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El Bileği ve Önkol Aktif Eklem Pozisyon Hissinin Gonyometrik Ölçümü: Test–Tekrar Test Güvenirliği ve Ölçüm Hatası

Goniometric Measurement of Wrist and Forearm Active Joint Position Sense: Test–Retest Reliability and Measurement Error

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ÖZ

Amaç: Bu çalışmanın amacı sağlıklı genç yetişkinlerde el bileği ve önkol aktif eklem pozisyon hissinin gonyometrik değerlendirilmesine ilişkin test–tekrar test güvenirliği ve ölçüm hatasını incelemektir.
Yöntem: Çalışmaya 28 sağlıklı genç yetişkin katıldı. El bileği fleksiyonu, ekstansiyonu, radyal deviasyonu ve ulnar deviasyonu evrensel gonyometreyle; önkol pronasyonu ve supinasyonu ise çekül hatlı gonyometreyle her iki tarafta değerlendirildi. Katılımcılar her hedef açıyı görsel geri bildirim olmadan üç kez yeniden oluşturdu; ortalama mutlak açı hataları analiz edildi. Ölçümler bir hafta sonra aynı değerlendirici tarafından tekrarlandı. Göreli güvenirlik sınıf içi korelasyon katsayılarıyla; mutlak hata ise standart ölçüm hataları, %95 güven düzeyindeki minimal saptanabilir değişimler, ortalama yanlılık ve Bland–Altman %95 uyum sınırlarıyla değerlendirildi.
Bulgular: Sınıf içi korelasyon katsayıları 0,690–0,913 arasında değişti. Nokta tahminlerine göre güvenirlik üç ölçümde orta, sekiz ölçümde iyi ve bir ölçümde mükemmeldi; ancak dominant radyal deviasyon, nondominant pronasyon ve nondominant ulnar deviasyon için %95 güven aralıklarının alt sınırları zayıf güvenirlik düzeyindeydi. Standart ölçüm hataları 0,33°–0,96°, minimal saptanabilir değişimler ise 0,93°–2,66° arasında değişti. Ortalama yanlılıklar −0,02° ile 0,06° arasında değişti; %95 güven aralıklarının tümü sıfırı içerdi. Uyum sınırlarının genişliği hareket ve tarafa göre farklılık gösterdi.
Sonuç: Gonyometrik değerlendirme, sağlıklı genç yetişkinlerde el bileği ve önkol aktif eklem pozisyon hissinin tekrarlı ölçümünde genel olarak güvenilir görünmektedir. Bununla birlikte, güvenirliğin hareket ve tarafa göre değişmesi, ölçümlerin tek bir ortak eşik kullanılarak yorumlanmaması gerektiğini göstermektedir. Bireysel izlem sırasında gerçek değişimin belirlenmesinde harekete özgü minimal saptanabilir değişim değerleri dikkate alınmalıdır.

Anahtar Kelimeler: Propriyosepsiyon, El bileği eklemi, Önkol, Artrometri, Sonuçların tekrarlanabilirliği.

ABSTRACT

Objective: This study aimed to examine the test-retest reliability and measurement error of goniometric assessment of wrist and forearm active joint position sense in healthy young adults.
Method: Twenty-eight healthy young adults participated. Wrist flexion, extension, radial deviation, and ulnar deviation were assessed bilaterally with a universal goniometer; forearm pronation and supination with a plumb-line goniometer. Participants reproduced each target angle three times without visual feedback; mean absolute angle errors were analyzed. The same assessor repeated measurements after one week. Relative reliability was evaluated with intraclass correlation coefficients; absolute error with standard errors of measurement, minimal detectable changes at the 95% confidence level, mean bias, and Bland–Altman 95% limits of agreement.
Results: Intraclass correlation coefficients ranged from 0.690 to 0.913. Point estimates indicated moderate-to-excellent reliability, but lower 95% confidence limits fell within the poor range for dominant radial deviation, nondominant pronation, and nondominant ulnar deviation.

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Standard errors of measurement ranged from 0.33° to 0.96°, and minimal detectable changes from 0.93° to 2.66°. Mean biases ranged from −0.02° to 0.06°; all 95% confidence intervals included zero. Limits of agreement differed in width by movement and side.

Conclusion: Goniometric assessment appears generally reliable for repeated wrist and forearm active joint position sense measurement in healthy young adults. Variation across movements and sides, however, indicates measurements should not be interpreted using a single common threshold. Movement-specific minimal detectable change values should guide determination of true change during individual follow-up.

Key words: Proprioception, Wrist joint, Forearm, Arthrometry, Reproducibility of results.

1. INTRODUCTION

Proprioception is a fundamental component of sensorimotor control that enables perception of the position and movement of body segments and changes in muscle force. This sensory process depends on the integration within the central nervous system of afferent information from muscle spindles, Golgi tendon organs, joint capsules and ligaments, and cutaneous receptors (1). Joint position sense (JPS), one of the conscious components of proprioception, refers to an individual's ability to perceive and reproduce the position of a joint in space without visual information (1,2). Sensory feedback from JPS is important for maintaining movement accuracy, ensuring joint stability, and generating motor responses appropriate to changing mechanical conditions (2,3).

The wrist and forearm play a central role in grip, object manipulation, and activities of daily living by positioning the hand appropriately in space. The functional stability of this region depends not only on passive structures such as bones and ligaments but also on dynamic neuromuscular control guided by sensory feedback. Mechanoreceptors in the wrist ligaments and triangular fibrocartilage complex have been reported to contribute to the generation of afferent information about joint position and movement; therefore, wrist proprioception is considered an important component of dynamic stability (4,5). Changes in sensory information from these receptors due to trauma, pain, or ligament injury may adversely affect the perception of joint position and the generation of appropriate motor responses (3-5). Indeed, impairments in hand and wrist sensorimotor function have been reported after distal radius fracture (6), and individuals with triangular fibrocartilage complex tears have shown greater errors in reproducing joint position than healthy individuals, particularly during forearm pronation and supination (7). These findings indicate that valid and reliable assessment of wrist and forearm JPS is important both for identifying sensorimotor impairments and for monitoring changes during rehabilitation.

Because proprioception is multidimensional, assessment outcomes should be interpreted according to the sensory component measured by the method used. One of the most common approaches to assessing JPS is the joint position reproduction test, in which a previously demonstrated target angle is reproduced without visual feedback (2). The difference between the target angle and the reproduced angle is usually expressed as the absolute angle error. Although robotic systems, isokinetic dynamometers, electrogoniometers, inclinometers, and various digital sensors can be used to measure JPS, the cost and limited availability of these systems may restrict their clinical use (2,8). A universal goniometer is a low-cost, portable instrument that can be readily adapted to clinical practice. High intrarater and interrater reliability has been demonstrated for measuring forearm pronation and supination range of

motion with a plumb-line goniometer (9). However, the ability to measure joint range of motion reliably does not directly show that the same instrument is also reliable for JPS measurements. JPS measurements may be influenced by protocol characteristics such as whether the movement is performed actively or passively, the magnitude of the target angle, the number of repetitions, the method used to eliminate visual feedback, the interval between tests, and the side on which measurements are performed (2,8). Therefore, the reliability of each assessment protocol should be examined under its own conditions of use.

Findings from studies on clinical assessment of wrist JPS have been inconsistent. Pilbeam and Hood-Moore reported that the test-retest reliability of wrist flexion and extension JPS measurements performed with a universal goniometer in healthy adults ranged from poor to moderate (10). In contrast, Tekin et al. obtained high test-retest reliability for wrist flexion, extension, radial deviation, and ulnar deviation using a sensor-based electrogoniometer (11). Another study comparing different clinical measurement tools showed that the reliability coefficients of wrist JPS measurements obtained with a goniometer were limited (12). Although recent normative data from healthy young adults suggest that the effects of movement direction and side dominance on JPS may be limited, these data were restricted to selected flexion and extension angles (13). In addition, test-retest reliability ranging from poor to moderate depending on movement direction has been reported in individuals with wrist problems assessed at a one-week interval (14). These different findings indicate that JPS measurements may be sensitive to the instrument used, target angle, movement direction, study population, and reassessment interval.

Current literature has mainly focused on wrist flexion and extension, while radial and ulnar deviation and forearm pronation and supination, which are important components of functional hand use, have been examined less often. Evidence is also insufficient regarding the assessment of the dominant and nondominant sides within the same protocol, the use of a test-retest interval that reflects clinical practice, and the reporting of relative reliability indices together with absolute measurement error parameters. Addressing these limitations is important for determining whether an observed change represents a true change or measurement error and for improving the clinical interpretability of goniometric JPS assessments.

Accordingly, this study aimed to examine the one-week test-retest reliability of active JPS measurements obtained with a goniometer for wrist flexion, extension, radial deviation, and ulnar deviation and for forearm pronation and supination in healthy young adults. The study also aimed to determine both the relative reliability and absolute measurement error of the measurements by analyzing the dominant and nondominant sides separately.

2. MATERIALS AND METHODS

Ethical Considerations

This test-retest reliability study was conducted at İzmir Katip Çelebi University between January 17, 2025, and February 6, 2026. Approval was obtained from an independent ethics committee before the study [İzmir Katip Çelebi University Health Research Ethics Committee, date: 16.01.2025, decision no.: 0009]. Written informed consent was obtained from all

participants before the assessments. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Participants

Participants constituted a university-based convenience sample recruited through advertisements posted on social media. Healthy individuals aged 18-39 years who provided written informed consent after receiving information about the study aim and assessment procedures were included. Individuals were excluded if they had experienced trauma affecting the wrist or undergone wrist surgery within the previous six months; had a current bone or soft tissue injury or skin infection; had a history of neuromuscular disease or congenital anomaly; or had any other health condition that could affect the assessment.

Sample size was calculated based on a one-sided hypothesis with a minimum acceptable intraclass correlation coefficient (ICC_0) of 0.50 and an expected coefficient (ICC_1) of 0.80. Assuming two measurements per participant, a one-sided $\alpha = 0.05$, and 80% statistical power, the required minimum sample size was 23 participants (15). To account for the possibility of nonattendance at the second assessment or incomplete measurements, an allowance of five participants was added to the target sample, and 28 participants were planned for inclusion in the study.

Assessments

The age, sex, body weight, height, and dominant side of all participants who agreed to take part in the study were recorded. Proprioception was assessed for wrist flexion-extension, ulnar-radial deviation, and forearm supination and pronation in both upper extremities.

Active joint position sense (AJPS) was measured to assess proprioception. A universal goniometer with 1° resolution (Baseline) was used to assess AJPS during wrist flexion, extension, ulnar deviation, and radial deviation, and a plumb-line goniometer was used to assess AJPS during supination and pronation (9,12). As described by Karagiannopoulos et al., the plumb-line goniometer was constructed by adding a handle and plumb line to a universal goniometer (9).

For wrist AJPS measurements, participants were first asked to sit in a chair and place their forearms on a table. For flexion-extension, the upper extremity was positioned with the longitudinal axis of the forearm between the radius and ulna perpendicular to the table, the forearm in midpronation, the elbow flexed and in contact with the table, and the wrist and fingers relaxed under the tenodesis effect. For ulnar-radial deviation, unlike the flexion-extension measurement position, the forearm was positioned with its longitudinal axis between the radius and ulna parallel to the table and the palm facing downward.

To measure AJPS during wrist flexion, the pivot point of the goniometer was placed on the dorsal aspect of the wrist at the level of the midcarpal joint. The moving arm followed the third metacarpal and third finger, while the stationary arm was positioned on the forearm, perpendicular to the axis of wrist flexion-extension and parallel to the radius. The target angle in this position was 20° (16).

To measure AJPS during wrist extension, the goniometer was positioned on the volar aspect. As in flexion, the moving arm followed the third metacarpal and third finger. The stationary arm was placed parallel to the radius. The pivot point was positioned at the level of the radiocarpal and midcarpal joints. The target angle for extension was 30° (12).

Wrist radial and ulnar deviation were measured with the forearm pronated and the goniometer placed on the dorsal aspect of the wrist. The pivot point of the goniometer was positioned at the level of the radiocarpal and midcarpal joints, the stationary arm along the long axis of the forearm, and the moving arm along the third metacarpal (16). Based on the movement requirements of daily activities, the target angles were set at 25° for radial deviation and 35° for ulnar deviation (17).

AJPS during forearm supination and pronation was assessed with a plumb-line goniometer (9). The participant was seated in an armless chair with the shoulder in neutral and the elbow flexed to 90°. The participant's elbow was held against the body and stabilized to eliminate the rotational effect of the shoulder joint (16). The forearm was positioned with its long axis between the radius and ulna perpendicular to the floor, and this position was used as the starting point for both movements. Based on the movement requirements of daily activities, the target angles were set at 50° for supination and 20° for pronation (17).

Protocol

All assessments were performed by one person (an experienced physiotherapist). After the tests were explained to the participants, the target angle was set on the goniometer, and the participant was asked to perform the relevant movement until reaching the target angle. When the target angle was reached, the participant was informed and the goniometer was removed. The participant was asked to hold this position for five seconds to learn the angle. The participant was then asked to return to the starting position. After this procedure had been repeated three times, the participant was asked to reproduce the learned angle three times, starting from the initial position (12). Participants were instructed to say “here” when they believed they had reached the angle. The angle of the position indicated by the participant was measured with the goniometer. The amount of error between the target angle and the reproduced angle was recorded. The assessment was repeated three times. No feedback was provided between trials. The arithmetic mean of the absolute values of the three errors was used to define AJPS (12). Participants wore a blindfold during all tests, and care was taken to keep the environment quiet. To reduce the potential effect of menstruation on proprioceptive performance, the test and retest assessments of female participants were scheduled not to coincide with self-reported days of menstruation (18). To minimize systematic order effects, the extremity (dominant/nondominant) and movement assessment order were randomized separately for each participant using the Random Sequence Generator on Random.org. The same participant-specific randomized order was retained at the one-week retest, which was conducted by the same assessor. The assessor did not have access to the T1 measurement values while performing the T2 assessments.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics 22 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as means and standard deviations, and categorical variables as counts and percentages. The normality of the difference scores between the second and first measurements (T2 - T1) was assessed using the Shapiro-Wilk test and graphical methods. Test-retest relative reliability of the AJPS score, calculated as the mean of the three absolute errors, was evaluated using a two-way mixed-effects, absolute-agreement intraclass correlation coefficient [ICC(A,1)] with a 95% confidence interval (CI). ICC values were interpreted as poor (<0.50), moderate (0.50-0.74), good (0.75-0.89), and excellent (≥0.90); both the point estimate and width of the 95% CI were considered in the interpretation (19). Absolute measurement error was examined using the standard error of measurement (SEM) and minimal detectable change at the 95% confidence level (MDC_{95}). SEM was calculated as the square root of the error mean square (SEM = √MSerror), and MDC_{95} was calculated using the formula $1.96 \times \sqrt{2} \times SEM$ (20). Systematic bias between sessions was assessed using the mean T2 - T1 difference and its 95% CI. Absolute agreement between measurements was also examined using the Bland-Altman method, and the 95% limits of agreement (LoA) were calculated as the mean difference ± 1.96 × the standard deviation of the differences (21). Because there were no missing measurements, analyses were conducted on all 28 participants, and no imputation method was used. All statistical tests were two-sided, and $p < 0.05$ was considered statistically significant. The Guidelines for Reporting Reliability and Agreement Studies (GRRAS) recommendations were followed when reporting reliability and agreement results (22).

3. RESULTS

Measurements at T1 and T2 were completed for all 28 participants. Participant demographics are shown in Table 1.

Table 1. Participant Demographic Characteristics (n:28).

Variable	Value
Age (years), mean ± SD	23.79 ± 1.66
Height (cm), mean ± SD	172.39 ± 9.47
Body weight (kg), mean ± SD	73.46 ± 13.18
Sex, n (%)	
Female	14 (50.0)
Male	14 (50.0)
Dominant side, n (%)	
Right	25 (89.29)
Left	3 (10.71)

Abbreviations: SD, standard deviation; cm, centimeter; kg, kilogram.

ICC(A,1) point estimates ranged from 0.690 to 0.913. On the dominant side, flexion, extension, supination, pronation, and ulnar deviation showed good reliability, whereas radial deviation showed moderate reliability. On the nondominant side, flexion, extension, and supination showed good reliability; pronation and ulnar deviation showed moderate reliability; and radial deviation showed excellent reliability. The highest relative reliability was found for nondominant radial deviation, and the lowest for dominant radial deviation. These classifications were based on the ICC point estimates. However, the lower 95% confidence

limits for dominant radial deviation (0.430), nondominant pronation (0.483), and nondominant ulnar deviation (0.447) fell within the poor reliability range. Mean T2 - T1 differences ranged from -0.02° to 0.06°, and all 95% confidence intervals included zero. SEM values ranged from 0.33° to 0.96°, and MDC_{95} values ranged from 0.93° to 2.66°. Descriptive statistics and analysis results are presented in Table 2.

Table 2. Mean Absolute Angle Errors at T1 and T2, Systematic Bias, Absolute Reliability, and Relative Reliability.

Side and movement	T1, mean ± SD (°)	T2, mean ± SD (°)	Bias (T2 - T1), 95% CI (°)	ICC(A,1), 95% CI	SEM (°)	MDC_{95} (°)	Bland-Altman 95% LoA (°)
Dominant							
Flexion	2.00 ± 1.22	2.04 ± 1.44	0.04 (-0.26; 0.34)	0.837 (0.678; 0.921)	0.55	1.51	-1.48 to 1.55
Extension	2.62 ± 1.56	2.62 ± 1.51	0.00 (-0.37; 0.37)	0.813 (0.635; 0.909)	0.67	1.87	-1.87 to 1.87
Supination	2.33 ± 1.47	2.35 ± 1.77	0.01 (-0.31; 0.33)	0.874 (0.745; 0.940)	0.59	1.63	-1.61 to 1.64
Pronation	1.89 ± 1.36	1.89 ± 1.52	0.00 (-0.37; 0.37)	0.790 (0.594; 0.897)	0.67	1.86	-1.86 to 1.86
Ulnar deviation	2.32 ± 1.46	2.35 ± 1.81	0.02 (-0.33; 0.38)	0.849 (0.699; 0.927)	0.65	1.80	-1.77 to 1.82
Radial deviation	1.63 ± 1.29	1.67 ± 1.33	0.04 (-0.37; 0.44)	0.690 (0.430; 0.844)	0.74	2.05	-2.01 to 2.08
Nondominant							
Flexion	1.46 ± 1.12	1.46 ± 1.06	0.00 (-0.25; 0.26)	0.822 (0.651; 0.914)	0.47	1.29	-1.29 to 1.29
Extension	3.17 ± 1.98	3.21 ± 2.20	0.05 (-0.48; 0.57)	0.798 (0.608; 0.901)	0.95	2.64	-2.60 to 2.69
Supination	2.76 ± 1.54	2.74 ± 1.61	-0.02 (-0.32; 0.28)	0.884 (0.764; 0.944)	0.54	1.51	-1.53 to 1.49
Pronation	1.27 ± 1.04	1.33 ± 1.26	0.06 (-0.28; 0.40)	0.723 (0.483; 0.862)	0.62	1.71	-1.65 to 1.77
Ulnar deviation	2.50 ± 1.41	2.54 ± 2.00	0.04 (-0.49; 0.56)	0.701 (0.447; 0.850)	0.96	2.66	-2.62 to 2.69
Radial deviation	1.50 ± 1.09	1.56 ± 1.15	0.06 (-0.12; 0.24)	0.913 (0.821; 0.958)	0.33	0.93	-0.87 to 0.99

Abbreviations: T1, first assessment; T2, second assessment; SD, standard deviation; CI, confidence interval; ICC, intraclass correlation coefficient; SEM, standard error of measurement; MDC_{95}, minimal detectable change at the 95% confidence level. Limits of agreement (LoA) = mean bias ± 1.96 × standard deviation of the differences between paired measurements.

The narrowest Bland-Altman 95% limits of agreement were observed for nondominant radial deviation, and the widest for nondominant ulnar deviation (Figures 1 and 2).

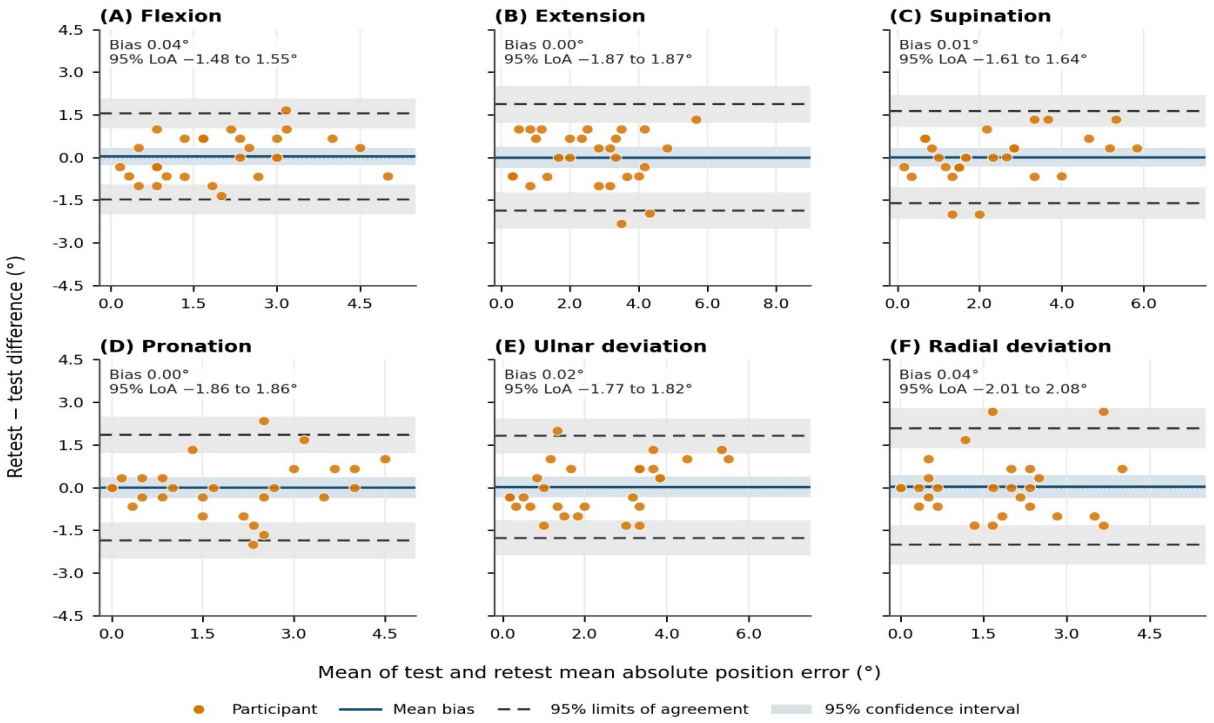


Figure 1. Bland-Altman plots for the dominant side

Figure 1 note. Bias: mean difference between the two measurements; LoA: limits of agreement.

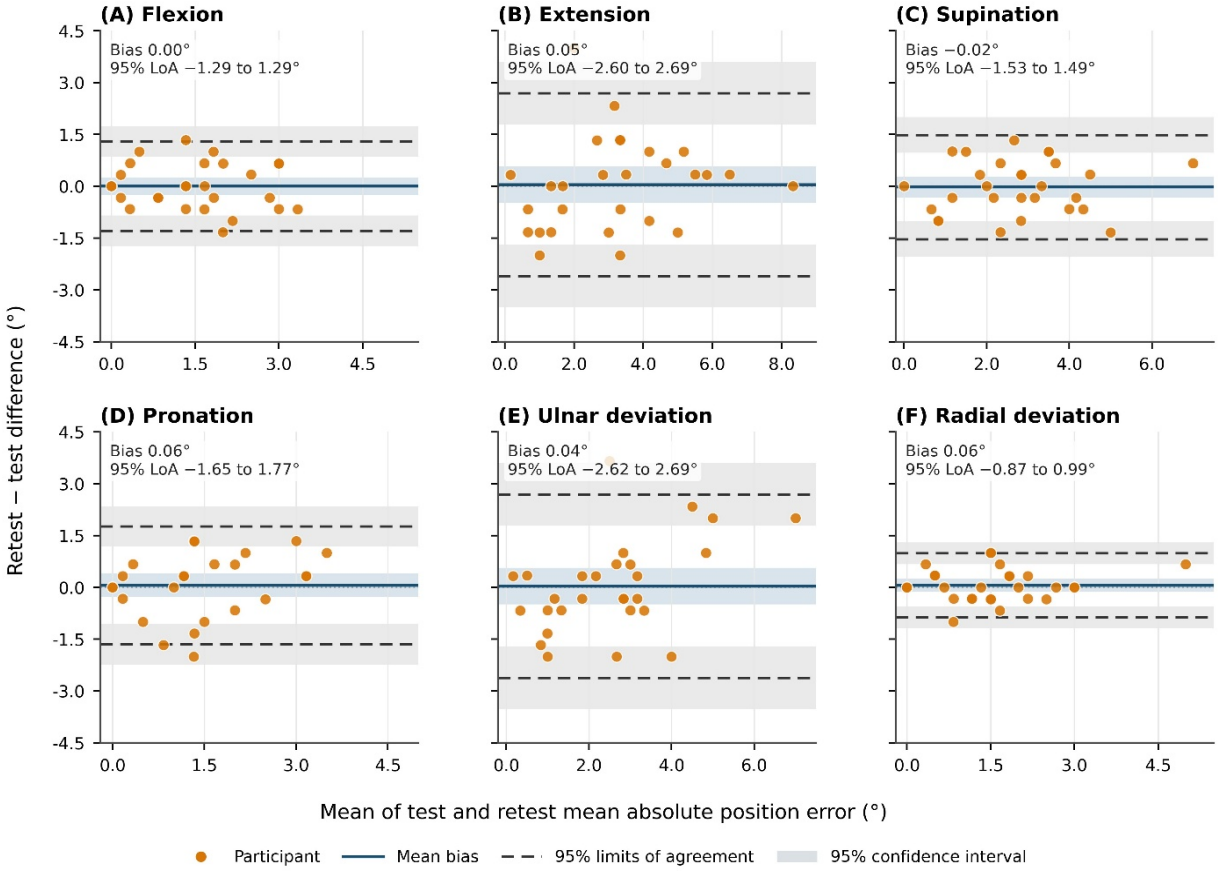


Figure 2. Bland-Altman plots for the nondominant side

Figure 2 note. Bias: mean difference between the two measurements; LoA: limits of agreement.

4. DISCUSSION

This study examined the test–retest reliability of goniometric assessment of wrist and forearm AJPS in healthy young adults. Although the ICC point estimates ranged from moderate to excellent depending on movement and side, the lower confidence limits for three measurements extended into the poor reliability range, indicating uncertainty in the precision of these estimates.

Although the ICC results were generally promising, the confidence intervals call for a more cautious interpretation of the precision of the findings. In particular, the lower bounds of the 95% confidence intervals for dominant radial deviation and nondominant pronation and ulnar deviation extended into the poor reliability range. Similarly, although AJPS for nondominant radial deviation showed excellent reliability, the lower bound of the confidence interval was in the good range. Therefore, the classifications identified in the current sample should be regarded as estimates that require confirmation in larger samples rather than as definitive and unchanging characteristics. This finding is consistent with recommendations that confidence intervals should be reported and interpreted together with ICC results (19).

Pilbeam and Hood-Moore reported ICC values of 0.07-0.47, an overall mean absolute error of 3.98°, and an SEM of approximately 2° at 20° and 45° flexion and extension targets in healthy adults (10). A study comparing the reliability of three approaches found an ICC of 0.422 for the goniometer and classified its reliability as poor (12). In contrast, ICC values in our study ranged from 0.690 to 0.913, and SEM values ranged from 0.33° to 0.96°. Because the ICC depends on between-person variability in the sample as well as absolute measurement error, higher ICC values alone do not indicate that a measurement method is superior to other protocols. The small SEM (0.32) and MDC (0.75) values reported by Seven et al. despite a relatively low ICC also support the need to interpret relative and absolute reliability indices together (12,20).

Tekin et al. reported that measurements performed with the KFORCE Sens® electrogoniometer in healthy participants showed high test-retest reliability on both the dominant and nondominant sides. In that study, the sensor was fixed to the relevant anatomical region, and joint angles were recorded electronically by the device. Thus, the universal goniometer did not need to be manually realigned with anatomical landmarks for each trial, and the measurement value did not need to be read visually. In addition, the reassessment was performed 24 hours after the first measurement (11). Karagiannopoulos also reported that the reliability of AJPS measurements could vary according to the target angle and assessor experience (23). The electrogoniometer may therefore have eliminated the effects of assessor experience and potential minimal day-to-day differences in goniometer placement. A recent pilot study conducted at a one-week interval in individuals with wrist injuries and symptoms such as pain obtained ICC values for AJPS ranging from poor to moderate depending on the movement (14). Pain and structural damage may explain why the reliability values were lower than those reported in both the study by Tekin et al. and our study. Thus, our findings demonstrate the repeatability of a standardized protocol in healthy young adults but do not directly establish reliability in patient populations.

The variation in our ICC results across movements and sides highlights the importance of evaluating reliability separately for each movement and side. The highest ICC was found for nondominant radial deviation, and the lowest for dominant radial deviation. However, because the ICC is affected by between-person variability in the sample, the confidence intervals partially overlapped, and the study was not designed to statistically compare reliability between sides, this finding should not be interpreted as an effect of dominance. Shetty et al. likewise found no statistically significant difference between the dominant and nondominant sides in absolute angle error at 20° of flexion and extension in healthy young adults (13). Rather than indicating that one side is more reliable, our findings support reporting measurement properties separately by movement and side.

Because they have been studied less often in the literature, the findings for forearm rotations broaden the clinical scope of our study. Supination measurements showed good reliability on both sides, whereas pronation showed good reliability on the dominant side and moderate reliability on the nondominant side. However, the uncertainty in the confidence interval for nondominant pronation should be considered. Goniometric AJPS studies have mainly focused on flexion, extension, and deviations. Pronation and supination have been studied less frequently. Given that position sense during forearm rotation may be impaired in injuries involving the wrist and forearm, such as triangular fibrocartilage complex injuries (7), the reliability levels obtained with the plumb-line goniometer provide useful findings for clinical research. However, we recommend that reliability also be confirmed in relevant patient populations before the protocol is used for clinical decision-making.

MDC_{95} values were lowest for nondominant radial deviation at 0.93° and highest for nondominant ulnar deviation at 2.66°. These values represent the approximate lower thresholds required for an individual change to exceed measurement error with 95% confidence when measurements are repeated by the same assessor under the present protocol. They should not be applied to measurements obtained by different clinicians. However, MDC_{95} is a threshold for healthy young adults rather than a threshold for clinically important change. The reported MDC values of 4.28°-4.94° and minimal clinically important difference values of 5.00°-7.09° after distal radius fracture using a different AJPS protocol (24) indicate that measurement error and change that is meaningful to the patient are different concepts and that thresholds should be determined for the specific population and protocol. In the Bland-Altman analysis, the mean differences were close to zero and their 95% confidence intervals included zero, indicating that no statistically detectable systematic bias at the group level (a tendency for the second measurements to be higher or lower than the first) was identified between sessions. However, the wide 95% limits of agreement for some movements indicate that differences between T1 and T2 measurements may vary over a wide range at the individual level.

These findings suggest that universal and plumb-line goniometers may be accessible options for monitoring active wrist and forearm position sense in healthy young adults in settings without expensive laboratory systems. However, clinicians should not interpret the results solely on the basis of good or excellent ICC labels. Measurements should be performed by the same assessor, using the same anatomical alignment and target angle, with visual input blocked and with the hand free and unloaded; the mean of three trials should be used. Unless a

change observed during follow-up exceeds the MDC_{95} value for the relevant movement and side, a true change should be interpreted cautiously.

In our study, measurements were performed under unloaded conditions with the fingers relaxed. A grip force equal to 15% of maximal voluntary isometric grip force has been shown to increase absolute position error in healthy individuals (25). Therefore, the current error thresholds should not be generalized to functional tasks such as gripping, load carrying, or tool use. However, JPS has been reported to be a responsive outcome measure in rehabilitation after distal radius fracture (24) and was used to evaluate the effects of closed kinetic chain exercises in a recent randomized study (26). This clinical interest increases the value of a feasible goniometric protocol.

The main strengths of this study were the assessment of the four primary wrist movements and forearm pronation and supination within the same protocol, separate reporting for the dominant and nondominant sides, randomization of the assessment order, standardization of all measurements by the same assessor, and use of a clinically realistic one-week test-retest interval. Calculating each score as the mean of three trials reduced random error, while reporting 95% confidence intervals, SEM, MDC_{95}, mean bias, and Bland-Altman limits of agreement in addition to the ICC allowed relative reliability and absolute measurement error to be evaluated together. The absence of missing data and loss to follow-up also supported the integrity of the analyses.

5. CONCLUSION AND RECOMMENDATIONS

In conclusion, under standardized single-assessor conditions, goniometric measurement provided a feasible approach for assessing wrist and forearm AJPS in healthy young adults. Although the ICC point estimates were generally moderate to excellent, the wide confidence intervals and poor lower confidence limits for some measurements warrant cautious interpretation. Movement-specific MDC_{95} values should also be considered when determining whether changes observed during individual follow-up represent true change. The applicability of the protocol with different assessors and in clinical populations should be confirmed in future studies.

Limitations of the Study

This study has several limitations that should be considered. First, because the ICC depends partly on between-participant variability, the relative homogeneity of this university-based convenience sample may have reduced the ICC estimates despite the small absolute measurement errors. The findings should not be generalized to older adults, athletes, or populations with pain, trauma, instability, or neurological disease. Second, although the sample size met the planned power, some ICC confidence intervals were wide, which limits precision, particularly for the movement- and side-specific estimates. Third, realignment of the manual goniometer on assessment days and the use of anatomical skin markings may have contributed to measurement error. Only one target angle was examined for each movement direction. Because AJPS reliability may vary according to the target angle, the reliability and measurement error estimates obtained in this study are specific to the angles used and should not be generalized to other angles, particularly end-range positions (23). In addition, our single-

plane, unloaded protocol does not fully represent the multiplanar, gripping, and variable-speed movements of daily life (25,27). Future studies should examine the test-retest and interrater reliability of the protocol in different age groups and disease/injury populations. Validity outside the laboratory should also be evaluated using protocols that include grip force, biplanar movements, or functional tasks (25,27). These studies should be planned in accordance with current methodological quality criteria for measurement error and validity (28).

Ethical Considerations

This test-retest reliability study was conducted at İzmir Katip Çelebi University between January 17, 2025, and February 6, 2026. Approval was obtained from an independent ethics committee before the study [İzmir Katip Çelebi University Health Research Ethics Committee, date: 16.01.2025, decision no.: 0009]. Written informed consent was obtained from all participants before the assessments. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Conflict of Interest

There is no conflict of interest among the authors.

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