BMJ Open

Psychometric properties of knee proprioception tests targeting healthy individuals and those with anterior cruciate ligament injury managed with or without reconstruction: a systematic review protocol

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To cite: Arumugam A, Strong A, Tengman E, *et al*. Psychometric properties of knee proprioception tests targeting healthy individuals and those with anterior cruciate ligament injury managed with or without reconstruction: a systematic review protocol. *BMJ Open* 2019;**9**:e027241. doi:10.1136/bmjopen-2018-027241

Received 12 October 2018
Revised 6 December 2018
Accepted 25 January 2019

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ABSTRACT

Introduction An anterior cruciate ligament (ACL) injury affects knee proprioception and sensorimotor control and might contribute to an increased risk of a second ACL injury and secondary knee osteoarthritis. Therefore, there is a growing need for valid, reliable and responsive knee proprioception tests. No previous study has comprehensively reviewed all the relevant psychometric properties (PMPs) of these tests together. The aim of this review protocol is to narrate the steps involved in synthesising the evidence for the PMPs of specific knee proprioception tests among individuals with an ACL injury and knee-healthy controls.

Methods and analysis The Preferred Reporting Items for Systematic reviews and Meta-Analyses will be followed to report the review. A combination of four conceptual groups of terms—(1) construct (knee proprioception), (2) target population (healthy individuals and those with an ACL injury managed conservatively or with a surgical reconstruction), (3) measurement instrument (specific knee proprioception tests) and (4) PMPs (reliability, validity and responsiveness)—will be used for electronic databases search. PubMed, AMED, CINAHL, SPORTDiscus, Web of Science, Scopus, the Cochrane Central Register of Controlled Trials and ProQuest will be searched from their inception to November 2018. Two reviewers will independently screen titles, abstracts and full text articles, extract data and perform risk of bias assessment using the updated COnsensus-based Standards for the selection of health Measurement INstruments risk of bias checklist for the eligible studies. A narrative synthesis of the findings and a meta-analysis will be attempted as appropriate. Each PMP of knee proprioception tests will be classified as 'sufficient', 'indeterminate' or 'insufficient'. The overall level of evidence will be ascertained using an established set of criteria.

Ethics and dissemination Ethical approval or patient consent is not required for a systematic review. The review findings will be submitted as a series of manuscripts for peer-review and publication in scientific journals.

PROSPERO registration number CRD42018108014.

Strengths and limitations of the study

- A comprehensive systematic review of the psychometric properties of specific knee proprioception tests, following the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines, using a broad search in several electronic databases.
- The corroboration of evidence using an established set of criteria that relies on the scores of the updated COnsensus-based Standards for the selection of health Measurement INstruments risk of bias evaluation of the eligible studies and the quality of psychometric properties graded with a standard set of criteria.
- The review provides an up-to-date compilation of current knowledge about the psychometric properties of specific objective knee proprioception tests, and identification of eventual need for further research.
- The review is limited to original research articles published in English.
- The review is limited to studies investigating adolescents (≥10 years) and adults with an ACL injury (with or without reconstruction) and/or healthy participants.

INTRODUCTION

Anterior cruciate ligament (ACL) ruptures are one of the most common knee injuries among athletes.[1] Annual incidence rates among amateur athletes range from 0.03% to 1.62%, with these figures rising further among professional athletes from 0.15% to 3.67%.[2] Treatment involves physiotherapy with or without surgery. Despite treatment, return-to-sport at pre-injury level is only achieved by approximately 65% of individuals with an ACL injury.[3] Those who do return-to-sport are at a six times higher risk for an

ACL injury than non-injured individuals.[4] Thus, despite completing rehabilitative interventions, the short-term consequences of an ACL injury include a reduced level of physical activity and increased risk for further ACL injury. The long-term consequences following an ACL injury also include the more than 50% chance of developing knee osteoarthritis.[5] An ACL injury therefore negatively affects the short-term and long-term health of affected individuals, which in turn places a burden on healthcare systems.

Proprioceptors such as Ruffini nerve endings, Pacini receptors and Golgi tendon organ-like endings are present in the intact/injured ACL.[6 7] These receptors provide afferent feedback to the central nervous system regarding the sensation of limb position and movement as well as the senses of force and effort.[8] Injury to the ACL causes damage to and loss of these proprioceptors[9 10] and, for instance, affects muscle spindle excitability of the thigh muscles.[11–13] Reduced proprioception is evident in ACL-injured knees as compared with the contralateral intact knee of the same individuals as well as to knee-healthy controls.[14 15] Such reduced proprioception/sensorimotor control is believed to be a major contributing factor to the 30–40 times increased risk of a second ACL injury[16] and post-ACL injury knee osteoarthritis development.[17] Identifying both knee-healthy individuals and those having an ACL injury with poor knee proprioception may thus aid the prescription of targeted neuromuscular training, which could facilitate injury/re-injury prevention strategies as well as short-term and long-term rehabilitation outcomes.

Assessing knee proprioception is currently performed in a number of ways, with each test aimed at isolating one of the proprioceptive senses. The most common methods strive to determine joint position sense (JPS) and threshold to detect passive motion (TTDPM).[18] JPS typically requires the attempted matching of a target knee joint angle either ipsilaterally or contralaterally using an active and/or a passive movement.[19 20] Test outcome is the difference in degrees between the target angle and the attempted reproduction angle. TTDPM most often involves blindfolded individuals signalling the onset of passive movement from a pre-set joint angle and also identifying the movement direction.[21] Test outcome is the time between actual movement onset and the signal provided as well as whether the correct movement direction is detected by the individual. Other tests targeting proprioception such as force sense (the ability to accurately reproduce forces and/or hold a force steadily for a brief period [e.g. 5 s]),[19 21 22] force perception/load identification (the ability to differentiate between different loads/weights),[23] velocity sense (the ability to actively reproduce the velocity of a passive movement),[21] active movement extent discrimination (AMEDA, the ability to discriminate between two or more active movements of different ranges of motion)[24] or psychophysical threshold methods (the ability to detect and discriminate between different joint positions following passive movements)[25] are also reported. However, it appears important to differentiate tests based on the specific targeted sense of proprioception due to the reported lack of correlation between knee position sense, motion sense and force sense.[26] Regardless of the targeted proprioceptive sense, there are many factors to be considered when designing a knee joint proprioception test such as determining body position, whether the knee should be weight-bearing or non-weight-bearing, knee angles and speed of movement, occluding visual input, restricting other somatosensory information and minimising extraneous variables. Further, the lack of data regarding the psychometric properties (PMPs) of existing knee proprioception tests challenge their utility and clinical application.[15] To date, no gold standard knee proprioception tests exist to guide clinicians or researchers to advocate their use.

Previous reviews of the literature have claimed that proprioception tests show uncertainty for their PMPs. Hillier *et al.* (2015)[27] failed to find a proprioception test with well substantiated PMPs and, therefore, questioned their clinical application. On the other hand, Han and colleagues (2016)[28] concluded that although JPS tests may be efficient, they have low testing validity owing to differences in the proprioceptive information perceived during (passive) target angle generation and (active) reproduction. Moreover, Smith and colleagues (2013)[29] found variable reliability of JPS tests and highlighted the limited evidence for the PMPs of such tests. Both JPS and TTDPM may have less ecological validity because they do not represent function during normal tasks.[28 30] On the other hand, AMEDA (ability to discriminate between two or more movements) has been claimed by Han *et al.* (2016)[28] to have (relatively) better ecological and testing validity. Despite the uncertain validity of these tests, they have been widely applied. The criterion and construct validity, reliability and responsiveness of these tests should be systematically evaluated. Moreover, previous reviews either systematically appraised only a few PMPs of one or more knee proprioception tests but not all of them[29] or did not corroborate the relevant literature systematically.[28 30] To date, neither a systematic review nor a meta-analysis has assimilated the data, as a whole, on all the relevant PMPs of established specific knee proprioception tests in healthy individuals nor those with ACL injuries.

Thus, a systematic review of the literature, implementing updated methodological quality assessment tools such as the COnsensus-based Standards for the selection of health Measurement INstruments (COSMIN) risk of bias checklist,[31] covering the PMPs of all documented proprioception tests specifically targeting the knee is lacking and is warranted. The current protocol narrates the study methods and reporting process of such an ongoing systematic review (and meta-analysis) aimed at corroborating the levels of evidence underpinning the PMPs of existing specific knee proprioception tests among individuals with an ACL injury managed conservatively or surgically and knee-healthy controls.

Table 1 Operational definitions of domains, psychometric properties and subsets of psychometric properties for the purpose of this review

Domains	Psychometric properties	Subsets of psychometric properties	Definitions adapted from COSMIN recommendations (except where indicated)
Reliability			The degree to which scores for (symptomatic or asymptomatic) individuals, who have not changed, are the same for repeated measurement of knee proprioception and free from measurement error.
	Test–retest		The extent of agreement in repeated measurements of knee proprioception using a specific test over time.
	Inter-rater		The extent of agreement between raters investigating knee proprioception scores on the same individual.
	Intra-rater		The extent of agreement between repeated measurements of knee proprioception scores on the same individual by the same rater.
	Measurement error		The systematic and random error of an individual's score that is not attributed to true changes in knee joint proprioception to be measured.
Validity			Concerns how well the specific knee proprioception test under assessment measures the construct it is designed to measure, e.g. how well a knee JPS test measures the target joint position/angle matching?
	Criterion validity		The extent to which knee proprioception measurements are an adequate reflection of a 'gold standard' method. As the 'gold standard' for each type of knee proprioception test is unclear, assessing the correlation of such tests with a reference standard (criterion) will be attempted.
		Concurrent validity*[55 56]	Addresses how well a knee proprioception test correlates to a reference standard (criterion) or instrument measuring a similar outcome, e.g. correlating the scores of a specific proprioception test such as JPS measured with dynamometer or angular motion chair method to that of position replication using a model, image-recorded angulation (photography method) and/or electrogoniometer method.
		Predictive validity*[55 56]	A focal measure of knee proprioception measured with a specific test at one point is used to predict another criterion measured at a later point of time, e.g. the scores of a proprioception test being used to predict the outcomes of an ACL reconstruction surgery, quality of life, return-to-sport or subsequent injury risk at a later time point.
	Construct validity		The extent to which the scores of a specific knee proprioception test are consistent with hypotheses regarding the scores of other measurement methods or differences between known groups, given that the proprioception test validly measures the construct it is purported to measure.
		Hypothesis testing: known groups or discriminative validity[56]	The degree to which the scores of a knee proprioception test can discriminate between groups known to differ in proprioception sense (e.g. individuals with an ACL injury managed conservatively vs. those managed with reconstructive surgery or knee-healthy individuals vs. individuals with an ACL injury).
		Hypothesis testing: convergent validity and discriminant (divergent) validity*[55 56]	The focal measures of knee proprioception tests (e.g. JPS, TTDPM, AMEDA, etc.) show conceptual convergence or divergence between them or with other outcome measures attributed to different constructs such as quantitative sensory testing methods (e.g. mechanical, thermal or electrical pain threshold/tolerance), thigh muscle strength, quality of life, etc. Correlations with related constructs are expected to be higher than those of unrelated constructs.
Responsiveness			The ability of a knee proprioception test to detect change in proprioceptive ability over time.

Continued

Table 1 Continued

Domains	Psychometric properties	Subsets of psychometric properties	Definitions adapted from COSMIN recommendations (except where indicated)
		Criterion approach	A focal measure of knee proprioception is consistent with a gold standard or a reference standard (idem construct validity) over time.
		Construct approach	A focal measure of knee proprioception is correlated with other outcome measurement instruments or discriminated between subgroups (idem hypothesis testing) or before and after intervention, measured over a period of time.

We expect that the definitions will evolve and become more specific because of the study methods, type of data and the findings reported in the eligible articles, further to discussion at team meetings.
*Definitions adapted from sources other than the COSMIN.
ACL, anterior cruciate ligament; AMEDA, active movement extent discrimination assessment; COSMIN, COnsensus-based Standards for the selection of health Measurement INstruments; JPS, joint position sense; TTDPM, threshold to detect passive motion.

METHODS

Design

The systematic review will follow the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines for conducting and reporting the review.[32 33]

ELIGIBILITY CRITERIA

Inclusion criteria

Studies will be included if they meet the following criteria:

1. **Participants:** Adolescents (≥10 years of age) and adults who are healthy as well as those with anterior cruciate ligament injury managed with or without reconstruction.
2. **Construct:** One or more specific methods measuring joint proprioception such as active or passive JPS (ipsilateral or contralateral matching,[19 20] verbal identification of joint position,[23] and identifying location of joint motion using contralateral limb),[23] TTDPM (low[21] or high velocity[30]), force sense,[19 21] force perception,[23] velocity sense,[21] AMEDA[24] or psychophysical threshold methods[25] designed for the knee.
3. **Equipment:** Any equipment that is readily available or customised for the purpose of quantifying knee joint proprioception (e.g. video cameras, two-dimensional/three-dimensional motion analysis system, electro-goniometer, isokinetic dynamometer, etc.).
4. **Setting:** The test procedure executed in a laboratory, clinical or any setting.
5. **Outcome measures:** Studies investigating any of the following PMPs of knee proprioception tests—reliability (absolute reliability (agreement) and relative reliability of test–retest, intra-rater and/or inter-rater designs), validity (criterion (concurrent or predictive), construct (hypothesis testing—known-groups or comparison with other outcome measurements), and responsiveness (table 1).
6. **Study type:** (1) Studies investigating PMPs of knee joint proprioception tests as one of the (primary) aims or the sole aim of their study, (2) if studies have reported reliability, validity and/or responsiveness as secondary or additional findings, then the full text of these studies will be reviewed and included only if adequate details to rate their quality/risk of bias are available, (3) if studies have included knee proprioception data of individuals with ACL injury and other lower limb disorders and knee-healthy controls, then these studies will be included only if data were reported separately for each group and (4) peer-reviewed observational studies, cross-sectional studies, randomised controlled trials, controlled clinical trials or quasi-experimental studies will be included if one or more PMPs of a specific knee proprioception test have been addressed in them. All studies should be English language full text publications that can be retrieved through electronic database or manual search.

Exclusion criteria

If studies were aimed at the following research questions/designs, they will be excluded: (1) validating self-reported knee function and/or physical activity levels without addressing specific knee proprioception tests; (2) validating proprioception-related function[23] such as dynamic balance, tendon tap (proprioceptive reflex), perturbation of actively positioned knee joint (proprioceptive reflex) or other nonspecific proprioception assessment methods such as a subjective questionnaire,[34] a scale[35] or other methods (cf. Röijezon *et al*. 2015)[36]; (3) validating measurement tools not specifically designed to assess knee joint proprioception (e.g. the Rivermead assessment of somatosensory performance)[37]; (4) investigating treatment effects following an intervention with a knee proprioception test without addressing PMPs of these tests; (5) pilot studies, abstracts, systematic reviews and meta-analyses, narrative reviews, book reviews, case series/reports, commentaries, editorials, letters to the editor, patient education handouts, consensus statements, clinical practice guidelines, theses/dissertations or unpublished literature; (6) non-English studies.

Table 2 Search terms and strategy used for the electronic databases included in our systematic review

Database	Search Strategy
The Cochrane Central Register of Controlled Trials (CENTRAL)	#1 (Proprioception OR Mechanoreceptors OR kinesthesis OR kinesthesia) #2 MeSH descriptor: [Proprioception] explode all trees #3MeSH descriptor: [Mechanoreceptors] explode all trees #4MeSH descriptor: [Kinesthesis] explode all trees #5(#1 OR #2 OR #3 OR #4) #6(Knee OR "lower extremity OR "Anterior Cruciate Ligament") #7MeSH descriptor: [Knee Joint] explode all trees #8MeSH descriptor: [Lower Extremity] explode all trees #9MeSH descriptor: [Anterior Cruciate Ligament] explode all trees #10(#6 OR #7 OR #8 OR #9) #11("outcome measure*" OR "Joint position sense" OR "active joint position detection" OR "passive joint position detection" OR "threshold to detect passive motion" OR "passive motion direction discrimination" OR "passive motion detection threshold" OR "threshold for motion detection" OR "threshold hunting" OR "psychophysical threshold hunting" OR "detection threshold" OR "discrimination threshold" OR "ipsilateral matching" OR "contralateral matching" OR "joint angle error" OR "distance estimation error" OR "passive recognition" OR "direction accuracy" OR "active reproduction" OR "active movement extent discrimination") #12MeSH descriptor: [Patient Outcome Assessment] explode all trees #13MeSH descriptor: [Treatment Outcome] explode all trees #14MeSH descriptor: [Outcome Assessment (Health Care)] explode all trees #15(#11 OR #12 OR #13 OR #14) #16(Psychometrics OR "discriminant analysis" OR "observer variation" OR "reproducibility of results" OR Psychometr* OR clinimetr* OR valid* OR "content validity" OR "construct validity" OR "structural validity" OR "hypothesis testing" OR "concurrent validity" OR "discriminative validity" OR "criterion validity" OR "predictive validity" OR "discriminant analysis" OR "convergent validity" OR sensitiv* OR specific* OR consistency OR precision OR accuracy OR reliab* OR absolute OR relative OR reproducib* OR repeatab* OR intrarater OR interrater OR intratester OR intertester OR interobserver OR intraobserver OR interexaminer OR intraexaminer OR interindividual OR intraindividual OR "test-retest" OR "observer variation" OR coefficient OR correlation* OR agreement OR error OR "measurement error" OR "standard error of measurement" OR "smallest real difference" OR "minimal detectable change" OR "minimal important difference" OR "clinically important difference" OR "meaningful change" OR "coefficient of variation" OR responsiv* OR generali* OR interpretab*) #17MeSH descriptor: [Psychometrics] explode all trees #18MeSH descriptor: [Discriminant Analysis] explode all trees #19MeSH descriptor: [Reproducibility of Results] explode all trees #20(#16 OR #17 OR #18 OR #19) #21(animals OR "Pilot studies" OR reviews OR "case series" OR "case reports" OR editorial OR "letter to the editor" OR news OR "patient education handout" OR "consensus statement" OR "clinical practice guideline"):ti,ab,kw #22(#5 AND #10 AND #15 AND #20) NOT #21
EBSCO Host (databases included: the **Cumulative Index to Nursing and Allied Health Literature** [**CINAHL**], the **Allied and Complementary Medicine** [**AMED**] and **SPORTDiscus**)	TX (proprioception OR kinesthes*) AND TX (knee OR "anterior cruciate ligament") AND TX ("patient outcome assessment" OR "treatment outcome" OR "outcome assessment" OR "outcome measure*" OR "joint position sense" OR "active joint position sense" OR "active joint position detection" OR "passive joint position sense" OR "passive joint position detection" OR "threshold to detect passive motion" OR "passive motion direction discrimination" OR "passive motion detection threshold" OR "threshold for motion detection" OR "threshold hunting" OR "psychophysical threshold hunting" OR "detection threshold" OR "discrimination threshold" OR "ipsilateral matching" OR "contralateral matching" OR "joint angle error" OR "distance estimation error" OR "passive recognition"" OR "direction accuracy" OR "active reproduction" OR "active movement extent discrimination" OR "force sense" OR "force perception" OR "velocity sense") AND TX ("discriminant analysis" OR "observer variation" OR "reproducibility of results" OR Psychometr* OR clinimetr* OR valid* OR "construct validity" OR "structural validity" OR "hypothesis testing" OR "concurrent validity"" OR "discriminative validity" OR "criterion validity" OR "predictive validity" OR "discriminant analysis" OR "convergent validity" OR sensitiv* OR specific* OR consistency OR precision OR accuracy OR reliab* OR reproducib* OR repeatab* OR intrarater OR interrater OR intratester OR intertester OR interobserver OR intraobserver OR interexaminer OR intraexaminer OR interindividual OR intraindividual OR "test-retest" OR "observer variation" OR correlation* OR agreement OR "measurement error" OR "standard error of measurement" OR "smallest real difference" OR "minimal detectable change" OR "minimal important difference" OR "clinically important difference" OR "meaningful change" OR "coefficient of variation" OR responsiv* OR "force sense" OR "force perception" OR "velocity sense") NOT TX (animal* OR "Pilot stud*" OR review OR "case series" OR "case report*" OR comment* OR editorial OR "letter to the editor" OR news OR "patient education handout" OR "consensus statement" OR "clinical practice guideline") Abstract Available; Document Type: Journal Article; Language: English; English Language; Research Article; Exclude MEDLINE records; Human; Language: English; Publication Type: Academic Journal AND Apply related words; Also search within the full text of the articles

Continued

Table 2 Continued

Database	Search Strategy
Physical Education Index (via **ProQuest**)	((((((((proprioception OR kinesthes*) AND (knee OR "anterior cruciate ligament") AND ("patient outcome assessment" OR "treatment outcome" OR "outcome assessment" OR "outcome measure*" OR "joint position sense" OR "active joint position sense" OR "active joint position detection" OR "passive joint position sense" OR "passive joint position detection" OR "threshold to detect passive motion" OR "passive motion direction discrimination" OR "passive motion detection threshold" OR "threshold for motion detection" OR "threshold hunting" OR "psychophysical threshold hunting" OR "detection threshold" OR "discrimination threshold" OR "ipsilateral matching" OR "contralateral matching" OR "joint angle error" OR "distance estimation error" OR "passive recognition" OR "direction accuracy" OR "active reproduction" OR "active movement extent discrimination" OR "force sense" OR "force perception" OR "velocity sense") AND ("discriminant analysis" OR "observer variation" OR "reproducibility of results" OR Psychometr* OR clinimetr* OR valid* OR "construct validity" OR "structural validity" OR "hypothesis testing" OR "concurrent validity" OR "discriminative validity" OR "criterion validity" OR "predictive validity" OR "discriminant analysis" OR "convergent validity" OR sensitiv* OR specific* OR consistency OR precision OR accuracy OR reliab* OR reproducib* OR repeatab* OR intrarater OR interrater OR intratester OR intertester OR interobserver OR intraobserver OR interexaminer OR intraexaminer OR interindividual OR intraindividual OR "test-retest" OR "observer variation" OR correlation* OR agreement OR "measurement error" OR "standard error of measurement" OR "smallest real difference" OR "minimal detectable change" OR "minimal important difference" OR "clinically important difference" OR "meaningful change" OR "coefficient of variation" OR responsiv* OR "force sense" OR "force perception" OR "velocity sense") NOT (animal* OR "Pilot stud*" OR review* OR "case series" OR "case report*" OR comment* OR editorial OR "letter to the editor" OR news OR "patient education handout" OR "consensus statement" OR "clinical practice guideline")) AND stype.exact("Scholarly Journals")) AND la.exact("English")) AND stype.exact("Scholarly Journals")) AND la.exact("English")) AND stype.exact("Scholarly Journals")) AND la.exact("English")) AND PEER(yes)
PubMed	(((((Proprioception[MeSH terms] OR Mechanoreceptors[MeSH terms] OR sensory thresholds[MeSH terms] OR kinesthesis[MeSH terms] OR Proprioception[Text Word] OR Mechanoreceptors[Text Word] OR sensory thresholds[Text Word] OR kinesthesis[Text Word] OR kinesthesia[Text Word])) AND ("Knee joint"[MeSH terms] OR "lower extremity"[MeSH terms] OR "Athletic injuries"[MeSH terms] OR sports[MeSH terms] OR "joint instability"[MeSH terms] OR "leg injuries"[MeSH terms] OR "Anterior Cruciate Ligament Injuries"[MeSH terms] OR "Joint Instability"[MeSH terms] OR Rupture[MeSH terms] OR "Knee joint"[Text Word] OR "lower extremity"[Text Word] OR "Athletic injuries"[Text Word] OR sports[Text Word] OR "joint instability"[Text Word] OR "leg injuries"[Text Word] OR "Anterior Cruciate Ligament Injuries"[Text Word] OR "Joint Instability"[Text Word] OR Rupture[Text Word] OR injur*[Text Word] OR Tear[Text Word] OR surger*[Text Word] OR "Anterior Cruciate Ligament"[Text Word] OR Reconstruction[Text Word])) AND ("patient outcome assessment"[MeSH terms] OR "treatment outcome"[MeSH terms] OR "outcome assessment health care"[MeSH terms] OR "patient outcome assessment"[Text Word] OR "treatment outcome"[Text Word] OR "outcome assessment"[Text Word] OR "outcome measure*"[Text Word] OR "Joint position sense"[Text Word] OR "active joint position sense"[Text Word] OR "active joint position detection"[Text Word] OR "passive joint position sense"[Text Word] OR "passive joint position detection"[Text Word] OR "threshold to detect passive motion"[Text Word] OR "passive motion direction discrimination"[Text Word] OR "passive motion detection threshold"[Text Word] OR "threshold for motion detection"[Text Word] OR "threshold hunting"[Text Word] OR "psychophysical threshold hunting"[Text Word] OR "detection threshold"[Text Word] OR "discrimination threshold"[Text Word] OR "ipsilateral matching"[Text Word] OR "contralateral matching"[Text Word] OR "joint angle error"[Text Word] OR "distance estimation error"[Text Word] OR "passive recognition"[Text Word] OR "direction accuracy"[Text Word] OR "active reproduction"[Text Word] OR "active movement extent discrimination"[Text Word])) AND (Psychometrics[MeSH terms] OR "discriminant analysis"[MeSH terms] OR "observer variation"[MeSH terms] OR "reproducibility of results"[MeSH terms] OR Psychometrics[Text Word] OR "discriminant analysis"[Text Word] OR "observer variation"[Text Word] OR "reproducibility of results"[Text Word] OR Psychometr*[Text Word] OR clinimetr*[Text Word] OR valid*[Text Word] OR "content validity"[Text Word] OR "construct validity"[Text Word] OR "structural validity"[Text Word] OR "hypothesis testing"[Text Word] OR "concurrent validity"[Text Word] OR "discriminative validity"[Text Word] OR "criterion validity"[Text Word] OR "predictive validity"[Text Word] OR "discriminant analysis"[Text Word] OR "convergent validity"[Text Word] OR sensitiv*[Text Word] OR specific*[Text Word] OR consistency[Text Word] OR precision[Text Word] OR accuracy[Text Word] OR reliab*[Text Word] OR absolute[Text Word] OR relative[Text Word] OR reproducib*[Text Word] OR repeatab*[Text Word] OR intrarater[Text Word] OR interrater[Text Word] OR intratester[Text Word] OR intertester[Text Word] OR interobserver[Text Word] OR intraobserver[Text Word] OR interexaminer[Text Word] OR intraexaminer[Text Word] OR interindividual[Text Word] OR intraindividual[Text Word] OR "test-retest"[Text Word] OR "observer variation"[Text Word] OR coefficient[Text Word] OR correlation*[Text Word] OR agreement[Text Word] OR error[Text Word] OR "measurement error"[Text Word] OR "standard error of measurement"[Text Word] OR "smallest real difference"[Text Word] OR "minimal detectable change"[Text Word] OR "minimal important difference"[Text Word] OR "clinically important difference"[Text Word] OR "meaningful change"[Text Word] OR "coefficient of variation"[Text Word] OR responsiv*[Text Word] OR generali*[Text Word] OR interpretab*[Text Word])) NOT (animals[MeSH terms] OR animals[Text Word] OR "Pilot studies"[Text Word] OR reviews[Text Word] OR "case series"[Text Word] OR "case reports"[Text Word] OR comment[Text Word] OR commentary[Text Word] OR editorial[Text Word] OR "letter to the editor"[Text Word] OR news[Text Word] OR "patient education handout"[Text Word] OR "consensus statement"[Text Word] OR "clinical practice guideline"[Text Word])

Continued

Table 2 Continued

Database	Search Strategy
Scopus	proprioception OR kinesthes* AND knee OR "anterior cruciate ligament" AND "patient outcome assessment" OR "treatment outcome" OR "outcome assessment" OR "outcome measure*" OR "joint position sense" OR "active joint position sense" OR "active joint position detection" OR "passive joint position sense" OR "passive joint position detection" OR "threshold to detect passive motion" OR "passive motion direction discrimination" OR "passive motion detection threshold" OR "threshold for motion detection" OR "threshold hunting" OR "psychophysical threshold hunting" OR "detection threshold" OR "discrimination threshold" OR "ipsilateral matching" OR "contralateral matching" OR "joint angle error" OR "distance estimation error" OR "passive recognition" OR "direction accuracy" OR "active reproduction" OR "active movement extent discrimination" OR "force sense" OR "force perception" OR "velocity sense" AND "discriminant analysis" OR "observer variation" OR "reproducibility of results" OR Psychometr* OR clinimetr* OR valid* OR "construct validity" OR "structural validity" OR "hypothesis testing" OR "concurrent validity" OR "discriminative validity" OR "criterion validity" OR "predictive validity" OR "discriminant analysis" OR "convergent validity" OR sensitiv* OR specific* OR consistency OR precision OR accuracy OR reliab* OR reproducib* OR repeatab* OR intrarater OR interrater OR intratester OR intertester OR interobserver OR intraobserver OR interexaminer OR intraexaminer OR interindividual OR intraindividual OR "test-retest" OR "observer variation" OR correlation* OR agreement OR "measurement error" OR "standard error of measurement" OR "smallest real difference" OR "minimal detectable change" OR "minimal important difference" OR "clinically important difference" OR "meaningful change" OR "coefficient of variation" OR responsiv* OR "force sense" OR "force perception" OR "velocity sense" AND NOT animals AND "Pilot studies" AND reviews AND "case series" AND "case reports" AND comment AND commentary AND editorial AND "letter to the editor" AND news AND "patient education handout" AND "consensus statement" AND "clinical practice guideline" AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English")) AND (EXCLUDE (SUBJAREA,"BIOC") OR EXCLUDE (SUBJAREA,"AGRI") OR EXCLUDE (SUBJAREA,"IMMU") OR EXCLUDE (SUBJAREA,"SOCI") OR EXCLUDE (SUBJAREA,"PHAR") OR EXCLUDE (SUBJAREA,"MATE") OR EXCLUDE (SUBJAREA,"CENG") OR EXCLUDE (SUBJAREA,"COMP") OR EXCLUDE (SUBJAREA,"ENVI") OR EXCLUDE (SUBJAREA,"ARTS") OR EXCLUDE (SUBJAREA,"VETE") OR EXCLUDE (SUBJAREA,"MATH") OR EXCLUDE (SUBJAREA,"PHYS") OR EXCLUDE (SUBJAREA,"BUSI") OR EXCLUDE (SUBJAREA,"CHEM") OR EXCLUDE (SUBJAREA,"DENT") OR EXCLUDE (SUBJAREA,"EART"))
Web of Science (Databases included: **Web of Science Core Collection**, **Korean Journal Database [KCI]**, **Russian Science Citation Index** and **SciELO Citation Index**)	#1 TS=(proprioception OR kinesthes*) #2 TS=(knee OR "anterior cruciate ligament") #3 TS=("patient outcome assessment" OR "treatment outcome" OR "outcome assessment" OR "outcome measure*" OR "joint position sense" OR "active joint position sense" OR "active joint position detection" OR "passive joint position sense" OR "passive joint position detection" OR "threshold to detect passive motion" OR "passive motion direction discrimination" OR "passive motion detection threshold" OR "threshold for motion detection" OR "threshold hunting" OR "psychophysical threshold hunting" OR "detection threshold" OR "discrimination threshold" OR "ipsilateral matching" OR "contralateral matching" OR "joint angle error" OR "distance estimation error" OR "passive recognition" OR "direction accuracy" OR "active reproduction" OR "active movement extent discrimination" OR "force sense" OR "force perception" OR "velocity sense") #4 TS=("discriminant analysis" OR "observer variation" OR "reproducibility of results" OR Psychometr* OR clinimetr* OR valid* OR "construct validity" OR "structural validity" OR "hypothesis testing" OR "concurrent validity" OR "discriminative validity" OR "criterion validity" OR "predictive validity" OR "discriminant analysis" OR "convergent validity" OR sensitiv* OR specific* OR consistency OR precision OR accuracy OR reliab* OR reproducib* OR repeatab* OR intrarater OR interrater OR intratester OR intertester OR interobserver OR intraobserver OR interexaminer OR intraexaminer OR interindividual OR intraindividual OR "test-retest" OR "observer variation" OR correlation* OR agreement OR "measurement error" OR "standard error of measurement" OR "smallest real difference" OR "minimal detectable change" OR "minimal important difference" OR "clinically important difference" OR "meaningful change" OR "coefficient of variation" OR responsiv* OR "force sense" OR "force perception" OR "velocity sense") #5 TS=(animals AND "Pilot studies" AND reviews AND "case series" AND "case reports" AND comment AND commentary AND editorial AND "letter to the editor" AND news AND "patient education handout" AND "consensus statement" AND "clinical practice guideline") #6 combined with AND = #1, #2, #3, #4 #7 = #6 NOT #5 Timespan=All years; Search language=English.

Box 1 A questionnaire to screen eligible studies for use at the title, abstract and full-text screening stages

Questions for all stages: title, abstract and full-text screening (follow steps 1 to 9)

1. Is the study published in a scientific journal with a peer-review process?
   a. No—exclude
   b. Yes or uncertain—go to step 2
2. Is the study published in English?
   a. No—exclude
   b. Yes or uncertain—go to step 3
3. Does the study deal with adolescents (≥10 years) and/or adults?
   a. No—exclude
   b. Yes or uncertain—go to step 4
4. Does this study investigate adolescents and/or adults with ACL injury (with or without reconstruction) and/or healthy individuals?
   a. No—exclude
   b. Yes or uncertain—go to step 5
5. Does the article represent a primary study other than a case report/series (and not other types of research such as theses/dissertations, nonpeer-reviewed articles, letters to the editor, systematic reviews and meta-analyses, narrative reviews, book reviews, pilot studies, published study designs/trial protocols, commentaries, editorials, interviews, newspaper articles, patient education handouts, consensus statements or clinical practice guidelines)?
   a. No—exclude
   b. Yes or uncertain—go to step 6
6. Does the study assess the knee?
   a. No—exclude
   b. Yes or uncertain—go to step 7
7. Does the study employ any specific test to measure knee proprioception (e.g. JPS (active or passive; ipsilateral or contralateral matching), AMEDA, TTDPM, motion direction discrimination, pursuit/tracking task, force steadiness, force reproduction, velocity replication, velocity threshold hunting, psychophysical threshold hunting or any other related tests)?
   a. No—exclude
   b. Yes or uncertain—go to step 8
8. Does this study report (objective) focal measures of knee proprioception (see point 7)?
   a. No—exclude
   b. Yes or uncertain— go to step 9
9. Is the study designed to evaluate one or more measurement properties (validity, reliability, and/or responsiveness) of instruments/test procedures measuring knee proprioception?
   a. No—exclude
   b. Yes or uncertain—choose one of the following options:
      i. If 'yes'—include at title and abstract screening stage
      ii. If 'uncertain'—follow steps 10–11

Additional questions for full-text stage only

10. Does this study use at least one (appropriate) statistical test to analyse a psychometric property of a knee joint proprioception test'?
    a. No—exclude
    b. Yes or uncertain—go to step 11
11. Are the points 1–10 scored as 'yes' or 'uncertain'
    a. If all 'yes'—include
    b. If any 'uncertain'—discuss with another reviewer to come to an agreement whether to include the study or not

ACL, anterior cruciate ligament; AMEDA, active movement extent discrimination assessment; JPS, joint position sense; TTDPM, threshold to detect passive motion.

Information sources

One reviewer (AS) will conduct a systematic search in the following electronic databases: PubMed, AMED (via EBSCO), the Cumulative Index to Nursing and Allied Health Literature ((CINAHL) via EBSCO), SPORTDiscus (via EBSCO), Web of Science, Scopus, the Cochrane Central Register of Controlled Trials (CENTRAL), and Physical Education Index (via ProQuest).

Search strategy

The search strategy has been designed for a comprehensive search to locate the widest spectrum of articles for consideration using a combination of four conceptual groups of terms: (1) construct, (2) target population, (3) measurement instrument and (4) psychometric properties. In addition, an exclusion filter to omit secondary studies or publication types irrelevant to the current review will be applied. Depending on the electronic database searched, the search terms will be either keywords or database-specific search terms (MeSH, subject terms, subject headings and CINAHL headings) in combination with keywords or text words. Boolean operators, 'OR' and 'AND', will be used to combine the search terms. The search limits will be full text articles written in English language published from the inception of databases to November 2018. Titles and abstracts retrieved by the electronic search will be exported to EndNote library and duplicates will be excluded (AS). Screening of articles will be done using the following steps: the titles will be examined for relevance, then abstracts will be screened and finally the full text articles will be retrieved for data extraction and risk of bias assessment. Furthermore, any articles retrieved by hand search will be assessed for inclusion in a similar manner. The search strategy for each database is summarised in table 2. The article screening process will be depicted using the PRISMA flow chart.

Study selection

Two reviewers (AS and ET) will independently evaluate titles and abstracts (and full text in case of doubt) of the retrieved references for eligibility using a screening questionnaire (box 1). Another reviewer (AA) will be consulted in case of any doubt in order to reach a consensus in determining the eligibility of studies to be included.

Data extraction process

The eligible articles will be divided between four reviewers (AA, AS, ET and UR) and a minimum of two reviewers (among AA, AS, ET and UR) will extract/verify

Table 3 Criteria for evaluating the quality of the psychometric properties

Measurement property	Rating*	Criteria
Reliability	+	Intraclass correlation coefficient or weighted Kappa ≥ 0.70
	?	Intraclass correlation coefficient or weighted Kappa not reported
	–	Intraclass correlation coefficient or weighted Kappa < 0.70
Measurement error	+	Smallest detectable change or limits of agreement < minimal important change†
	?	Minimal important change not defined
	–	Smallest detectable change or limits of agreement > minimal important change†
Hypotheses testing for	+	The results are in accordance with the hypothesis‡
construct validity	?	Hypothesis is not defined (by the review committee)
	–	The result is not in agreement with the hypothesis‡
Criterion validity	+	Correlation with gold/reference standard ≥ 0.70 or area under the curve ≥ 0.70
	?	Not all information for '+' reported
	–	Correlation with gold/reference standard < 0.70 or area under the curve < 0.70
Responsiveness	+	The results are in agreement with the hypothesis‡ or area under the curve ≥ 0.70
	?	Hypothesis is not defined (by the review committee)
	–	The result is not in agreement with the hypothesis‡ or area under the curve < 0.70

The criteria list has been adapted from Prinsen *et al*.[53]
*Rating: '+'=sufficient, '?'=indeterminate, '– '=insufficient.
†This rating of evidence may be obtained from different studies.
‡The findings of all studies must be complied together and then it must be decided if 75% of the findings are in agreement with the hypotheses.

Table 4 Levels of evidence rating for the quality of the psychometric properties

Level	Rating*	Criteria†
Strong	+++ or – – –	Test‡ was evaluated in multiple studies of adequate risk of bias score or one study of very good risk of bias score (implying a low risk of bias).
Moderate	++ or – – –	Test was evaluated in multiple studies of doubtful risk of bias score or one study of adequate risk of bias score.
Limited	+ or – – –	Test was evaluated in one study of doubtful risk of bias score.
Conflicting	±	Test was evaluated in studies with contradictory findings.
Unknown	?	Test was evaluated in studies of inadequate risk of bias score or not investigated at all.

Adapted from Kroman *et al*.[54]
*Sufficient (+), indeterminate (?), or insufficient (-) rating.[53]
†Modified using the new 4-point scoring system of the updated COSMIN checklist.[38]
‡A specific knee proprioception test.

the following data from each included study: (1) aims or research questions, (2) study design, (3) PMPs, (4) participant characteristics, (5) details of assessment (type of test, start position (e.g. sitting, standing, lying), equipment used, active or passive knee movement, velocity of knee motion, direction of motion, joint angle, muscle force, raters, number of sessions, time interval between trials/sessions, etc.), (6) objective outcome measures of knee joint proprioception including, among others, errors in joint position/angle matching (joint position sense error: constant error, variable error and absolute error), verbal identification of joint position,[23] identifying location of joint motion,[23] (passive) motion and direction detection,[21] active reproduction of target force,[19 21] weight identification,[23] active reproduction of target velocity,[21] the ability to discriminate between two or more movements,[24] (7) data analysis specific to PMPs and (8) study findings (on validity, reliability, and responsiveness) and conclusions.

Risk of bias assessment of individual studies

A minimum of two reviewers (among AA, AS, ET and UR) will independently assess risk of bias of each included study using the updated COSMIN risk of bias checklist.[38]Any disagreement will be discussed and resolved by consensus and, if no consensus can be achieved, another reviewer (CH) will be available for cross-referral.

The COSMIN checklist is a standardised tool used to assess the risk of bias of studies investigating patient reported health outcomes. Nevertheless, in recent times, it has been used to assess the risk of bias of studies reporting measurement properties of physical performance tests[39–41] using a four-point scoring system (very good, adequate, doubtful and inadequate). The criteria listed for reliability, measurement error, criterion validity, hypotheses testing for construct validity and responsiveness in the updated COSMIN checklist[38 42] will be used for studies evaluating the PMPs of knee proprioception tests. The scoring will be done using the worst score of any standard in the box depicting the overall score in each subsection.

Planned methods of analysis

A qualitative narrative synthesis (text and/or table format) will include, but not limited to, sample size, participant characteristics, study design, specific knee proprioception tests, type of proprioception sense, direction of knee movement, knee joint angles, type of equipment, type of outcome measures, between-limb/group comparisons, data analysis and PMPs. In addition, risk of bias assessment scores achieved with the updated COSMIN tool will be summarised.

A meta-analysis using a random-effects model will be attempted when a minimum of three studies[43] with relevant data on each knee proprioception test and with adequate homogeneity is available. Similar to papers[44 45] published previously, a pooled estimate of appropriate statistical measures (e.g. intraclass correlation coefficient, area under the receiver operator characteristic curve, effect sizes, etc.) and their 95% CIs will be derived with forest plots along with estimates of statistical heterogeneity, wherever plausible. For instance, separate meta-analysis will be attempted to investigate inter-rater and intra-rater reliability; intraclass correlation coefficients from each study will be transformed to Fisher's z scale and then pooled using a random-effects model.[46 47] The weighted average values will then be converted back to intraclass correlation coefficient values again to allow interpretation of the findings.[46 47] In cases where the same proprioception sense has been measured in different units in various studies then standardised mean difference instead of raw mean differences will be used for pooling the data in meta-analysis, if appropriate, for evaluating responsiveness. The standardised mean difference is the mean difference in outcome between groups or posttest vs pretest scores divided by the SD of outcome among participants.[48 49] With the I^2 statistic as a measure of statistical heterogeneity, a rough estimate of an $I^2 >$ 40% will be considered as a threshold for heterogeneity.[49] At the same time, as the clinical relevance of heterogeneity present across studies (between-study variability) is important, τ^2 statistic might be taken into account while performing meta-analysis.[50]

The feasibility of subgroup meta-analysis will be assessed based on the following factors: (1) each type of knee joint proprioception test and (2) population studied (healthy or those with ACL injuries managed conservatively or surgically). Moreover, if required, sensitivity analysis (the findings of high vs. low risk of bias studies) will be attempted in case of heterogeneous results. The trim and fill analyses (funnel plots) will be used to identify publication bias[51] if at least 10 studies are included in the meta-analysis.[52]

When a meta-analysis is precluded then each PMP of knee proprioception tests will be evaluated using the criteria: sufficient (+), indeterminate (?) or insufficient (-) rating (table 3).[53] Furthermore, the level of evidence for each knee proprioception test, based on the risk of bias scores of the included studies and the quality of PMPs, will be ascertained using an established criteria[54] summarised in table 4.

Ethics and dissemination

A systematic review of the available literature does not need ethical approval. Once the review is complete, it will be submitted as a series of manuscripts to scientific journals for peer-review and consideration for publication. The review findings may be presented at local and/or international conferences.

Contributors AA and CKH conceived the idea of the project. AA was responsible for designing the review, conceptualising the initial review protocol and led the writing of the manuscript. AS, ET, UR and CKH contributed to the design of the review and drafting the manuscript. All authors have reviewed and revised the manuscript for important content and approved the final version of it. AA is the guarantor of this work.

Funding This review is conducted as a part of a larger ongoing project related to functional assessment of individuals with anterior cruciate ligament reconstruction, knee-healthy controls and elite athletes. Funding was received from the Swedish Scientific Research Council (Grant No. K2014-99X-21876-04-4), Västerbotten County Council (Grant No. ALF VLL548501), Swedish Scientific Research Council for Sports Science (Grant No. CIF 2016/6 P2017-0068). The funders were not involved in any aspect of the review protocol.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

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