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Systematic review

The effects of ACL injury on knee proprioception: a meta-analysis

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Abstract

Background It is suggested the anterior cruciate ligament (ACL) plays a significant role in knee proprioception, however, the effect of ACL injury on knee proprioception is unclear. Studies utilising the two most common measurement techniques, joint position sense and threshold to detect passive motion, have provided evidence both for and against a proprioceptive deficient following ACL injury.
Objective The objective of the study was to undertake a meta-analysis investigating the effects of ACL injury, treated conservatively or by reconstruction, on proprioception of the knee, measured using joint position sense and/or threshold to detect passive movement techniques.
Data sources Seven databases were searched from their inception to September 2013 using the subject headings ‘anterior cruciate ligament, proprioception, postural sway, joint position sense, balance, equilibrium or posture’ to identify relevant studies.
Eligibility criteria PRISMA guidelines were followed as much as possible. Studies that investigated the effect of ACL injury on either knee joint kinaesthesia or position sense were included in this review.
Data extraction and synthesis Two reviewers independently extracted data using a standardised assessment form. Comparisons were made using a fixed effect model with an inverse variance method using Review Manager Software (V5.1).
Results Patients with ACL injury have poorer proprioception than people without such injuries (SMD = 0.35°; P = 0.001 and SMD = 0.38°; P = 0.03) when measured using joint position sense and threshold to detect passive motion techniques respectively. Patients had poorer proprioception in the injured than uninjured leg (SMD = 0.52°; P < 0.001) and the proprioception of people whose ACL was repaired was better than those whose ligament was left unrepaired (SMD = −0.62°; P < 0.001).
Limitations Heterogeneity of measurement techniques and lack of psychometric details.
Conclusion ACL injuries may cause knee proprioception deficits compared to uninjured knees and control groups. Although differences were statistically significant, the clinical significance of findings can be questioned. Clinical practitioners using joint position sense or threshold to detect passive motion techniques need to consider the reliability and validity of data provided.

Keywords: Anterior cruciate ligament (ACL); Knee proprioception; Joint position sense; Threshold to detect passive motion

Introduction

The anterior cruciate ligament (ACL) controls knee movement in six directions; three rotations and three translations and thus is critical for stable lower extremity movement [1]. The ligament’s main role in knee joint stability is to prevent excessive anterior translation (forward movement) of the tibia in relation to the femur and help direct the ‘screw-home’ mechanism which occurs during femoral and tibial rotation into full knee extension [2]. The ACL is also thought to play a significant role in knee proprioception [2]. Proprioception is a component of the somatosensory system which plays an important role in normal human performance [2–4]. Its main aim is to provide afferent information on the position and movements of a joint. In the ACL, 1% of its total area [5] is made up of three types of proprioceptive receptors; pacinian capsules, ruffini nerve endings and Golgi tendon organs [6], each has a specific role. The pacinian capsules adapt rapidly to low degrees of joint stress, are sensitive to rapid changes in accelerations and classified as dynamic receptors [7]. Whereas, ruffini nerve endings and Golgi

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tendon organs are slow adapting with a high threshold to stress and are believed to provide information on the position of the knee joint [7].

Following ACL injury, secondary problems such as osteoarthritis are common [8,9]. It has long been thought that ACL injuries can be detrimental to proprioception of the knee and this may lead to abnormal movement patterns which are a mechanism for further injuries and long-term secondary problems [9]. However, research in to the effects of ACL injury on knee proprioception has yielded conflicting results [10]. Therefore, we undertook a systematic review with meta-analysis of pooled data to investigate the effects of ACL injury, whether treated conservatively or by reconstruction, on proprioception of the knee. The two most common proprioception measurement techniques [11]; joint kinaesthesia (threshold to detect passive motion) and joint position sense were considered. Joint position sense (JPS) involves passively moving a joint to a target angle, then the patient actively reproduces this angle [11]. Joint kinaesthesia traditionally measures the passive movement of a joint before movement is detected, called a threshold to detect passive motion (TTDPM). This involves asking the patient to indicate the first instance they perceive motion of the joint [11].

Methods

Protocol

No review protocol exists for meta-analysis of descriptive data, thus the PRISMA guidelines on meta-analysis were followed as far as was practicable for the type of data concerned (http://www.prisma-statement.org/statement.htm).

Data sources

The following electronic databases were accessed from their inception to September 2013: AMED, CINAHL, PubMed, Medline, PeDro, Sports Discus and the Cochrane Library. Primary journals in the field: *The Knee*, *American Journal of Sports Medicine* and the *British Journal of Sports Medicine* were also manually searched, as were the reference lists of all selected studies to ensure the search was comprehensive. Key terms were: anterior cruciate ligament, proprioception, postural sway, joint position sense, balance, equilibrium or posture using the Boolean operator 'OR'. Limits of the search were: English language studies (none of the researchers spoke foreign languages); human studies, adult participants and peer reviewed published full access articles. Unpublished literature and trial registries of current studies were not included in the search.

Study selection

Studies were eligible for inclusion if they (1) investigated proprioception of the knee following ACL injury (conservatively managed or reconstructed) (2) recruited adults (over 16 years) with an ACL injury, including participants with ACL injuries combined with meniscus and/or collateral ligament damage and (3) included a primary outcome measure of knee proprioception measured by mean angle of error in degrees. The primary outcome measure could take two forms; studies measuring knee kinaesthesia used the TTDPM method where the mean angle of error was defined as *the difference in degrees from initiation of motion and the participant's perception of motion*, studies measuring JPS utilising an index angle matching method in which the mean angle of error was defined *as the difference in degrees between the target angle and the angle reproduced by the participant*. The type of control measure (the participant's contra-lateral leg or the leg of an external matched control) was also collected along with the corresponding data.

Study selection

The search results were merged using reference management software (Endnote X6) and duplicates removed. The titles and abstracts were screened and articles which obviously did not meet the selection criteria removed. The full text of the remaining studies was then checked against the selection criteria. Studies with outcome data that did not meet our criteria were excluded at this stage. The selection of appropriate articles was agreed through discussion between two authors (NR and LH) and a third party was available to arbitrate if necessary.

Quality assessment

The methodological quality of the studies that met the selection criteria was appraised by two of the research team independently to identify studies that had a low risk of bias. There is no established tool to assess the methodological quality of descriptive studies, therefore we amended a quality assessment tool previously developed and used by the authors [12]. This tool considered eight potential sources of bias; confirmation of ACL deficiency, representation of population, representation of sample, homogeneity of participants, sample size, study design, assessor blinding/bias, statistical analysis (available from NR). Summating the scores for items on the assessment gave a maximum score of 88. The methodological quality scores were arbitrarily, but logically, grouped as 'poor' (a score of less than 29/88), 'moderate' (a score of 30 to 58/88) or 'good' (a score of 59+/88). Studies of moderate to good quality (that is, 30 to 88/88) were selected as providing data of sufficient low risk of bias to enter in to the meta-analysis.

Data extraction and analysis

Studies that met the eligibility criteria and were of sufficient quality were included in the meta-analysis. The following data were extracted by one reviewer: the number of participants, mean angle of error measured using TTDPM and/or JPS methods and accompanying standard deviation values to include in the meta-analysis and the following comparisons were made.

For joint position sense data:

- ACL injured leg vs contra-lateral leg control.
- ACL injured leg vs external control leg.
- Patients with a reconstructed ACL vs patients with a deficient ACL.

For data on the threshold to detect passive motion:

- ACL injured leg vs contra-lateral leg control.
- ACL injured leg vs external control leg.

The comparisons were made using a fixed effect model with an inverse variance method and presented as forest plots using Review Manager Software (version 5.1). Standard mean difference between groups measured the effect size. Heterogeneity between comparable trials was tested using the Chi-squared test (level of significance = $P < 0.10$ [13]). Heterogeneity was further tested using I^2 percentages to consider the impact potential heterogeneity would have on the meta-analysis.

Results

Study selection

The initial search strategy yielded 3076 articles, 2737 of which did not relate to the research question. Screening of the titles and abstracts of the remaining 339 articles revealed that 290 did not fully meet the inclusion criteria; the main exclusion factor was the use of techniques to measure proprioception other than TTDPM and/or JPS. A further 43 articles were excluded as they provided 'poor' quality data with a high risk of bias and/or had missing or inadequate outcome data. The main reasons for missing data were that median data were presented instead of mean data [14–16] or measures of the variability of the data (standard deviation) were missing [17]. This left six studies which were selected for inclusion in the meta-analysis. The flow chart detailing the selection process is shown in Fig. S1.

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2013.11.002.

Study characteristics

Six studies involving 191 ACL injured patients were selected (Table 1). Sixty-one participants were ACL deficient and 130 had had an ACL reconstruction. There were 82 healthy controls from five studies [18–22]. The participants' contralateral leg was used as the control in four studies [19,20,22,23]. Confirmation of ACL injury was provided by arthroscopy or MRI in five studies [18–22]. Only Barrack *et al.* [18] stated a Lachman's test and Pivot Shift test had been used in addition to the arthroscopy. Mir *et al.* [22] did not report how the ACL injury had been confirmed. An autograft using the patella tendon was the most common surgery used to reconstruct the ACL [19–21] but, none of the included studies assessed laxity before and after surgery. Angoules *et al.* [23] was the only study to use the same surgeon for every reconstruction to minimise surgical skill as a confounder. Mir *et al.* [22] and Anguoles *et al.* [23] stated the type and number of surgical complications. None of the patients in the included studies had a previous ACL injury to the injured knee. One [20] stated patients with an ACL injury had concurrent damage to other structures in the knee during the ACL injury. A rehabilitation programme had been completed by patients in four studies [18,20,22,23].

All six selected studies were of moderate quality (Table 2). Most recruited a convenience sample [18,20,21,23]. Five studies matched the injured patients to controls by age [18–22] and four matched by gender [19–22]. None justified the sample size with a power calculation or the minimal detectable difference of the measurement tool. Two studies [18,23] blinded assessors to the type of participant.

Generally the statistical analysis in the selected studies did not provide appropriate detail (Table 2). For example, only two [22,23] reported whether the data was normally distributed and hence justified the use of parametric statistics. Most used 'home-made' measurement devices prepared specifically for the study but the reliability and sensitivity were infrequently reported. Indeed only two studies reported reliability statistics. Mir *et al.* [22] stated test–retest reliability using a correlation coefficient (0.99); however this was from a 'previous study' which was not referenced. Only one study [23] comprehensively reported the accuracy of their data collection methods, reporting the standard error of measurement (SEM), coefficient of variation (CV), smallest detectable differences (SDD) and intraclass correlation coefficients (ICCs) for each of their seven measures of knee proprioception.

During analysis, data from the external control subjects and patients with an ACL injury in some studies were used in several comparisons, for example if a control group was compared to patients with an ACL deficiency and a separate group of patients with an ACL reconstruction or if the same patients with an ACL injury were measured from two different starting positions [19,22]. Unfortunately the RevMan software did not allow us to stipulate the actual control and patient number values. However this number is clearly noted as a footnote to the affected figures and should be considered when analysing the comparison data.

Synthesis of results

Effects of ACL injury on JPS

Five studies compared the injured leg to the participant's un-injured leg ($n = 170$) as the control [19–23]. The pooled standard mean difference of mean angle of error was 0.52° (95% CI: 0.41 to 0.63; $P < 0.001$; $I^2 = 63\%$) indicating that the

Table 1
Characteristics of the articles included in the meta-analysis investigating the effects of ACL injuries on proprioception deficits.

Study	Participants	Age, mean (SD) and gender of patients with an ACL injury	Age, mean (SD) and gender controls	Equipment	Knee ROM	Method of measuring proprioception
Barrack *et al.* 2003 [17]	11 ACL-D 10 Controls	25 (NP) years 9 men, 2 women	25 (NP) years NP	Purpose built proprioception device	From a starting angle of 40° at an angular velocity of 0.5°/second	TTDPM – Mean angle of error in degrees from 10 trials randomly assigned to flexion or extension
Fischer-Rasmussen and Jensen 1989 [18]	20 ACL-D 18 ACL-R 20 Controls	ACL-D 27 (5) years 11 men, 9 women ACL-R 27 (5) years 9 men, 9 women	27 (4) years 11 men, 9 women (plus uninjured knees of patients)	Purpose built proprioception device	From a starting angle of 25° flexion to 15°, 20°, 25°, 30°, 35° or 60° flexion to full extension	JPS (passive positioning then active repositioning task) – mean angle of error in degrees from 20 trials randomly assigned to target angles
Fremerey *et al.* 2000 [19]	10 ACL-D 20 ACL-R 20 Controls	ACL-D 22.7 (3.2) years 7 men, 3 women ACL-R 28.4 (4.4) years 13 men, 7 women	26.4 (4.8) years 13 men, 7 women (plus uninjured knees of patients)	Purpose built proprioception device	From a starting angle of 0° to random target angles in 3 intervals; extension 0° to 20°, mid range 40 to 60° and flexion 80° to 100°. All passive motion was set at 0.5°/second	JPS (passive positioning then passive repositioning task) – mean angle of error in degrees from trials randomly assigned from the extension range, mid-range and flexion range
Ozenci *et al.* 2000 [20]	20 ACL-R (auto-graft) 20 ACL-R (allo-graft) 20 ACL-D 20 Controls	ACL-D 29.0 (5.4) years 18 men, 2 women ACL-R Auto – 29.5 (6.9) years 20 men Allo – 30.2 (4.6) years 16 men, 4 women	27.6 (2.6) years 17 men, 3 women (plus uninjured knees of patients)	Cybex dynamometer	JPS – from full extension to flexion (no further details given). TTDPM – from 15° flexion to either flexion or extension at an angular velocity of 1°/second	JPS (passive positioning then active repositioning task) – mean angle of error in degrees from 10 trials TTDPM – mean angle of error in degrees from 10 trials randomly assigned to either flexion or extension
Anguoles *et al.* 2007 [21]	20 ACL-R (hamstring) 20 ACL-R (patella tendon)	16 men, 4 women 18 men, 2 women	N/A	Con-Trex dynamometer	JPS – from full extension (0°) to flexion angles of 15°, 45° and 75°	JPS (passive positioning then active repositioning task) – mean angle of error in degrees from three trials
Mir *et al.* 2008 [22]	12 ACL-R 12 Controls	23 (4.75) years 12 men	22 (4.35) years 12 men (plus uninjured knees of patients)	Digital camera, markers	From a starting angle of 60° flexion to 30° flexion and from a starting angle of 0° flexion to 30° flexion. All motion was at an angular velocity of 10°/second	JPS (active positioning then active repositioning task) – mean error angle in degrees over 3 trials

ACL-D, patients with an ACL deficiency; ACL-R, patients with a reconstructed ACL; TTDPM, threshold to detect passive motion; JPS, joint position sense; NP, not provided; NA, not applicable.

Table 2
Methodological quality score for each of the articles included in the meta-analysis.

Scoring section (maximum score)	Barrack *et al.* 2003 [17]	Fischer-Rasmussen and Jensen 1989 [18]	Fremerey *et al.* 2000 [19]	Ozenci *et al.* 2000 [20]	Angoules *et al.* 2007 [21]	Mir *et al.* 2008 [22]
Confirmation of ACL deficiency (3)	3	1	3	1	3	0
Representation of population (19)	9	8	10	14	13	10
Representation of sample (5)	3	0	3	3	3	0
Homogeneity of participants (13)	5	11	11	7	4	11
Sample size (25)	3	9	7	9	6	4
Study design (4)	1	1	1	1	4	1
Assessor blinding/bias (5)	5	0	0	0	5	0
Statistical analysis (14)	1	1	4	3	14	9
Total (88)	30	31	39	38	52	35
Quality level	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

Notes: Studies were grouped in to poor (a score of less than 29/88), moderate (a score of 30 to 58/88) or good (a score of 59+/88) studies based on their final methodological quality score.

un-injured leg had a lower mean angle of error (better joint position sense) compared to the injured leg (Fig. 1). Four studies compared the injured legs ($n = 140$) to an external control ($n = 104$) [18–21,23]. The pooled standard mean difference of the mean angle of error was 0.35° (95% CI: 0.14 to 0.55; $P = 0.001$; $I^2 = 78\%$) indicating that the control group had better joint position sense than patients with an ACL injury (Fig. 2). Three studies compared ACL reconstructed ($n = 116$) and ACL deficient legs ($n = 100$) [19,21,23]. The pooled standard mean difference of the mean angle error (°) was −0.62° (95% CI: −0.76 to −0.48; $P < 0.001$; $I^2 = 42\%$) indicating that ACL reconstructed patients had better joint position sense (Fig. 3).

Effects of ACL injury on TTDPM

Two studies compared the injured leg ($n = 71$) with the un-injured ($n = 71$) leg in patients with an ACL injury [18,21]. The pooled standard mean difference of mean angle error was 0.02° (95% CI: −0.32 to 0.35; $P = 0.91$; $I^2 = 61\%$) indicating no difference. These studies also compared ACL injured legs ($n = 71$) to external control legs ($n = 30$) which showed a difference in mean angle error of 0.38° (95% CI: 0.04 to 0.72; $P = 0.03$; $I^2 = 73\%$) indicating that the external control group had a better TTDPM than the injured leg group (Fig. 4).

Joint position sense studies and threshold to detect passive motion studies both indicated differences between injured leg and external controls. However, only data collected using the JPS method detected proprioception differences between injured and non-injured legs.

Discussion

This review examined the effect of ACL injury on proprioception, in terms of joint position sense and threshold to detect passive motion. The results cautiously indicate significantly poorer proprioception, in terms of JPS acuity and threshold to detection of movement, in patients with ACL injury compared to their uninjured leg and to people without such injuries. The proprioception of people whose ACL was reconstructed was statistically significantly better than those whose ligament is left unreconstructed (ACL-deficient). These differences are seen whether the comparator group was the patient's uninjured leg, or a control group of people with no injuries; suggesting that either can be used as a control group in future research. The differences in proprioception were seen most clearly when joint position sense was measured but was less consistent when threshold to detect passive motion measurement techniques were used. This indicates that proprioception acuity (measured by joint position sense) may be a greater problem for patients with ACL injuries than TTDMP and should be the priority during proprioceptive rehabilitation.

It is thought that mechanoreceptors in the ACL provide afferent information on the relative position and movement of the knee joint [3,7,24,25] and that ACL injury impairs proprioception by disturbing transmission of this sensory information [5]. Our results give some support to this belief. However, although statistically significant, the differences found were very small (<1°) which is unlikely to be clinically or functionally important. A proprioceptive deficit of at least 5° is thought to be the minimum to indicate a clinically

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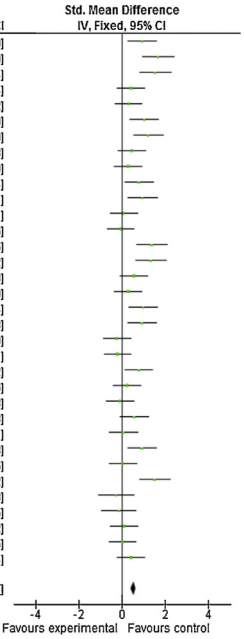
Study or Subgroup	ACL Mean	ACL SD	ACL Total	Contra Lateral Leg Mean	Contra Lateral Leg SD	Contra Lateral Leg Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Angolues (u)	4.13	1.51	20	2.63	1.64	20	2.9%	0.93 [0.28, 1.59]
Angoules (a)	3.98	1.38	20	1.98	0.92	20	2.4%	1.67 [0.94, 2.40]
Angoules (b)	3.9	1.48	20	1.98	0.92	20	2.5%	1.53 [0.81, 2.24]
Angoules (c)	2.43	1.19	20	1.98	0.92	20	3.2%	0.41 [-0.21, 1.04]
Angoules (d)	2.27	0.97	20	1.98	0.92	20	3.2%	0.30 [-0.32, 0.92]
Angoules (e)	3.95	2.2	20	2.2	0.85	20	2.8%	1.03 [0.36, 1.69]
Angoules (f)	3.72	1.5	20	2.2	0.85	20	2.7%	1.22 [0.54, 1.90]
Angoules (g)	2.73	1.4	20	2.2	0.85	20	3.2%	0.45 [-0.18, 1.08]
Angoules (h)	2.47	1.05	20	2.2	0.85	20	3.2%	0.28 [-0.35, 0.90]
Angoules (i)	3.8	1.96	20	2.52	1.1	20	3.0%	0.79 [0.14, 1.44]
Angoules (j)	3.65	1.23	20	2.52	1.1	20	2.9%	0.95 [0.29, 1.61]
Angoules (k)	2.63	1.37	20	2.52	1.1	20	3.3%	0.09 [-0.53, 0.71]
Angoules (l)	2.45	1.2	20	2.52	1.1	20	3.3%	-0.06 [-0.68, 0.56]
Angoules (m)	5.32	2.77	20	2.5	0.7	20	2.6%	1.37 [0.67, 2.06]
Angoules (n)	4.36	1.81	20	2.5	0.7	20	2.6%	1.33 [0.64, 2.02]
Angoules (o)	3.18	1.58	20	2.5	0.7	20	3.1%	0.55 [-0.09, 1.18]
Angoules (p)	2.78	1.23	20	2.5	0.7	20	3.2%	0.27 [-0.35, 0.90]
Angoules (q)	4.73	2.51	20	2.83	0.98	20	2.9%	0.98 [0.32, 1.64]
Angoules (r)	3.97	1.41	20	2.83	0.98	20	2.9%	0.92 [0.27, 1.58]
Angoules (s)	2.62	0.79	20	2.83	0.99	20	3.2%	-0.23 [-0.85, 0.39]
Angoules (t)	2.63	0.86	20	2.83	0.98	20	3.2%	-0.21 [-0.83, 0.41]
Angoules (v)	3.85	1.42	20	2.63	1.64	20	3.0%	0.78 [0.13, 1.42]
Angoules (w)	2.98	1.23	20	2.63	1.64	20	3.2%	0.24 [-0.39, 0.86]
Angoules (x)	2.5	1	20	2.63	1.64	20	3.3%	-0.09 [-0.71, 0.53]
Fischer Rasmussen (a)	3.5	1.37	18	2.7	1.42	18	2.8%	0.56 [-0.11, 1.23]
Fischer Rasmussen (b)	3.1	1.54	18	3.02	0.93	18	2.9%	0.06 [-0.59, 0.71]
Fischer Rasmussen (c)	4.06	1.21	20	3.1	0.79	20	2.9%	0.92 [0.27, 1.58]
Fischer Rasmussen (d)	3.14	1.03	20	3.1	0.9	20	3.3%	0.04 [-0.58, 0.66]
Fremery (a)	6.7	2.2	20	3.6	1.8	20	2.5%	1.51 [0.80, 2.22]
Mir (a)	3.65	2.39	12	4.28	2.08	12	1.9%	-0.27 [-1.08, 0.53]
Mir (b)	3.77	2.04	12	4.13	2.51	12	2.0%	-0.15 [-0.95, 0.65]
Ozenci (a)	4.75	2.15	20	4.54	1.98	20	3.3%	0.10 [-0.52, 0.72]
Ozenci (b)	4.58	1.87	20	4.52	1.55	20	3.3%	0.03 [-0.59, 0.65]
Ozenci (c)	5.3	1.74	20	4.64	1.37	20	3.2%	0.41 [-0.21, 1.04]
Total (95% CI)			**660**			**660**	**100.0%**	**0.52 [0.41, 0.63]**

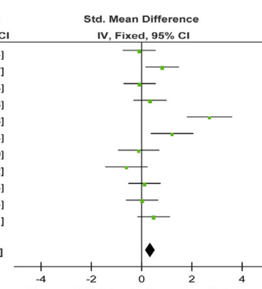
Heterogeneity: Chi² = 88.54, df = 33 (P < 0.00001); I² = 63%
Test for overall effect: Z = 9.15 (P < 0.00001)



2

Study or Subgroup	ACL Mean	ACL SD	ACL Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Fischer Rasmussen (b)	3.1	1.54	18	3.22	0.96	20	10.5%	-0.09 [-0.73, 0.54]
Fischer Rasmussen (c)	4.06	1.21	20	3.06	1.18	20	10.2%	0.82 [0.17, 1.47]
Fischer Rasmussen (d)	3.14	1.03	20	3.22	0.96	20	11.1%	-0.08 [-0.70, 0.54]
Fischer-Rasmussen (a)	3.5	1.37	18	3.06	1.18	20	10.4%	0.34 [-0.30, 0.98]
Fremery (a)	6.7	2.2	20	2.2	0.7	20	5.5%	2.70 [1.82, 3.58]
Fremery (b)	3.6	1.7	10	2.2	0.7	20	6.2%	1.21 [0.39, 2.04]
Mir (a)	3.65	2.39	12	3.9	1.77	12	6.7%	-0.11 [-0.92, 0.69]
Mir (b)	3.77	2.04	12	5.49	3.31	12	6.3%	-0.60 [-1.43, 0.22]
Ozenci (a)	4.75	2.15	20	4.54	1.34	20	11.1%	0.11 [-0.51, 0.74]
Ozenci (b)	4.58	1.87	20	4.54	1.34	20	11.1%	0.02 [-0.60, 0.64]
Ozenci (c)	5.3	1.74	20	4.54	1.34	20	10.8%	0.48 [-0.15, 1.11]
Total (95% CI)			**190**			**204**	**100.0%**	**0.35 [0.14, 0.55]**

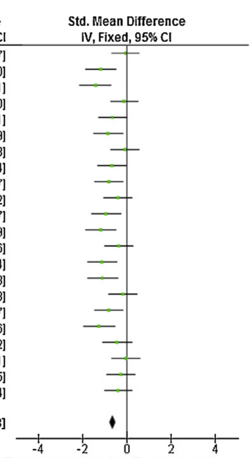
Heterogeneity: Chi² = 45.63, df = 10 (P < 0.00001); I² = 78%
Test for overall effect: Z = 3.28 (P = 0.001)



3

Study or Subgroup	ACL-R Mean	ACL-R SD	ACL-R Total	ACL-D Mean	ACL-D SD	ACL-D Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Angoules (b)	3.9	1.48	20	3.98	1.38	20	4.9%	-0.05 [-0.67, 0.57]
Angoules (c)	2.43	1.19	20	3.98	1.38	20	4.1%	-1.18 [-1.86, -0.50]
Angoules (d)	2.27	0.97	20	3.98	1.38	20	3.9%	-1.41 [-2.10, -0.71]
Angoules (f)	3.72	1.5	20	3.95	2.2	20	4.9%	-0.12 [-0.74, 0.50]
Angoules (g)	2.73	1.4	20	3.95	2.2	20	4.7%	-0.65 [-1.29, -0.01]
Angoules (h)	2.47	1.05	20	3.95	2.2	20	4.5%	-0.84 [-1.49, -0.19]
Angoules (j)	3.65	1.23	20	3.8	1.96	20	4.9%	-0.09 [-0.71, 0.53]
Angoules (k)	2.63	1.37	20	3.8	1.96	20	4.6%	-0.68 [-1.32, -0.04]
Angoules (l)	2.45	1.2	20	3.8	1.96	20	4.5%	-0.81 [-1.46, -0.17]
Angoules (n)	4.36	1.81	20	5.32	2.77	20	4.8%	-0.40 [-1.03, 0.22]
Angoules (o)	3.18	1.58	20	5.32	2.77	20	4.4%	-0.93 [-1.59, -0.27]
Angoules (p)	2.78	1.23	20	5.32	2.77	20	4.1%	-1.16 [-1.84, -0.49]
Angoules (r)	3.97	1.41	20	4.73	2.51	20	4.8%	-0.37 [-0.99, 0.26]
Angoules (s)	2.62	0.79	20	4.73	2.51	20	4.2%	-1.11 [-1.78, -0.44]
Angoules (t)	2.63	0.86	20	4.73	2.51	20	4.2%	-1.10 [-1.77, -0.43]
Angoules (v)	3.85	1.42	20	4.13	1.51	20	4.9%	-0.19 [-0.81, 0.43]
Angoules (w)	2.98	1.23	20	4.13	1.51	20	4.5%	-0.82 [-1.47, -0.17]
Angoules (x)	2.5	1	20	4.13	1.51	20	4.0%	-1.25 [-1.93, -0.56]
Fischer Rasmussen (a)	3.5	1.37	18	4.06	1.21	20	4.5%	-0.43 [-1.07, 0.22]
Fischer Rasmussen (b)	3.1	1.54	18	3.14	1.03	20	4.7%	-0.03 [-0.67, 0.61]
Ozenci (a)	4.75	2.15	20	5.3	1.74	20	4.9%	-0.28 [-0.90, 0.35]
Ozenci (b)	4.58	1.87	20	5.3	1.74	20	4.8%	-0.39 [-1.02, 0.24]
Total (95% CI)			**436**			**440**	**100.0%**	**-0.62 [-0.76, -0.48]**

Heterogeneity: Chi² = 36.03, df = 21 (P = 0.02); I² = 42%
Test for overall effect: Z = 8.85 (P < 0.00001)



Figs. 1–3. Forest plots of the comparisons between ACL injury and non-injured knees in studies that measured joint position sense. For brevity only the comparisons which showed significant differences are shown. The letters in brackets following the first authors name refer to subgroups and/or knee motion during proprioception measurement. Angoules (a–x) measured joint position sense data from two reconstruction techniques (hamstring and patella tendon procedures) at three different target angles (15°, 45° and 75°) across four time points (pre-operatively, and 3 months, 6 months and 12 months after surgery). Fischer–Rasmussen (a–d) measured joint position sense in two ACL groups (reconstructed and non-reconstructed) at two different target angles (0° and 60°). Fremerey (a and b) measured joint position sense in two ACL groups (reconstructed and non-reconstructed). Mir (a and b) measured joint position sense in an ACL-reconstructed group at two different target angles (0° and 60°). Ozenci (a–c) measured joint position sense in three different ACL groups (autograft reconstruction, allograft reconstruction and non-reconstructed).

Study or Subgroup	ACL Mean	ACL SD	ACL Total	Control Group Mean	Control Group SD	Control Group Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Barrack	3.53	1.22	11	2.67	0.84	10	14.5%	0.78 [-0.11, 1.68]
Ozenci (a)	1.01	0.16	20	1.03	0.91	20	30.3%	-0.03 [-0.65, 0.59]
Ozenci (b)	0.96	0.27	20	1.03	0.91	20	30.3%	-0.10 [-0.72, 0.52]
Ozenci (c)	1.93	0.42	20	1.03	0.91	20	24.9%	1.24 [0.56, 1.93]
Total (95% CI)			**71**			**70**	**100.0%**	**0.38 [0.04, 0.72]**

Heterogeneity: Chi² = 10.93, df = 3 (P = 0.01); I² = 73%

Test for overall effect: Z = 2.20 (P = 0.03)

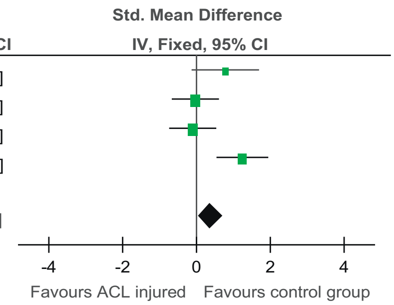


Fig. 4. Forest plot of the comparisons between ACL injury and non-injured knees in studies that measured threshold to detect passive motion comparison. For brevity only the comparisons which showed significant differences are shown. The letters in brackets following the first authors name refer to subgroups and/or knee motion during proprioception measurement; Ozenci (a–c) measured threshold to detect passive motion in three different ACL groups (autograft reconstruction, allograft reconstruction and non-reconstructed).

important difference [26] although there is little evidence to support, or refute, this value.

The discrepancy in statistical and functional significance of the proprioceptive differences may be because the measurement techniques were insufficiently accurate to detect clinically significant differences between groups [11] as only one selected study included sufficient information on the psychometrics of the measurement techniques. Therefore the differences in reliability statistics between different JPS equipment and techniques could not be established. We found studies using joint position sense reported greater differences than studies using TTDPM. This may be a consequence of the type of movements tested. TTDPM techniques detect the responses of rapid receptors such as the pacinian capsules in the ACL [5] and would therefore require a more sensitive measurement technique than measures of JPS which measures the slower responses of the ruffini nerve endings and Golgi tendon organs [25].

Another explanation is that the comparisons were underpowered because the sample was too small (none of the included studies calculated sample size using power estimations). However our pooled analysis involved nearly 200 patients and the 95% confidence intervals of the comparisons made were small, indicating that a lack of power was not an issue. Clinicians should be cautious when using knee proprioception techniques without corresponding psychometric properties. Further researcher is needed to evaluate the sensitivity and reliability of techniques to measure proprioception at the knee, before they can meaningfully be used as an evaluation tool in either research or clinical practice.

A more likely, but controversial, explanation for our results is that ACL injury may not have a major impact on proprioception at the knee. This support's the view that muscle, rather than ligaments, provide the primary afferent information in the sensorimotor system [10], which is not surprising given that only 1% of the ACL total area may be made up of proprioceptive receptors and that receptors are often still deficient six months after reconstructive surgery [5]. It may, to some degree, also explain the inconclusive evidence for reconstructive surgery and conservative (non-surgical) rehabilitation [10,27,28]. Joint stability relies on synergy between muscles and ligaments [1,2,29,30]. Once the ligament is damaged, rehabilitation programmes may help patients adapt by using proprioceptive information from the muscles to compensate for the lack of information from the ligament. Therefore, there may be no restoration of ACL proprioception [20]. This may explain why some patients cope better with ACL injury (however it is managed) than others, some may be more able to make that adaption [5,10,12,27].

A limitation of this meta-analysis is that only English language papers were included. Another limitation is that all data collection was retrospective, which inevitably means that pre-injury proprioception is unknown. It is possible that the patients who suffered injuries had poorer proprioception which predisposed them to injury. Large scale normative studies are needed to give insight into the distribution of proprioception abilities across the population and whether this predisposes people to ACL injury. Such studies should consider a measurement technique that explores the full range of knee motion and direction using large sample sizes that represents the complete ACL patient population and normative data on proprioception ability. A further potential limitation is the high proportion of data provided by a single paper [23] which reported several data sets provided by different methods. Therefore we viewed these as separate studies written as one academic paper. Further research is needed to replicate their findings and to add this to a future meta-analysis.

Heterogeneity of variance was greater than the recommended level of 50% [13] in all but one comparison; this may be due to variability in recruitment strategies and measurement techniques: The time since injury when proprioception was measured ranged from 12 days [20] to over two years [21] and involvement in rehabilitation programmes was inconsistent. Furthermore highly varied measurement techniques were used including three different pieces of equipment and varied knee movements (in terms of direction and speed). This may have hampered the degree to which data could be pooled and as proprioception increases towards the extremes of range of movement (to protect the joint from injury [5,31]), could have contributed to the high levels of heterogeneity. Future research needs to include measurements across the whole range of movement as taking measurements over specific positions may either under- or over-estimate knee proprioception.

Conclusions

This review examined the effect of ACL injury on proprioception, in terms of joint position sense and threshold to detect passive motion. The results cautiously indicate that patients with ACL injury may have poorer proprioception than an uninjured knee. These differences are seen whether the comparator group is a patient's uninjured leg, or a control group of people with no injuries; suggesting that either can be used as a control group in future research. However, the lack of sufficient data on the psychometric properties of knee proprioception measurement techniques is a major limitation that clinicians or researchers must consider if using knee JPS or TTDPM data during assessment of a rehabilitation programme.

Ethical approval: None required.

Conflict of interest: None declared.

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