Validity and Reliability of a Digital Inclinometer to Assess Knee Joint-Position Sense in a Closed Kinetic Chain

Natalia Romero-Franco, Juan Antonio Montaño-Munuera, and Pedro Jiménez-Reyes

Context: Knee joint-position sense (JPS) is a key parameter for optimal performance in many sports but is frequently negatively affected by injuries and/or fatigue during training sessions. Although evaluation of JPS may provide key information to reduce the risk of injury, it often requires expensive and/or complex tools that make monitoring proprioceptive deterioration difficult. Objective: To analyze the validity and reliability of a digital inclinometer to measure knee JPS in a closed kinetic chain (CKC). Design: The validity and intertester and intratester reliability of a digital inclinometer for measuring knee JPS were assessed. Setting: Biomechanics laboratory. Participants: 10 athletes (5 men and 5 women; 26.2 ± 1.3 y, 71.7 ± 12.4 kg, 1.75 ± 0.09 m, 23.5 ± 3.9 kg/m²). Intervention: Knee JPS was measured in a CKC. Main Outcome Measures: Absolute angular error (AAE) of knee JPS in a CKC. Results: Intraclass correlation coefficient (ICC) and standard error of the mean (SEM) were calculated to determine the validity and reliability of the inclinometer. Data showed that the inclinometer had a high level of validity compared with an isokinetic dynamometer (ICC = 1.0, SEM = 1.39, P < .001), and there was very good inter- and intratester reliability for reading the inclinometer (ICC = 1.0, SEM = 0.85, P < .001). Compared with AutoCAD video analysis, inclinometer validity was very high (ICC = .980, SEM = 3.46, P < .001) for measuring AAE during knee JPS in a CKC. In addition, the intertester reliability of the inclinometer for obtaining AAE was very high (ICC = .994, SEM = 1.67, P < .001). Conclusion: The inclinometer provides a valid and reliable method for assessing knee JPS in a CKC. Health and sports professionals could take advantage of this tool to monitor proprioceptive deterioration in athletes.

Keywords: proprioception, athletes, CKC

Knee proprioception refers to a key parameter in sports performance due to its association with the accuracy and efficiency of sports movements and also with injuries incurred during many sports. In terms of injuries, several studies have shown poorer accuracy during repositioning tasks in athletes with injuries such as femoropatellar syndrome or anterior cruciate ligament (ACL) tears, even months after the original injury. In terms of sports performance, it seems that poorer accuracy in recognizing and reproducing a position may partly determine athletes’ capacity to perform optimal sports movements such as free throws in basketball.

Proprioception can be impaired during a sports event due to fatigue from training sessions or the competition itself or as a consequence of previous injuries. It seems that the deterioration of the muscle spindles modifies the proprioceptive information that is sent to the central nervous system, blunting motor control. Several studies have analyzed the effects of fatigue induced by exercise or competition on knee JPS. Salgado et al showed that athletes had less acuity in knee position sense after a football match. Similar results were found by Bottoni et al, who found impairments in knee proprioception after uphill and downhill walking, and by Romero Franco and Jimenez Reyes, who reported deterioration of knee proprioception after high-intensity anaerobic training. Fatigue has been associated not only with proprioceptive deterioration but also with injury risk; several studies estimated higher rates of injuries in situations involving fatigue (i.e., during the second part of a match in football or during the last part of the race in marathon runners).

Based on the previous arguments, an evaluation of knee JPS in field conditions is necessary to monitor and control proprioceptive impairments due to fatigue induced by exercise. To this end, previous studies have included the JPS test due to its capacity to detect subjects’ ability to recognize and reproduce a position. Typically, studies have used isokinetic dynamometers or video-analysis systems to perform this test; however, this involves expensive tools or a laborious process.

In this regard, previous studies have provided affordable and easy-to-use instruments as valid and reliable methods to assess JPS, such as the inclinometer. Dover and Powers and Vafadar et al validated the
inclinometer for measuring internal and external shoulder rotation in open kinetic chain and active modalities, while Krause et al\textsuperscript{15} used a digital inclinometer to measure hip rotation in open kinetic chain and active modalities. To date, this methodology has been used only for rotational JPS testing of the shoulder and hip joints.\textsuperscript{13,16} The aim of this study was to analyze the reliability and validity of the inclinometer in assessing knee JPS. A closed kinetic chain (CKC) was considered because this modality of proprioceptive assessment has been shown to be more sensitive in detecting proprioceptive deterioration in athletes, which may go unnoticed in open kinetic chain modalities.\textsuperscript{17}

**Method**

**Participants**

Ten subjects (5 male and 5 female; 26.2 ± 1.3 y, 71.7 ± 12.4 kg, 1.75 ± 0.09 m, 23.5 ± 3.9 kg/m\textsuperscript{2}) from a regional track and field team voluntarily participated in this study. Participants were excluded if they had suffered any lower-limb injury in the 6 months before the assessment or had received surgical intervention to a lower limb. Before the beginning of the study, an informed consent was signed by all the athletes according to the Declaration of Helsinki. This study was approved by the ethical committee of our university.

**Procedures**

**Inclinometer Validity and Reliability.** A 0.3°-precision Limit miniature digital inclinometer (50 × 50 × 32 mm) (Alingsas, Sweden) was used (Figure 1[C]). The inclinometer’s validity and reliability were assessed using a System 4 Pro isokinetic dynamometer (Biodex, Shirley, NY, USA) integrated into a computer using System 4 Advance version 4.2 software (Biodex, Shirley, NY, USA). The inclinometer was attached to the dynamometer arm using the magnetic side of the inclinometer, and both the inclinometer and the isokinetic dynamometer were zeroed. The dynamometer arm was placed in 10 different angle positions, while 2 testers (tester 1 and tester 2) who did not know the purpose of the study and were blinded to the dynamometer angles recorded the angles shown on the inclinometer concurrently but independently. Each angle position was repeated twice in a randomized order.

![Figure 1](image-url) — (A) Knee joint-position-sense test, (B) the piece of iron inside the hook-and-loop strap, and (C) the digital inclinometer used for the test.
**Knee JPS (Inclinometer).** After determining that the inclinometer was a valid and reliable tool, an inclinometer was used to assess knee JPS in a CKC using an active modality (athletes actively reached and maintained the knee position) (Figure 1[A]). The dominant leg (the leg with which they normally kick the ball) was tested in all subjects. In addition, all subjects had been previously instructed to wear sports shorts to perform the JPS test. A digital inclinometer was attached to the middle third of the athletes’ thighs with a hook-and-loop strap, with the inclinometer positioned on the anterior aspect of the thigh (Figure 1[A–B]). The subjects stood on their dominant leg while supporting themselves using a chair as a stable object, as previous studies have recommended, with a wedge under the heel of their dominant leg (height 5 cm) to reduce passive tension in the triceps surae during the test. In addition, the contralateral leg was relaxed in slight hip flexion by resting on a step (height 20 cm) with slight hip flexion (Figure 1[A]). The subjects’ visual inputs were blocked with a mask while they actively squatted until the stance leg reached the target joint angle, at which point they were asked to stop and maintain this position for 5 seconds to recognize the exact angle of the knee. This target position was 50° of knee flexion in the dominant leg, which refers to the intermediate range of knee flexion, where mediation by muscle sensors in the detection of knee position predominates. After 5 seconds, they were asked to return to the initial position (full knee extension). At a spoken “reposition” order, the subjects tried to reproduce the target joint angle as accurately as possible and maintain the estimated position for 3 seconds until a “return” order was given. They underwent 3 trials. The subjects rested for 2 seconds before each trial. Two testers with no prior information about the nature of the investigation recorded the angles that the inclinometer showed to determine intertester reliability. Based on the data, the absolute angular error (AAE) was obtained as the most important variable in determining JPS. This variable was calculated as follows:

\[
\text{AAE} = \frac{|(\text{target position} - \text{trial 1})| + |(\text{target position} - \text{trial 2})| + |(\text{target position} - \text{trial 3})|}{3}
\]

**Knee JPS (Video Analysis With AutoCAD).** At the same time that the inclinometer method was performed, the entire sequence was recorded with a high-resolution camera; these visual records were analyzed later using AutoDesk AutoCAD 2015 (San Rafael, CA, USA) video analysis. To facilitate this analysis, 4 nonreflective markers were placed on the dominant limb in the following locations: greater trochanter, lateral thigh, fibular head, and fibular malleolus (Figure 1[A]). The test–retest reliability of the AutoCAD video-analysis method had been assessed in a previous pilot study (ICC = .990). For the video analysis with AutoCAD, a line was created between markers 1 and 2 (representing the thigh movement) and another between markers 3 and 4 (representing the leg movement); then, the angle formed by the intersection of both lines was calculated using the command designed for this in the software.

**Statistical Analysis**

Intraclass correlation coefficient (ICC 2,1) and standard error of the mean (SEM) were obtained to determine the validity of the inclinometer compared with the isokinetic dynamometer. In addition, ICC and SEM were calculated to determine the intratester and intertester reliability for reading the inclinometer.

The ICC and SEM were obtained to compare the inclinometer with the AutoCAD measurements for the CKC JPS task, as well as the intertester reliability during the same task. In this case, the AAE was determined from the AutoCAD and inclinometer measurements as the main parameter of the knee JPS. Data were analyzed using SPSS for Windows version 17 (SPSS, Inc, Chicago, IL, USA) and MedCalc 12.1 (Mariakerke, Belgium). Significance was determined at \( P < .05 \).

**Results**

The mean values and standard deviations for trials made for each tool and tester are presented in Table 1.

Information regarding the reliability measures is presented in Table 2. The data show very high values

**Table 1 Values for Angle Measurements**

<table>
<thead>
<tr>
<th>Tool</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodex isokinetic dynamometer</td>
<td>39.20°</td>
<td>25.48°</td>
</tr>
<tr>
<td>Inclinometer T1</td>
<td>39.08°</td>
<td>25.42°</td>
</tr>
<tr>
<td>Inclinometer T1'</td>
<td>39.09°</td>
<td>25.43°</td>
</tr>
<tr>
<td>Inclinometer T2</td>
<td>39.07°</td>
<td>25.44°</td>
</tr>
<tr>
<td>Absolute angular error AutoCAD</td>
<td>3.72°</td>
<td>2.21°</td>
</tr>
<tr>
<td>Absolute angular error T1</td>
<td>3.76°</td>
<td>2.07°</td>
</tr>
<tr>
<td>Absolute angular error T2</td>
<td>3.75°</td>
<td>2.11°</td>
</tr>
</tbody>
</table>

Abbreviations: T1, tester 1; T2, tester 2; T1', tester 1, second repetition of the angles.

**Table 2 Validity and Reliability Measures**

<table>
<thead>
<tr>
<th>Method</th>
<th>ICC (95% CI)</th>
<th>SEM</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamometer vs inclinometer</td>
<td>1.0 (.996–1.000)</td>
<td>1.39</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Intertester reliability T1 vs T1'</td>
<td>1.0 (.998–1.000)</td>
<td>0.85</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Intertester reliability T1 vs T2</td>
<td>1.0 (.998–1.000)</td>
<td>0.85</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>AutoCAD vs inclinometer</td>
<td>.980 (.927–.995)</td>
<td>3.46</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Intertester reliability T1 vs T2</td>
<td>.994 (.978–.998)</td>
<td>1.67</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Abbreviations: CI = confidence interval; ICC = intraclass correlation coefficient; SEM = standard error of the mean; T1, tester 1; T2, tester 2; T1', tester 1, second repetition of the angles.
for the validity of the inclinometer against the isokinetic dynamometer (ICC = 1.0, SEM = 1.39, $P < .001$). In addition, the intratester and intertester reliabilities for reading the inclinometer were very high (ICC = 1.0, SEM = 0.85, $P < .001$). The data for inclinometer and AutoCAD video-analysis comparisons show high validity values for the inclinometer in comparison with AutoCAD video analysis (ICC = .980, SEM = 3.46, $P < .001$). The intertester reliability during the CKC JPS task was very high (ICC = .994, SEM = 1.67, $P < .001$).

**Discussion**

Because of the importance of proprioception as a key parameter in injury risk and performance,$^{1,5}$ monitoring proprioceptive capability has a significant role during both rehabilitation and training. However, the current instruments to measure this ability are sophisticated and nonportable or involve very labor-intensive measurements to obtain the necessary proprioceptive values.$^{12}$ Therefore, the purpose of the current study was to demonstrate the validity and reliability of a digital inclinometer in measuring knee JPS in athletes. This study found the inclinometer to be a valid tool compared with an isokinetic dynamometer, and it also showed high levels of intratester and intertester reliability. In addition, a very high validity has been supported for our proposed inclinometer method by a low SEM compared with video analysis using AutoCAD for CKC knee JPS tasks. Likewise, the inclinometer showed very high intertester reliability and a low SEM during knee JPS tasks. These findings suggest the ease of use of the inclinometer method because of its high validity and reliability in field testing conditions, supported by the low SEM reported.

Despite the fact that previous studies used other tools to analyze knee JPS,$^{3,5}$ the inclinometer has been shown to be more affordable and portable. These characteristics highlight the inclinometer as a more useful tool for field evaluation, allowing coaches and health professionals to obtain immediate feedback. In contrast, video analysis cannot provide JPS values immediately after performing the test; it requires a very laborious and time-consuming process for obtaining the results of the test. Regarding the isokinetic dynamometer, although it provides immediate results, it is a sophisticated and nonportable instrument, which is difficult to access for the majority of coaches and health professionals due to its high cost. This hinders provision of immediate feedback for athletes and coaches during field evaluation and slows the planning of training or rehabilitation sessions.$^{1,4,5}$

Based on the aforementioned arguments, the inclinometer is an affordable and portable instrument that provides a valid and reliable method, applicable in training sessions and even in competition, when exertion may lead to an injury event. Studies that evaluated the effects of fatigue on proprioception$^4$ reported impairments in the acuity of athletes during knee JPS tasks. Romero-Franco et al$^{22}$ evaluated the effects of a high-intensity anaerobic session as a fatigue protocol for knee JPS and found increases in the AAE during JPS after the fatigue protocol. Similarly, Bottoni et al$^7$ described the effects of a “hiking fatigue protocol” on the knee JPS in sportswomen. After a fatigue protocol consisting of 30 minutes of uphill walking, the knee JPS of the subjects was impaired. Due to the effect of fatigue on proprioception, previous studies have shown the role of knee JPS in injury risk.

Despite the lack of prospective studies, some authors tried to associate knee JPS with common knee injuries including damage to the ACL. Mir et al$^{23}$ compared JPS in a neutral knee valgus/toes position in healthy subjects, reporting significantly worse values in the latter relative to the former position in JPS. They suggested that imbalances associated with proprioception in this “risky” position may be related to increased incidence of ACL injury. Mohammadi et al$^{24}$ prospectively evaluated the effects of military exercises on JPS in injured and noninjured subjects. All subjects did a specific 8-week training for lower-limb injury and JPS. Those authors reported significantly greater changes in proprioceptive acuity after a fatiguing exercise condition in those who became injured than those who remained injury free. Likewise, Lee et al$^{13}$ evaluated knee proprioception in subjects with acute and chronic ACL injury, showing a knee JPS impairment in both ACL injury types, although with a higher grade in subjects with chronic ACL injury. They suggest that the damage produced in the mechanoreceptor located in the ACL may decrease knee proprioception. In addition, those authors reported that the longer the elapsed time to recover from the ACL injury, the higher the loss of proprioception, highlighting the importance of prompt rehabilitation. Therefore, JPS monitoring during the rehabilitation process is needed to prevent a higher loss of knee proprioception, which could facilitate new injuries.

Since fatigue may lead to JPS deterioration, and knee proprioception may play a role in future injuries, health and sport professionals could use the immediate and easy feedback provided by the inclinometer to monitor proprioceptive capabilities during rehabilitation processes or training sessions. This could facilitate monitoring during the rehabilitation process is needed to prevent a higher loss of knee proprioception, which could facilitate new injuries.

**Limitations and Future Research**

Despite the reliability of the inclinometer as a method for assessing knee JPS, in our investigation only knee proprioception was examined in a CKC in healthy athletes. In this sense, the nonathletic population or a population with joint pathology may not be able to satisfactorily perform a single-leg squat, which may influence the outcome of the test. In addition, the open kinetic chain involves a different methodology whose validity and reliability should be tested in future studies.
References


