 72-hour interval.

DISCUSSION

In clinical practice, impaired cervical proprioception has been shown to contribute to neck pain, dizziness, altered motor control, and postural instability. Proprioceptive training has demonstrated effectiveness in improving joint position sense, sensorimotor control, and functional outcomes, highlighting the need for precise measurement to guide treatment decisions and evaluate intervention efficacy [3]. high rate of reliability of the measurement. The somewhat larger ICC values in this report could also be explained by the fact that standardised testing procedures, controlled experimental conditions, and the presence of a fixed retest interval were used in the study [12]. The reliability differences are also possible due to the fact that different testing procedures, participants, and intervals are reported.

Recent studies have also investigated the reliability and the validity of the device based cervical proprioception tests where the measurement properties are good to excellent by depending

on the methodology and the direction of movement measured [8,12,19]. These results justify the sustained clinical utility of repositioning-based tests in case they are conducted in a controlled scenario.

Several systematic reviews of the past highlighted the roles of evaluating cervical sensorimotor control in both the symptomatic and asymptomatic cohorts in order to inform clinical treatments [7,20-22]. The results obtained in this study of low SEM and MDC_{95} value mean that there are minimal random error of measurement and reasonable changes above the MDC_{95} value mean that changes could be due to actual change and not due to measurement error [15]. The aspect of reporting the relative and absolute reliability validates the clinical applicability of the current findings.

The low amount of change that can be detected at the 95% confidence level (MDC_{95}) in the current study was between 0.08 and 0.12 0, which means the highest level of measurement precision. The minimal change which can be clinically considered as a verifiable change as opposed to error of measurement is MDC. According to previous research findings, patients with neck pain exhibit a higher error in the position of neck-related joints than asymptomatic patients, and the difference is usually between two and four degrees [7,12]. Comparatively, the comparatively low MDC_{95} values that are found in the current study indicate that the instrument suggests potential ability to detect clinically meaningful changes of significance. Thus, modifications that go beyond the MDC can be regarded as a sign of actual changes in sensorimotor activity in the cervical area and not variability in measurements.

Limitation(s)

Several limitations should be acknowledged. First, the participants used in the study consisted of healthy adults only; as such, the research results cannot be directly applied to patients having neck pains or sensorimotor disabilities. Second, one examiner was used to carry out the measurements and inter-rater reliability was not measured. Third, the present study evaluated reliability but did not establish criterion or construct validity. Future research is required to evaluate the device's reliability in clinical population and examine concurrent validity with inertial motion capture systems or optoelectronic motion analysis systems that use gold standards.

CONCLUSION(S)

The localised design of the laser pointer on the head proved to have very high test-retest reliability and low measurement error of evaluation of the cervical JPE in healthy individuals over the period of 72 hours. Such results justify its possible use as an inexpensive clinical instrument in measuring cervical proprioception. The validity and performance in patients with neck pain should be assessed in further studies.

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