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Interexaminer, Intraexaminer, and Test–Retest Reliability of Clinical Knee Joint-Position-Sense Measurements Using an Image-Capture Technique

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Context: Knee joint-position sense (JPS) plays a critical role in controlled and stable joint movement. Poor ability to sense position of the knee can therefore increase risk of injury. There is no agreed consensus on JPS measurement techniques and a lack of reliability statistics on methods. ***Objective:*** To identify the most reliable knee JPS measurement technique using image capture. ***Design:*** Interexaminer, intraexaminer, and test–retest reliability of knee JPS measurements. ***Setting:*** Biomechanics laboratory. ***Participants:*** 10 asymptomatic participants. ***Interventions:*** None. ***Main Outcome Measures:*** Relative and absolute error scores of knee JPS in 3 conditions (sitting, prone, active) through 3 ranges of movement (10–30°, 30–60°, 60–90°), into 2 directions (flexion and extension) using both legs (dominant and nondominant) collected during 15 trials and repeated 7 d after the first data collection. ***Results:*** Statistical analysis by intraclass correlations revealed excellent interexaminer reliability between researchers (.98) and intraexaminer reliability within 1 researcher (.96). Test–retest reliability was highest in the sitting condition from a starting angle of 0°, target angle through 60–90° of flexion, using the dominant leg and absolute-error-score variables (ICC = .92). However, it was noted smallest detectable differences were a high percentage of mean values for all measures. ***Conclusions:*** The most reliable JPS measurement for asymptomatic participants has been identified. Practitioners should use this protocol when collecting JPS data during prescreening sessions. However, generalizability of findings to a class/group of clients exhibiting knee pathologies should be done with caution.

Keywords: static proprioception, screening, injury risk

Joint-position sense (JPS) is defined as the static awareness of limb position in space.[1] Poor knee JPS may result in an increased risk of injury.[2] The use of JPS in a clinical setting is used to identify patients that may be more at risk for injury due to poor JPS ability.[3] It is vital that clinicians are confident the data are reliable and results are not masked by measurement error.

Practitioners use a range of equipment to measure JPS, such as an isokinetic dynamometer,[1] however, this is not considered the most viable or reliable equipment to measure knee JPS.[3] Other techniques include image capture and electrogoniometery.[1] A review[3] evaluated the reliability of these knee joint position assessment methods and concluded reliability was highly variable between all techniques. Each method may measure a different aspect of JPS, therefore techniques should not be used interchangeably. However, image-capture techniques appear to have the highest feasibility and most consistent knee JPS results.[3]

In addition to equipment selection, JPS protocols must also be considered. The most common method of JPS is that of the passive position of a target angle, then active reposition to identify knee JPS ability.[4] There are additional variables to consider, such as position of the patient, selected starting and target angles, and direction of movement. Previous studies have yielded conflicting results regarding the most representative JPS protocol, due to the apparent inconsistencies in methodological details. For example, it has been suggested weight-bearing closed-chain tests are more ecologically valid than non-weight-bearing open-chain tests, as they provide maximal afferent information from adjacent joints and structures.[5] However, not all literature produced optimal JPS performance in weight-bearing conditions.[6] Given the total number of variables practitioners must consider when selecting a JPS protocol, it is unsurprising that a comprehensive reliability analysis is absent from the literature. There is a need for a study to consider a large range of dependent variables with the same participants.[3] It is stated "while the importance of proprioception as a clinical outcome measure is becoming well recognised, the best measurement techniques have yet to be

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defined."[4(p128)] There is no previous data on the reliability of JPS measurement using image capture within a range of protocols. Therefore, the aim of the current study is to identify the most reliable, in terms of test–retest, intraexaminer, and interexaminer factors, knee JPS measurement technique using image-capture equipment.

Methods

Using a repeated-measures design, 10 participants (age 30.2 ± 8.87 y, mass 71.5 ± 18.30 kg, height 1.71 ± 11.23 m, Tegner 5.3 ± 2.50) took part in the study. All were free from lower-extremity injury and neurological disease. Participants provided written informed consent and the study was approved by the institutional research ethics committee.

Procedures

Markers were placed on anatomical points: a point on a line following the greater trochanter to the lateral femoral epicondyle, close to the lateral femoral epicondyle, the lateral femoral epicondyle, and the lateral malleolus of both legs. Testing was conducted in 3 conditions: sitting, prone, and active. The sitting and prone conditions took place on an orthopedic plinth with the participant blindfolded. Each leg was passively moved through either 10° to 30°, 30° to 60°, or 60° to 90° of knee flexion (from a starting angle of 0°) or knee extension (from a starting angle of 90°) to a randomized target angle at an angular velocity of approximately 10°/s. The participant was instructed to focus on the position of the knee and actively hold the leg in this position for 5 seconds. A photograph of the leg was taken using a camera (Casio Exilim, EX-FC100, Casio Electronics Co Ltd, London, UK) placed 3 m from the sagittal plane of movement on a fixed-level tripod (Camlink TP-2800, Camlink UK, Leicester, UK). The leg was then passively returned to the starting angle and the participant was instructed to actively move the same leg to the target angle and hold the leg in this position while another photograph was taken.

For the active condition, the participant was positioned supine on a "total trainer" (Model TT2500P, Bayou Fitness, Shreveport, LA; see Figure 1) and blindfolded. The equipment was set at level 1 incline, providing 10% body weight (BW) resistance. Each leg was actively moved to the same random order range of target angles as in the previous conditions, using the sliding seat on the total trainer at approximately 10°/s. The participants were instructed to actively contract into flexion or extension until verbally told to stop by the experimenter and hold that position for 5 seconds while a photograph was taken. The participant then returned the leg to the starting position and was instructed to actively move the same leg to the target angle without verbal cues. Another photograph was taken. The process was repeated 15 times for each target angle on both dominant and nondominant legs in all 3 conditions. The protocol was repeated 7 days later.

Analysis

Knee angles were measured using open access digitizing software (ImageJ, US National Institutes of Health, Bethesda, MD; http://imagej.nih.gov/ij/, 1997–2013). Knee JPS was calculated from the average delta scores between target and reproduction angles across 15 trials,

Figure 1 — The total trainer, model TT2500P (Bayou Fitness, Shreveport, LA).

producing relative (magnitude and direction) error scores (RES) and absolute (magnitude only) error scores (AES).[4]

Statistical analysis used SPSS (Version 19, IBM Corp, Armonk, NY). The Shapiro-Wilk test examined normality of data, which was confirmed. Interexaminer and intraexaminer reliability was confirmed using intraclass correlation coefficients ($ICC_{2,1}$), 95% confidence intervals (CIs), and Cronbach alpha.[7] A randomly selected data set of 30 trials was analyzed by the researcher and then by an independent rehabilitation practitioner. The researcher repeated the analysis of the randomly-selected data set of 30 trials.

Test–retest reliability was assessed using

- ICCs (specifically $ICC_{3,1}$)
- Standard error of the mean (SEM):

$$\mathrm{SD} \times \sqrt{1-\mathrm{ICC}}$$

- 95% CIs: $1.96 \times \mathrm{SEM}$
- Smallest detectable difference (SDD):

$$1.96 \times \sqrt{2 \times \mathrm{SEM}}$$

ICC results greater than .75 were excellent, .40 to .75 were modest, and less than .40 were poor.[8]

Results

The ICC value corresponding to interexaminer reliability was .98 and 95% CIs ranged from .96 to .99. The Cronbach alpha value was .99. The ICC value for intraexaminer reliability was .96 and 95% CIs ranged from .91 to .98. The Cronbach alpha value was .98.

Tables 1, 2, and 3 display all data. ICCs ranged from .03 to .80 in RES data and .65 to .92 in AES data in the sitting condition. In the prone condition, ICCs ranged from .53 to .79 in RES data and .27 to .90 in AES data. For the active condition, ICCs ranged from –.18 to .89 in RES data and –.13 to .82 in AES data. Furthermore, SDDs ranged from 2.26° to 5.48° in RES data and 1.10° to 2.45° in AES data in the sitting condition. In the prone condition, SDDs ranged from 2.37° to 8.71° in RES data and 1.65° to 8.37° in AES data. For the active condition, SDDs ranged from 0.85° to 5.39° in RES data and 1.23° to 3.14° in AES data. The results indicated the test of knee JPS with the highest ICC value is the sitting condition from a starting angle of 0° and target angle through 60° to 90° of flexion, using the dominant leg and calculating AES.

Discussion

This is the first study to comprehensively consider reliability of knee JPS using image-capture data acquisition techniques. The interexaminer reliability results were excellent, indicating it may be appropriate for different practitioners to analyze images collected during JPS testing. The test–retest reliability results indicate a large range of ICCs. The highest ICC score and, hence, excellent reliability measure of knee JPS was tested in a sitting condition, using the dominant leg from a starting angle of 0° and moving into flexion through 60° to 90° of movement, calculating AES (ICC = .92). Practitioners should adopt the techniques with excellent levels of test–retest reliability when using JPS to screen asymptomatic populations.

The sitting condition provided the most reliable position for JPS data collection; 11 out of 24 JPS measurements had excellent ICC scores. However, the active condition presented the poorest level of test–retest reliability, with only 2 out of 24 measures producing excellent test–retest reliability results. It has been suggested active positioning and active repositioning weight-bearing JPS measures may illicit maximum JPS performance due to an increase of mechanoreceptor activity across the kinetic chain.[9] However, authors have criticized weight-bearing conditions, as they are not true representations of isolated knee JPS.[10] Therefore, we aimed to create a semi-weight-bearing condition in which the participant was under 10% body weight to increase ecological validity but still isolate knee joint proprioceptors by minimizing movement in adjacent joints. However, the motor control needed to complete this procedure may require greater learning time before data collection begins. Longer practice sessions and also individualized loading rates may be necessary to ensure participants are accustomed to this JPS protocol.

Results suggest AES were more consistent than RES in all 3 conditions. Therefore, practitioners should use AES in asymptomatic JPS testing. This is perhaps unsurprising due to the additional dimension provided by RES (direction of error), as consistency is harder to attain. There is little evidence to suggest direction in which the error occurs will influence an increased injury risk. For example, we do not know if overestimating the position of a limb is any worse than underestimating. It has also been suggested average RES mask JPS ability, as the average of repeated trials can incorrectly reduce the error score.[11] Therefore, it is appropriate to use magnitude of error (AES) only in JPS testing.

An important finding in this study was the high SDD scores within all JPS measurements. The most reliable measurement had a SDD value that was 34% of the AES, and some SDDs were more than the mean scores. To our knowledge, SDD scores for JPS testing using image-capture techniques have not been previously reported. Previous research[12] reported standard error of measurement values of up to 50% of the mean knee JPS error score, however testing was completed using a perturbation protocol, not reproduction of an angle as in the current study. Future studies need to confirm SDD values so practitioners can be confident athlete progression in screening programs is not masked by measurement error.

A limitation of this study is the sample did not include symptomatic patients. Therefore, results should not be generalized to knee pathology groups. Future research should collect normative JPS data from both uninjured and injured populations. However, practitioners should use the results to review reliability of

Table 1 Test Results for the Sitting Condition

	Session 1		Session 2						
	Mean	SD	Mean	SD	ICC	95% CI		SEM	SDD
Relative Error Scores									
Dominant leg									
extension 10–30°	2.0	1.20	2.4	1.18	.54	–.08	.86	0.82	2.26
extension 30–60°	2.0	1.83	1.5	2.25	.78	.36	.94	0.96	2.65
extension 60–90°	–0.1	1.50	–0.3	2.06	.80	.38	.95	0.83	2.31
flexion 10–30°	–0.8	1.88	–1.2	1.27	.03	–.65	.63	1.58	4.38
flexion 30–60°	–1.0	1.83	–2.0	1.91	.67	.09	.91	0.94	2.59
flexion 60–90°	–1.7	1.53	–0.8	2.20	.40	–.20	.80	1.45	4.02
Nondominant leg									
extension 10–30°	2.4	1.77	2.1	2.24	.75	.27	.93	1.04	2.87
extension 30–60°	1.9	1.64	1.2	2.09	.66	.15	.90	1.05	2.91
extension 60–90°	0	1.46	0	1.72	.51	–.18	.86	1.14	3.17
flexion 10–30°	–0.2	1.83	–0.8	1.57	.62	.08	.89	1.01	2.81
flexion 30–60°	–2.1	3.11	–2.1	1.79	.58	–.07	.88	1.68	4.66
flexion 60–90°	0.2	2.72	–0.9	2.00	.30	–.31	.76	1.98	5.48
Absolute Error Scores									
Dominant leg									
extension 10–30°	2.5	1.09	2.5	1.06	.76	.26	.93	0.55	1.53
extension 30–60°	2.6	1.49	2.4	1.63	.86	.54	.96	0.60	1.67
extension 60–90°	1.7	0.89	2.1	0.98	.70	.20	.91	0.49	1.35
flexion 10–30°	2.3	1.05	2.4	0.97	.79	.37	.94	0.47	1.31
flexion 30–60°	3.1	1.27	3.3	1.00	.86	.54	.96	0.44	1.23
flexion 60–90°	3.2	1.40	3.3	1.35	.92	.72	.98	0.40	1.10
Nondominant leg									
extension 10–30°	2.9	1.45	2.8	1.84	.73	.22	.93	0.88	2.45
extension 30–60°	2.4	1.27	2.4	1.34	.87	.55	.97	0.50	1.38
extension 60–90°	1.9	0.82	2.0	1.27	.76	.31	.76	0.53	1.47
flexion 10–30°	2.2	0.64	2.2	1.04	.65	.05	.90	0.52	1.45
flexion 30–60°	4.0	1.80	3.6	1.54	.79	.38	.94	0.75	2.09
flexion 60–90°	3.8	1.89	3.5	2.08	.84	.50	.96	0.80	2.23

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; SDD, smallest detectable difference.

their chosen knee JPS measurement technique. It is suggested that a method that seats the patient, uses a starting position of 0°, and goes through flexion to a target angle between 60° to 90° will yield the highest test–retest reliability data. It is also recommended AES be used rather than RES to collect consistent data. However, practitioners should consider the high SDD figure if using measurements of knee JPS in a longitudinal screening. It may be that measurement error masks true improvement of JPS acuity. The results of this study indicate that the type of JPS protocol using image-capture techniques that provide excellent reliability is in a sitting position and uses passive then active knee positioning to a target near the end range of movement at approximately 10°/s.

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Table 2 Test Results for the Prone Condition

	Session 1		Session 2						
	Mean	SD	Mean	SD	ICC	95% CI		SEM	SDD
Relative Error Scores									
Dominant leg									
extension 10–30°	2.0	2.16	2.5	2.96	.75	.26	.93	1.31	3.62
extension 30–60°	0.9	3.19	1.4	2.07	.54	–.09	.86	1.82	5.05
extension 60–90°	0.4	1.55	0.6	1.69	.53	–.10	.86	1.11	3.08
flexion 10–30°	–0.7	1.34	–1.2	1.34	.67	.12	.91	0.77	2.13
flexion 30–60°	–2.6	3.74	–2.3	3.03	.69	.15	.91	1.90	5.28
flexion 60–90°	–1.6	1.74	–2.3	1.67	.68	.12	.91	0.97	2.69
Nondominant leg									
extension 10–30°	2.1	2.7	1.3	2.45	.74	.24	.93	1.33	3.68
extension 30–60°	1.4	2.61	0.6	2.04	.61	.02	.89	1.45	4.03
extension 60–90°	–0.2	1.51	–0.4	1.94	.74	.24	.93	0.89	2.48
flexion 10–30°	–1.5	1.50	–2.0	2.15	.79	.35	.94	0.85	2.37
flexion 30–60°	–2.4	4.20	–1.7	5.61	.60	–.01	.88	3.14	8.71
flexion 60–90°	–2.1	3.08	–1.8	3.03	.58	–.04	.88	1.98	5.50
Absolute Error Scores									
Dominant leg									
extension 10–30°	3.0	1.54	4.1	1.86	.75	.27	.93	0.86	2.37
extension 30–60°	3.4	2.10	3.5	1.56	.74	.26	.93	0.94	2.60
extension 60–90°	2.0	0.83	2.0	0.86	.44	–.23	.82	0.64	1.76
flexion 10–30°	1.9	0.84	2.1	1.71	.27	–.40	.75	1.15	3.20
flexion 30–60°	5.0	2.35	4.5	2.03	.87	.56	.97	0.79	2.19
flexion 60–90°	3.7	1.53	3.8	1.38	.61	.01	.89	0.91	2.53
Nondominant leg									
extension 10–30°	4.0	1.85	3.0	1.57	.67	.11	.91	0.99	2.75
extension 30–60°	3.9	1.88	3.2	1.65	.82	.42	.95	0.76	2.10
extension 60–90°	2.2	1.39	2.3	1.37	.71	.19	.92	0.75	2.07
flexion 10–30°	2.7	1.64	2.9	1.91	.85	.51	.96	0.69	1.90
flexion 30–60°	5.1	2.52	6.0	4.23	.25	–.42	.74	3.02	8.37
flexion 60–90°	5.2	2.02	4.7	1.77	.90	.66	.98	0.59	1.65

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; SDD, smallest detectable difference.

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Table 3 Test Results for the Active Condition

	Session 1		Session 2						
	Mean	SD	Mean	SD	ICC	95% CI		SEM	SDD
Relative Error Scores									
Dominant leg									
extension 10–30°	0.8	0.59	0.5	1.16	–.18	–.71	.47	1.00	2.78
extension 30–60°	1.5	1.59	1.1	2.13	.49	–.16	.84	1.34	3.71
extension 60–90°	0.2	2.30	–0.1	2.16	.24	–.42	.74	1.94	5.39
flexion 10–30°	–1.4	1.97	–0.8	1.57	.33	–.34	.78	1.46	4.04
flexion 30–60°	–1.4	1.60	–1.3	1.77	.36	–.31	.79	1.35	3.74
flexion 60–90°	–0.7	0.92	0.1	0.89	.14	–.50	.69	0.84	2.32
Nondominant leg									
extension 10–30°	0.9	1.03	0.4	0.80	.89	.62	.97	0.30	0.85
extension 30–60°	1.1	1.67	1.8	2.11	.26	–.40	.75	1.64	4.54
extension 60–90°	0.6	1.62	0.4	1.19	.03	–.59	.62	1.40	3.89
flexion 10–30°	–1.9	1.51	–1.6	1.84	.37	–.30	.80	1.33	0.85
flexion 30–60°	–1.5	1.29	–1.2	1.51	.37	–.30	.80	1.11	4.54
flexion 60–90°	–0.8	0.83	–0.5	1.30	.51	–.13	.85	0.76	3.89
Absolute Error Scores									
Dominant leg									
extension 10–30°	1.8	0.52	1.6	0.49	–.13	–.68	.51	0.54	1.49
extension 30–60°	3.0	1.49	3.0	1.02	.41	–.25	.81	0.98	2.72
extension 60–90°	3.8	1.01	3.3	0.89	.06	–.56	.64	0.92	2.56
flexion 10–30°	3.2	1.27	2.3	0.84	.42	–.25	.81	0.82	2.28
flexion 30–60°	2.5	1.01	2.6	1.24	.00	–.60	.60	1.13	3.14
flexion 60–90°	1.7	0.58	1.8	0.62	–.20	–.72	.46	0.66	1.83
Nondominant leg									
extension 10–30°	1.7	0.79	1.5	0.72	.66	.09	.90	0.44	1.23
extension 30–60°	2.9	1.23	3.0	1.00	.67	.11	.91	0.64	1.78
extension 60–90°	3.5	1.15	3.0	0.88	.54	–.09	.86	0.69	1.92
flexion 10–30°	2.8	1.05	3.0	1.15	.82	.42	.95	0.47	1.31
flexion 30–60°	2.7	0.52	3.0	1.10	.22	–.44	.72	0.76	2.11
flexion 60–90°	1.7	0.51	1.9	0.84	.17	–.48	.70	0.63	1.76

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; SDD, smallest detectable difference.

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