Test–Retest Reliability of a New Device Versus a Long-Arm Goniometer to Evaluate Knee Proprioception

Fei Tian, Yaqi Zhao, Jixin Li, Wenjin Wang, Danni Wu, Qiang Li, Liyun Guo, and Shaobai Wang

Context: Many methods used to evaluate knee proprioception have shortcomings that limit their use in clinical settings. Based on an inexpensive 3D camera, a new portable device was recently used to evaluate the joint position sense (JPS) of the knee joint. However, the test–retest reliability of the new method remains unclear. This study aimed to evaluate the test–retest reliability of the new device and a long-arm goniometer for assessing knee JPS, and to compare the variability of the 2 methods. Design: Prospective observational study of the test–retest reliability of knee JPS measurements. Methods: Twenty-one healthy adults were tested in 2 sessions with a 1-week interval. Three target knee flexion angles (30°, 45°, and 60°) were reproduced in each session. Target and reproduced angles were measured with both methods. Intraclass correlation coefficients, standard error of the measurement, and Bland–Altman plots were used to quantify test–retest reliability. Paired t tests were used to compare knee JPS (absolute error of the target-reproduced angle) between the methods. Results: The new device (good to excellent intraclass correlation coefficients .74–.80; standard error of the measurement 0.52°–0.61°) demonstrated better test–retest reliability than the goniometer (poor to fair intraclass correlation coefficients .23–.43; standard error of the measurement 0.89°–2.07°) and better test–retest agreement (respective mean differences for the 30°, 45°, and 60° knee angles: 0.11°, 0.13°, and 0.41° for the new system; 0.84°, 1.52°, and 1.18° for the goniometer). The measurements (absolute errors of the target-reproduced angles) with the goniometer were significantly greater than with the new device (P < .05); the SDs of repeated measurements with the goniometer (1.50°–2.41°) were greater than with the new device (1.08°–1.38°). Conclusions: Given that the new device has good reliability and sufficient precision, it is the better alternative for evaluating knee JPS. Goniometers should be used with caution to assess knee JPS.

Keywords: joint position sense, reproducibility, motion capture system, agreement, method

Joint position sense (JPS) is a subcomponent of proprioception. JPS is often assessed by actively or passively reproducing joint position, which is determined by the absolute or relative error between the reproduced angle and the target angle; less error indicates better JPS. Although many methods for assessing knee JPS exist, their shortcomings limit their use in clinical settings. Isokinetic dynamometers, such as the Biodex, are commonly used to evaluate JPS; however, these instruments are too expensive to be feasible for many clinics, especially those in low to middle income countries. Image capture or video analysis has often been used for assessing knee JPS, but requires data processing via high-precision software that is time consuming. Sensor-based electrogoniometers require access to an optical motion capture system or a universal goniometer for calibration before knee JPS evaluation. Therefore, for clinicians, these instruments are neither feasible (high cost) nor user-friendly (time-consuming and complex to operate).

Based on the same principles as the OptiKnee system (Innomotion, Shanghai, China), a new portable motion capture system with an inexpensive 3D camera was recently used to assess knee JPS. The new device can detect knee 3D angles in real time, which is convenient for clinicians. In addition, a long-arm goniometer has often been used to measure knee angles and is reportedly more precise than a short-arm goniometer. However, the test–retest reliability of the new portable device for assessing knee JPS with respect to that of the long-arm goniometer is unclear. Good test–retest reliability is an important prerequisite for clinical application and data interpretation and may enable the new device to become the “gold,” “silver,” or other standard for evaluating knee JPS.

The purpose of this study was to determine the test–retest reliability of the new portable device and that of a long-arm goniometer for assessing knee JPS, and to compare the variability of the 2 methods. We hypothesized that (1) the new device will have good reliability that is greater than that of the long-arm goniometer, and (2) the new device will have smaller measurement variability than the long-arm goniometer.

Methods

Participants

The study cohort comprised 21 healthy adults (13 men and 8 women; age: mean 25.95 y, SD 4.59 y; height: mean 168.6 cm, SD 7.9 cm; weight: mean 63.48 kg, SD 11.45 kg; body mass index: mean 22.26 kg/m², SD 2.56 kg/m²). All participants met the following inclusion criteria: age 20–40 years (noninclusive), body mass index 18–24 kg/m² (noninclusive), and no history of knee complaints. Because benign joint hypermobility syndrome causes marked impairments in knee proprioception, individuals with benign joint hypermobility syndrome (defined as a Beighton scale score ≥4/9) were excluded. In addition, individuals with a history

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of chronic systemic disease or musculoskeletal trauma or surgery in the lower extremity were excluded. According to Fleiss,10 15 to 21 participants are sufficient for analyzing the reliability of a quantitative variable. This study was approved by the Ethics Committee of Shanghai University of Sport (2017042). All participants provided written informed consent prior to participating.

**Procedures**

The new portable device (Pmotion, Innomotion, Shanghai, China) and a 50-cm long-arm goniometer (precision ±0.3°, EM-KAL500; Elecall, Wenzhou, China) were used to measure knee angles to assess the JPS of the dominant limb of each participant (the preferred leg for kicking a ball). Measurements were performed with both instruments on 1 day, and measurements were repeated after a 1-week interval. The hardware components of the new device included a 120 frames per second (fps) trinocular camera with submillimeter precision (Optitrack V120 Trio; NaturalPoint, Inc, Corvallis; Figure 1A), 2 rigid bodies, and 1 digitizing probe with 4 infrared reflective markers embedded within each (OK_Marquer; Innomotion; Figure 1B). Customized software (OK_Marquer) recorded the position of the rigid bodies, one each placed laterally on the lower leg and distally on the thigh (Figure 2), to establish the local coordination of the tibia and femur and obtain the angle of the knee joint.

Participants sat on an examination bed in a quiet environment with their arms crossed and trunk relaxed (Figure 2). The digitizing probe was held at the bony landmarks of the lower limb (including greater trochanter, lateral epicondyle, medial epicondyle, lateral plateau, medial plateau, medial malleolus, and lateral malleolus) to acquire the local 3D coordinates of the knee.11 White stickers were attached to mark the positions of the greater trochanter, femoral lateral epicondyle, and lateral malleolus to facilitate measurement with the long-arm goniometer.

Knee JPS was assessed with passive positioning and active reproduction. The participant sat with eyes covered and lower limbs hanging comfortably over the edge of the bed. The knee was passively positioned by the training examiner (at approximately 10°/s) to one of 3 target angles (30°, 45°, and 60° of knee flexion, in a random order) using the goniometer. The examiner had performed the training at least 50 times to ensure that the knee moved evenly during testing at approximately 10°/s based on a timer. The target angles, based on those from previous studies,12 were chosen by considering knee range of motion in typical daily activities (ie, walking and running)9 and in sports, as well as to stimulate primarily musculotendinous mechanoreceptors.2 The participant was asked to actively hold the knee at the target angle for 5 seconds to get a sense of the position, then the lower limb was passively moved to the starting position by the examiner. The participant then attempted (to the best of their ability) to actively reproduce the target angle, maintaining the position for 5 seconds. Both the target and reproduced angles were recorded using the new portable device and the long-arm goniometer. The procedure was repeated 3 times for each target angle, so that 9 repetitions were performed for each knee joint.12 The whole process took approximately 10 to 12 minutes. All participants were blinded to their results.

**Data**

Using the new device, knee joint angle plots were displayed in real time (Figure 3). In each plot, the first stable signal (prior to the start of the peak) represents the knee after being passively positioned at the target angle, and the second stable signal (after the end of the peak) represents the angle during attempted reproduction. The mean value of each stable signal was used as the measurement. For both the new device and the goniometer, knee JPS was quantified as the absolute error between the target angle and the reproduction angle. For both methods, the average absolute error of 3 repetitions

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was calculated as the value of knee JPS at each target angle to be statistically analyzed.

**Statistical Analysis**

Statistical analysis was performed with SPSS software (version 22.0; SPSS Inc, IBM, Armonk, NY). Results were described with the mean and SD, and statistical significance was set at $P < .05$. Intraclass correlation coefficients ($ICC_{2,1}$: a single measure, absolute agreement, and 2-way random effects model), standard error of the measurement (SEM), and Bland–Altman plots showing the mean difference and 95% limits of agreement (LoA) were used to evaluate the test–retest reliability of each method (ie, the new device and the goniometer). $ICC_{2,1}$ values from .0 to .39 were considered poor, values from .40 to .59 were considered fair, values from .60 to .74 were considered good, and values from .75 to 1.00 were considered excellent; an ICC ≥.70 is usually considered acceptable. The SEM was calculated as $s \sqrt{1 - ICC}$, where $s$ is the sample SD, and ICC is the corresponding ICC. The SEM was used to test the absolute reliability and estimate the precision of the measurement, which also provide important information about reliability. A lower SEM value represents a smaller systematic error and better precision of the measurement. Bland–Altman plots were used to assess test–retest agreement with differences between test and retest values plotted against the means of test and retest values. The closer the mean difference is to 0, the smaller the systematic error, which represents a more reliable measurement. The narrower the 95% LoA and the more points within the LoA, the better the agreement of the measurement. Paired $t$ tests were used to compare the differences in assessing knee JPS between the new device and the goniometer, and SDs were used to assess the variability of each method. The SDs of each method were calculated at each target angle for both tests, giving 3 SD values for each method. Smaller SDs represented less variability of the data (ie, less measurement error).

**Results**

The new portable device exhibited good to excellent correlations between test and retest measurements for 30°, 45°, and 60° target knee flexion with ICCs of .76, .74, and .80, respectively; the corresponding SEM values were 0.52°, 0.56°, and 0.61°, respectively. The goniometer exhibited poor to fair correlations between test and retest measurements for 30°, 45° and 60° target knee flexion with ICCs of .43, .23, and .35, respectively; the corresponding SEM values were 0.89°, 2.07°, and 1.95°, respectively (Table 1).

Bland–Altman plots show the test–retest agreement of knee JPS measured at 30°, 45°, and 60° of target knee flexion using the new device and the goniometer (Figure 4). For the new device, the mean differences for 30°, 45°, and 60° target knee flexion were 0.11° (LoA −1.76° to 1.98°), 0.13° (LoA −1.86° to 2.12°), and 0.41° (LoA −1.78° to 2.60°), respectively; for the goniometer, the mean differences were 0.84° (−1.50° to 3.17°), 1.52° (−5.07° to 8.11°), and 1.18° (−4.65° to 7.01°), respectively. The mean differences and 95% LoA of test–retest measurements with the new device were smaller than those of the goniometer. However, Figure 4 shows that the value of 0 lies within the 95% LoA, and no more than 2 points (9.5% of the measurements) are outside the 95% LoA, indicating no significant disagreement between test–retest measurements for either of the 2 methods.

Table 2 presents a comparison of the absolute error measured using the new device with that measured using the goniometer.

**Figure 3** — The knee joint angle plots of one participant measured by the new device.

**Table 1 Test–Retest Reliability of Knee JPS for 30°, 45°, and 60° Target Knee Flexion Using the New Device and Long-Arm Goniometer**

<table>
<thead>
<tr>
<th>Knee position</th>
<th>Methods</th>
<th>Session 1, °</th>
<th>Session 2, °</th>
<th>ICC</th>
<th>ICC (95% CI)</th>
<th>SEM, °</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>New device</td>
<td>2.41 (1.12)</td>
<td>2.30 (1.06)</td>
<td>.76</td>
<td>.42 to .90</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>Goniometer</td>
<td>3.53 (1.17)</td>
<td>2.70 (1.05)</td>
<td>.43</td>
<td>−.40 to .77</td>
<td>0.89</td>
</tr>
<tr>
<td>45°</td>
<td>New device</td>
<td>2.51 (1.08)</td>
<td>2.38 (1.16)</td>
<td>.74</td>
<td>.36 to .90</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>Goniometer</td>
<td>4.84 (2.37)</td>
<td>3.32 (2.15)</td>
<td>.23</td>
<td>−2.04 to .50</td>
<td>2.07</td>
</tr>
<tr>
<td>60°</td>
<td>New device</td>
<td>3.12 (1.38)</td>
<td>2.71 (1.38)</td>
<td>.80</td>
<td>.52 to .92</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>Goniometer</td>
<td>5.98 (2.23)</td>
<td>4.80 (2.50)</td>
<td>.35</td>
<td>−.60 to .74</td>
<td>1.95</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; JPS, joint position sense.
Measurements with the new device differed significantly from those with the goniometer (P < .05) for all target knee flexion angles. The SDs using the new device (SD range 1.08°–1.38°) were smaller than those using the goniometer (SD range 1.50°–2.41°).

**Discussion**

Given the importance of evaluating knee JPS and the lack of feasibility of most instruments in the clinical setting, a new portable device can be used to assess knee JPS. This study investigated and compared the test–retest reliability of the new device and that of a standard long-arm goniometer in evaluating knee JPS. The reliability of the new device was good to excellent, while the reliability of the goniometer was poor to fair. The statistical power of this study was >0.80. Measurements with the new method demonstrated more reliability and less variability than those with the goniometer.

Knee JPS measurements of the new device (for 30° knee flexion: mean 2.35°, SD 1.08°; for 45° knee flexion: mean 2.44°, SD 1.11°; for 60° knee flexion: mean 2.92°, SD 1.38°; Table 2) were comparable with those of other methods—knee JPS measured with a self-made device (mean 2.5°, SD 1.0°)15; knee JPS measured using image capture method during extension from 90° to 0° in a general sample (mean 2.5°, SD 0.7°),16 in men aged 15–29 years (mean 2.6°, SD 1.32°),3 and in women aged 15–29 years (mean 2.7°, SD 1.61°)3; knee JPS measured using a Biodex system at 30° (mean 2.3°) and at 70° (mean 3.0°).17 In studies reporting greater knee JPS than those reported herein—one using a Vicon marker-based motion capture system to measure JPS during seated knee extension (range 3.18°–3.19°, SD 1.5°)18 and one using video analysis of lateral lower limb marker movement to assess knee JPS (mean 4.9°, SD 2.7°)19—the higher values may reflect study design, such as differences between participants (active people or elite athletes) and methods.

Knee JPS test–retest reliability findings for the new device (ICCs .74–.80; SEM values 0.52°–0.61°) in our study were consistent with those reported for an image capture method for 30° to 60° knee flexion of the dominant leg (ICC .86; SEM 0.60°)20 and better than those reported for 45° knee flexion when seated (ICC .13; SEM 1.3°).18 In the study,18 knee JPS was measured in Vicon with 4 lateral lower limb markers without establishing a bone model. Our study demonstrated better reliability, possibly because knee JPS measurements used a local knee coordinate system. In 2 other studies4,11 in which electrogoniometers were used, the test–retest correlations (for 45° target angle: ICC .864; for 75° target angle: ICC .874 and ICC .86111) were slightly greater than those in our study, but measurement distributions (SEM 0.90°–1.25°4; SEM 0.53°11) were greater or similar to those in our study and within an acceptably small range. Moreover, the ICC3,k model was used in the study,4 which typically results in ICC values that are

![Figure 4](image-url)
greater than those of ICC_{2,1} models. In addition, the test–retest Bland–Altman plots showed acceptable consistency between test–retest measurements (mean difference 0.11° for 30° knee flexion, 0.13° for 45° knee flexion, and 0.41° for 60° knee flexion) for the new device in the current study, which were comparable to those of Piriyaprasarth et al^4 (mean difference 0.27° for 45° target angle, and 0.35° for 75° target angle).

Values and SDs quantifying knee JPS obtained using the long-arm goniometer (absolute error 3.02°–5.39°, SD 1.5°–2.41°) significantly exceeded those obtained using the new device (absolute error 2.35°–2.92°, SD 1.08°–1.38°; Table 2), and the SDs of the long-arm goniometer were similar in magnitude to the JPS measurements of the new device. Using a long-arm goniometer, Hancock et al^7 reported a SD of 4.9° and a minimum significant difference of 9.6° for healthy subjects to distinguish changes in knee angle, which supports our findings of large variability in goniometer measurements; however, the study reported an ICC value of >.99, while the ICC values in the current study were <.50. Furthermore, the test–retest mean differences and 95% LoA of the goniometer were greater than those of the new device, demonstrating that the goniometer results in greater systematic errors than the new device. Thus, the long-arm goniometer should be used with caution for knee JPS assessment because of over-representative measurements, large measurement variability, and systematic errors. Furthermore, according to a meta-analysis of knee proprioception assessment using the method of active repositioning, the mean difference in the mean angle of error was 2.04° greater (95% confidence interval, 1.11° to 2.97°; P < .001) in osteoarthritic knees than in the unaffected knees of a healthy control group;^21 similarly, another meta-analysis reported that the mean angles of error were 1.25° higher (95% confidence interval, 0.72° to 1.78°; P < .001) in knees with anterior cruciate ligament injury than in contralateral intact knees.^22 These previous findings suggest that the minimum clinically relevant angle of error may be about 2°. In our study, the mean differences of the test–retest measurements were 0.11° to 0.41°, and the SDs of the repeated measurements were 1.08° to 1.38° for the new device; as these values were <2°, the new system can be applied clinically.

The strengths of the present study include being the first to use the new device to evaluate knee JPS using a rigorous trial design with appropriately powered study outcomes. Nevertheless, the present study has limitations. First, the participants were healthy adults between 22 and 40 years age; therefore, the results with respect to reliability are only applicable to the assessment of knee JPS in healthy adults. Future studies should be repeated with other groups, such as patients with anterior cruciate ligament injuries and knee osteoarthritis. Second, the heterogeneity of responses within a selected population may substantively influence the observed single-measurement reliability of an outcome measure. Third, to minimize other sensory input, the evaluation was performed without distractions while seated; however, most injuries occur during weight-bearing activities. In future, the reproducibility of knee position should be investigated in more complex conditions. It may be necessary to explore the dynamic JPS performance, including the spatiotemporal information of knee repositioning.

Conclusions
The reliability of the new device was good to excellent, while the reliability of the long-arm goniometer was poor to fair in assessing knee JPS. Given that the new device has good reliability and sufficient precision, it is the better alternative for knee JPS evaluation. Goniometers should be used with caution to measure knee JPS.

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