Proprioception in osteoarthritis

S.B. Zoethout[a] (Studentnumber: 3282945)

E.D. Wind[a] (Studentnumber: 3246914)

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Utrecht University, School of Clinical Health Sciences, Physical Therapy Sciences

Supervising investigators

Dr. M. van der Esch[b]

Dr. T. Takken[a,c]

Dr. M. Steultjens [d]

Prof. Dr. J. Dekker[b,e]

[a]School of Clinical Health Sciences at Utrecht University, [b]Jan van Breemen Institute, Amsterdam, [c]Child Development Exercise Centre Wilhelmina Childrens Hospital University Medical Centre Utrecht, [d] Professor of Musculoskeletal, School of Health, Glasgow Caledonian University and [e]Department of Rehabilitation Medicine, Department of Psychiatry and EMGO Institute for Health and Care Research, VU University Medical Center, Amsterdam,

Samenvatting

Doelstelling: Onderzoeken van de gewrichtsproprioceptie van de knie onderverdeeld in bewegingszin (BZ), actieve houdingszin (HZA) en passieve houdingszin (HZP), en hun onderlinge samenhang bij gezonde ouderen.

Methode: Het meetinstrument bestond uit een stoel met twee beensteunen. Deze beensteunen konden afzonderlijk worden bewogen door computer gestuurde elektromotoren. Om de BZ te meten werd het relatieve verschil tussen de starthoek en de positie waarin de beweging werd waargenomen als uitkomstmaat gebruikt. De HZA- en HZP-metingen bestonden uit het repositioneren van een gegeven testhoek met behulp van hetzelfde apparaat. Het verschil tussen de testhoek en de repositiehoek werd gebruikt als uitkomstmaat. Zowel de correlaties tussen BZ, HZA en HZP binnen de linker en rechter knie als de relaties tussen de linker en rechterknie, werden berekend met behulp van de Pearsons correlatie coëfficiënt.

Resultaten: In totaal hebben 46 gezonde ouderen (26 vrouwen, 20 mannen) met een leeftijd van 50 tot en met 72 jaar zonder knieklachten deelgenomen. De correlaties tussen BZ en HZA binnen de linker en rechter knie waren respectievelijk r= -0,07 en r= -0,03 en tussen BZ en HZP: r= -0,11 tot en met -0,04(links) en r= 0,08 tot en met 0,10 (rechts). De correlaties tussen HZA en HZP waren r= 0,28-0,46 (links) en r= -0,03-0,31 (rechts).

Conclusie: In deze populatie van gezonde oudere bestaat geen samenhang tussen BZ en HZ (HZA noch HZP). De samenhang tussen HZA en HZP is zwak. Deze resultaten suggereren dat BZ en HZ verschillende componenten van gewrichtsproprioceptie vertegenwoordigen. De zwakke samenhang tussen HZA en HZP suggereert dat zij als maat voor houdingszin niet uitwisselbaar voor elkaar zijn.

Trefwoorden: propriosepsis, bewegingszin, houdingszin, gezonde ouderen

Abstract

Objective. To examine knee proprioception measured by joint motion sense (JMS), active joint position sense (AJPS) and passive joint position sense (PJPS) and to assess their associations in a healthy elderly population.

Methods. The measuring device consisted of a custom made chair with a computer-controlled motor and two attached free-moving arms. For JMS, the angular displacement between the starting position and the position at the instant of movement detection was recorded. Both AJPS (30°) and PJPS (30°, 45°, 60°) comprised of a reproduction task performed with the same device; angular displacement between starting position and reproduction angle was recorded. The correlation between JMS, AJPS and PJPS within the same knee and between left and right knee were calculated with the Pearson correlation coefficient.

Results. The study group consisted of 46 healthy participants (26 female, 20 males), without knee complaints in the age of 50 to 72. The correlation within the left and right knee between JMS and AJP was r= -0.07 and r= -0.03 respectively, and between JMS and PJPS (left: r= -0.11 to -0.04; right: r= 0.08 to 0.10). The correlation between AJPS and PJPS was r= 0.28-0.46 (left) and r= -0.03-0.31 (right).

Conclusion. In a population of healthy elderly participants, there was no association of JMS with JPS (either AJPS or PJPS) and the association of AJPS with PJPS was weak. These results suggest that JMS and JPS are representing different aspects of joint proprioception. The weak association between PJPS and AJPS suggests that they are no interchangeable aspects of JPS.

Keywords: proprioception, joint motion sense, joint position sense, healthy elderly

Potentially published in : Arthritis and Rheumatism

Content

Review:

Hip proprioception measurement

- A systematic review of hip proprioception measurement -

Research:

Knee joint proprioception in the healthy elderly

- The association of joint motion sense with joint position sense -

Hip proprioception measurement

- A systematic review of hip proprioception measurement -

Introduction

Osteoarthritis (OA) is the most common form of arthritis, especially in the hip (1). A recent review shows that proprioceptive acuity in OA patients is impaired, compared to age and gender matched healthy controls (2). It also shows that limitations in activity are related to proprioceptive inacuity in OA patients (2). Little is known however of the assessment of hip proprioception in OA patients (3). There is also no overview on how hip proprioception is measured in general. Therefore this review will summarize current knowledge on hip proprioception measurement.

Proprioception is considered to be the afferent information from mechanoreceptors that contributes to conscious sensations, total posture and segmental posture (4). Submodalities of the conscious sensations are (a) joint position sense (JPS), (b) joint motion sense (JMS) (4). Therefore both JPS and JMS seem to be valid descriptors of joint proprioception. To enable research on these senses of the hip, a valid assessment method or instrument with good indices of reproducibility is needed. To appraise the current assessment methods and instruments the methodological quality of the studies is of great interest. Therefore the first aim of this review is to asses the methodological quality of studies measuring hip proprioception; secondly, to give an overview of hip proprioception assessment methods and available instruments and thirdly, to assess their clinimetric properties.

Methods

Design

Systematic literature review

Inclusion and exclusion criteria

The following inclusion criteria were used: (a) assessment of hip proprioception was used as outcome measure or measurement of hip propriocepion was the main topic; (b) studies had to describe the proprioception assessment; (c) in multiple joint measurement exclusive data of hip proprioception were available; (d) the study was published in English, German, French, Italian or Dutch and (e) only original full text studies were included. Studies with measurements of total posture were excluded.

Search

To identify publications, a search was made in PUBMED, EMBASE, CINAHL, SPORTDISCUS and the Cochrane Library. All databases were searched from earliest dates available until December 2009. In addition the reference lists of all the included publications were checked. A sensitive search was designed for PUBMED and adapted to the other databases. Different variations of the following text words were used to search the selected databases: Hip and proprioception. Subject headings of the selected databases were used to define the right keywords such as "Mesh-heading" or "Cinahl-heading". The full PUBMED search is listed in appendix 1.

Selection and data extraction

By title and abstract, both main reviewers (SZ and EW) independently selected potential publications for full text examination. After reading the full text articles, publications that met the selection criteria were included. The same reviewers extracted the data using a standardised data extraction form. Data such as movement direction, outcome, measurement instrument, subject position, starting angle, target angle, testing velocity and admission time were recorded. When needed, researchers in the field were contacted for additional data. Disagreements between the reviewers were identified, and discussed until consensus was achieved.

Assessment of methodological quality

To determine whether the methods of the study design were appropriate, applicable criteria according to Downs and Black were scored independently by the two researchers (5) (Table 1). Cohen's Kappa was used to asses a measure of agreement between the two researchers (6). In case of disagreement consensus was achieved by discussion. When consensus was not achieved a third researcher was asked to make the final decision.

Assessment of clinimetric properties

The clinimetric properties were assessed independently by the 2 reviewers, using a criteria list published by van der Leeden et al. (7). Besides the items for clinimetric quality, this checklist also provides levels of evidence for reliability, validity and responsiveness, depending on the methodological quality. Once the applicable level of evidence had been identified, a positive or negative rating was assigned corresponding to the results of the study. If the methodological quality was not appropriate, the measurement property was rated as indeterminate. If no information was available, a zero was recorded. Some small adaptations were made to make the criteria suitable for this review: (a) the item for internal consistency was removed because this was not applicable for performance-based studies. (b) Criterion validity was removed because no criterion existed for proprioception. (c) The criterion to receive a positive rating for reliability was adapted by removing the requirement that if the Minimal important difference (MID) was not known, the smallest detectable change (SDC) should be smaller than 0.5 SD. This would mean that the ICC had to be at least > 0.97. (d) The criterion for receiving a positive rating on content validity was set on to measure only hip proprioception, a negative rating was given when multiple joints were measured. The used criteria are presented in table 2.

Results

The search strategy provided 7,528 unique publications (see flowchart). After reading title and abstract, 22 publications were selected for full text examination. In addition, 8 publications were added by reference tracking of the retrieved articles. In total, 30 publications were read full text. Finally 13 publications were included in this review. The publications dates range from 1973 (25) to a recent study from Bejaminse et al. (26) in 2009. No other study than the study of Gelecek et al. (3) examined hip proprioception in subjects with OA.

Methodological quality

The methodological quality of the studies is summarized in table 1. The Cohen's Kappa score was k=0.638 and considered to be a substantial agreement (6). Six studies had sufficient methodological quality (26-31) only one had a positive score on all items (28). The OA study had insufficient methodological quality.

Measurement of proprioception

A total of 13 studies provide 24 different methods in measuring hip proprioception. Only the two studies of Ishii et al. (13,32) used the same method to measure hip proprioception. A distinguish can be made by methods measuring joint motion sense

(JMS), often called kinesthesia, and joint position sense (JPS). JPS can additionally be divided in active JPS (AJPS) and passive JPS (PJPS). One study also measured force sense (FS) as a component of joint proprioception (26). Two studies measured only JMS (33,34) and four studies only AJPS (13,29,30,32). PJPS was not measured solely. A combination of JMS, PJPS and AJPS was only investigated in one study (25). The OA study investigated JMS and PJPS.

JMS

In total seven studies report measures of eight methods of JMS-measurement (3,25-27,31,33,34). Two different methods for measuring JMS were used in the study of Grigg et al. (25). JMS was measured in all general moving directions of the hip. All studies used different sets of measurement tools to assess JMS. For a summery see Table 3.

In general, the measurement procedure for JMS was: First, the hip was mechanically or manually moved. Next, the participant had to detect the start of this movement as quick as possible. Except for two studies (31,33), the threshold to detect passive motion (TTDPM) was used as main outcome. However calculations of TTDPM differ throughout the studies. Three studies calculated the TTDPM as mean value of angular displacement between starting position and threshold position (3,25,26). Movement, measured in millimeters, was converted into angular deflection in the study of Eakin et al. (27). Threshold for 70% accurate detections was used as to determine TTDPM in one study (34). High testing velocities (range 0.5°/sec to 12.5°/sec) were used in these studies compared to the other methods (range 0.1°/sec to 1.0°/sec). A total administration time of 2-3 hours was given for the method of Refshauge et al. (34). For the other methods no information of administer time was reported.

PJPS

There are five studies reporting five methods of PJPS measurement (3,25,27,28,35). PJPS was measured in abduction, flexion and extension. Different devices were used, three methods consisted of the same devices to measure JMS (3,25,27). For a summary see Table 4.

Despite different methods and devices, the purpose of PJPS tests was testing the participants' capability in reproducing a certain angle of the hip. In general the participants hip was manually (3,28,35) or mechanically (25,27) moved with a specific velocity to a testing angle. Than the hip was moved back into the original position. Next, the hip was again passively moved toward the testing angle. The participants had to reproduce the perceived testing angle by pushing a button or give a verbal signal to stop the movement. Reposition error in degrees (RE°), the relative or absolute angular displacement in degrees between the testing angle and reproduction angle, was the main outcome in four methods (3,27,28,35). Instead of RE°, Grigg et al. (25) used the ability of a participant to judge the magnitude of an abduction in relation to a given magnitude of a standard abduction to measure PJPS. An abduction of 7.5° was given the magnitude of fifteen. The participant was asked to give a number to certain abduction, thus large abductions would be assigned large numbers and small abduction, small numbers. Outcome was the correlation between given magnitude and angular excursion. Starting angle in combination to the target angle varied the most throughout the methods. Testing velocity was not reported in two methods (3,35).

AJPS

Nine studies report measures of AJPS resulting in 11 different methods of AJPS measures (13,25,26,28-32,35). One study used two different methods and devices (26); the study of Stender et al. used three different methods. For a summery of the different methods see Table 5.

The purpose of an AJPS test is similar to PJPS to reproduce a target angle. When testing AJPS, reproduction was performed actively instead of passively. Three methods used different examples to indicate which angle had to be reproduced. (a) Grigg et al. (25) converted the range of angles into a range of magnitudes, where the participant had to reproduce a given magnitude). (b) Stender et al. (35) used a picture with a certain angle of the hip which the participant had to reproduce; the second task the participant slowly flexes one leg with the foot sliding over the surface, the other hip attempts to match the angle with a straight leg (c) Wingert et al. (31) first tested a random set of angles in a vision condition followed by a session without sight of pointing direction. Six methods used the so called active-active method; the participants had to actively move the hip to the target angle; move back to the starting angle and finally moving the hip again to the testing angle without any cues whether the target angle was reached or not. In one study the hip was moved passively into the target angle by the researcher and then reproduced by the participant. Except for one, all methods used the RE° as main outcome.

Clinimetric properties

An overview of all reported clinimetric propterties is given in table 6. Only one study was designed as a clinimetric study (26). This study provided clinimetric results for methods measuring JMS and AJPS.

Reproducibility for JMS was only determined in one study. Inter-rater reliability, intra-rater reliability and agreement were investigated. With a time interval of one week, the ICC for intra-rater reliability ranged from 0.54(extension) to 0.825(abduction). The ICC for inter-rater reliability ranged from 0.777(extension) to 0.906(abduction). The standard error of measurement (SEM) for the intra-rater agreement was ranged from 0.219°(flexion) to 0.31°(extension) and inter-rater agreement SEM was 0.81° (flexion) to 0.906° (abduction).

None of the studies investigated reproducibility of the PJPS methods. For AJPS two studies (26,29) did; Mendelsohn et al. (29) investigated intra-rater reliability (ICC= 0.22 to 0.49; time interval 1 day); Benjaminse et al. studied besides intra-rater reliability and agreement (ICC= 0.54 to 0.825; SEM°= 0.219° to 0.31°), also inter-rater reliability and agreement (ICC= -0.079 to 0.753; SEM=0.143° to 0.195°).

The methods of three studies (27,30,35) and the method measuring AJPS from Benjaminse et al.(26) received a negative rating on content validity because of afferent input from other joints.

The level of evidence for construct validity was found sufficient in six studies. Hypotheses formulated in these studies can be divided in (a) fundamental hypotheses about the theoretical construct of hip proprioception (35); (b) hypotheses about variables influencing joint proprioception (27,28,30); or (c) relation to other measurement tools (29).

Responsiveness was examined in one study (29). No information about floor and ceiling, and interpretability was reported. The study investigating proprioception in subjects with OA did not provide any information of clinimetric properties.

Discussion

The objective of this review was to investigate how hip proprioception is measured and to indentify the methodological quality and clinimetric properties. We found 13 studies with 24 different methods to measure hip proprioception; 8 methods for measuring JMS; 5 for PJPS; and 11 for AJPS. Six studies had sufficient methodological quality (26-31). Information about clinimetric properties was sparse. Because of insufficient methodological quality and no information about clinical properties the study with patients with OA provides no relevant information how to measure hip proprioception. Based on available clinimetric properties, only one method for JMS can be recommend to be used in future research.

Methodological quality was insufficient for seven studies. Most of these studies did not provide information of the study population and did not use appropriate statistical analyses. We found these items to be of great importance to compare the future results. The reason that recent studies had more often adequate methodological quality may be found in the increase in guidelines for writing of scientific publications, such as the consort statement and the critical appreciation with instruments as the Downs and Black checklist (5) and PEDro checklist (36).

Measurement of JMS seems to be reliable when using the methods of Benjaminse et al. (26). They used the Biodex System 3 Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc, Shirley, New York) in combination with sixteen 14-mm retroreflective markers according to the Plug-in-Gait model (Plug-in-Gait; Vicon Inc, Englewood, Colorado). This method was rated with a 3+ for reliability and therefore recommend for the use in future research. Based on current literature no recommendation could be made to measure PJPS. Further research is needed to asses reproducibility of the current methods or new methods have to be developed. AJPS was measured using a electro goniometer and in supine position (29), in standing position using an analogue angle indication (26) and sixteen 14-mm retroreflective markers according to the Plug-in-Gait model (Plug-in-Gait; Vicon Inc, Englewood, Colorado) (26). These methods could not be recommend because of a 3- rating.

Content validity was rated negative when afferent input from other joints then the hip was likely to influence the results, for example when testing in standing position. Although we agree that testing in standing position is more realistic we argue that current fundamental knowledge of hip proprioception should be of primary interest. Without knowledge of hip proprioception, relationships with diseases or physical functioning can hardly be investigated.

Hypotheses formulated to asses construct validity in the presented studies must be viewed with caution. Although these hypotheses received ratings varying from 1+ to 3- none of the methods used had an adequate index of reproducibility.

Limits of this review can be found in the search strategy. Although we think that we performed a sensitive search for hip proprioception we only used synonyms for ‘proprioception’ and ‘hip’ and did not include terms for clinimetric properties. This could have caused some selection bias. We have tried to minimize selection bias by independent selection of studies by the two main reviewers according to the selection criteria.

Because no standardized criteria existed to evaluate clinimetric properties of measurement methods we used the criteria according Van der Leeden et al. (7). Although these criteria are, arbitrary they provide transparency as to whether the clinimetric properties are appropriate or not.

In conclusion, different methods with a variety of devices have been indentified for measuring hip proprioception. Because of lacking information on clinimetric properties only a recommendation can be made how to measure JMS in patients with OA. For PJPS and AJPS more clinimetric studies are needed to make measurement of hip proprioception useful in research.

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Tables

Table 1: Methodological quality

				Methodological assessment									
Study	**Study population**	**Study size**	**Type proprio-cetpion**	**Main outcome**	**Population character**	**Distribution confound**	**Main finding**	**Estimates variability**	**Description instrument**	**Enhance reliability**	**Appropriate statistic**	**Sufficient power**	**Methodo-logical adequate**
Grigg 1973	Patients pre and post recent hip surgery	22	JMS I, JMS II, AJPS, PJPS	+	-	-	+	-	+	+	-	+	**NO**
Karanjia 1983	Patients with unilateral hipreplacement, hetrolateral hip served as control	10	JMS	+	-	-	+	+	-	+	-	-	**NO**
Eakin 1992	Patients with above knee amputation	10	JMS, PJPS	+	+	-	+	+	+	+	+	+	**YES**
Stender 1994	Patients with totalatrhroplasty of the hip, Healthy controls	23	AJPS, PJPS	+	-	-	+	+	+	+	-	-	**NO**
Refshauge 1995	Healthy adults	10	JMS	+	-	-	+	-	+	+	+	+	**NO**
Ischii 1999	Patients with hemiatrhroplasty after fracture, Total hip arthroplasty due to osteoarthritis, Healthy age matched controls	35	AJPS	+	-	-	-	+	+	-	-	-	**NO**
Ischii 2000	Patients with hemi- or totalatrhroplasty of the hip after fracture, Healthy age matched controls	36	AJPS	+	-	-	+	+	+	-	-	-	**NO**
Pickard 2003	Healthy young and healthy aged	59	AJPS, PJPS	+	+	+	+	+	+	+	+	+	**YES**
Mendelsohn 2004	Patients after hip surgery secondary to an unilateral hip fracture	30	AJPS	+	+	-	+	+	+	+	+	+	**YES**
Gelecek 2006	Patients with osteoarthritis	63	JMS, PJPS	+	+	-	+	+	-	-	+	-	**NO**
Lin 2006	Elite, amateur and novice tennisplayers	62	AJPS	+	+	-	+	+	+	+	+	+	**YES**
Wingert 2009	Patients with spastic diplegia, Patients with hemiplegia, Healthy aged matched controls	59	JMS, AJPS	+	+	+	+	+	+	-	+	+	**YES**
Benjaminse 2009	Healthy adults	20	JMS, AJPS	+	+	-	+	+	+	+	+	+	**YES**

JMS: Joint Motion Sense; AJPS: Active Joint Position Sense; PJPS: Passive Joint Position Sense

Table 2: Criteria for Clinimetric properties

	Level of evidence		Recuirements for level of evidence			Recuirements for rating
Reliability	1	*if*	Intraclass correlation coefficient (ICC) or kappa and N ≥ 50	+	*if*	ICC/Kappa > 0.70, with the lower limit of the confidence interval (CI) > 0.60
	2	*if*	Pearson and N ≥ 50	+	*if*	r > 0.80
	3	*if*	ICC, kappa or Pearson and N< 50	+	*if*	ICC/Kappa > 0.80, with the lower limit of the CI > 0.60; or pearson > 0.90
Measure-ment Error	1	*if*	Limits of agreement (LOA) OR smallest detectable change (SDC)	+	*if*	LOA/SDC < Minimal inportant difference (MID)
Content validity				+	*if*	Only measures of the hip joint
				-	*if*	Multiple joints measures explaining hip joint proprioception
Criterion validity	NA					
Construct validity	1	*if*	Specific hypothesis defined concerning expected relationships with other measures or expected differences in scores between specific subgroups.	+	*if*	A positive level 1 rating was assigned if at least 75% of these hypotheses were confirmed in (sub)groups of at least 50 patients
	2	*if*	No hypothesis about expected relationships with other measures was defined beforehand	+	*if*	Plausible relationships with other mea- sures were found in a (sub)group of at least 50 patients.
	3	*if*	No hypothesis about expected relationships with other measures was defined beforehand	+	*if*	Plausible relation- ships with other measures were found in a (sub)group of at least 20 patients.
Floor and Ceiling effects			Floor and ceiling effects were considered present if >15% of respondents achieved the highest and lowest possible score, respectively	+	*if*	No floor or ceiling effects
Responsiveness	1	*if*	Specific hypothesis defined concerning expected longitudinal relationships with other measures or expected longitudinal differences in scores between specific subgroups.	+	*if*	A positive level 1 rating was assigned if at least 75% of these hypotheses were confirmed in (sub)groups of at least 50 patients
	2	*if*	No hypothesis about expected longitudinal relationships with other measures was defined beforehand	+	*if*	Plausible relationships with other mea- sures were found in a (sub)group of at least 50 patients.
	3	*if*	No hypothesis about expected longitudinal relationships with other measures was defined beforehand	+	*if*	Plausible relation- ships with other measures were found in a (sub)group of at least 20 patients.
Interpretability				+	*if*	MID is calculated in a sample size of ≥ 50 patients
			Other possible ratings are	-		Negative rating
				?		Indeterminate rating
				0		No information availible
				NA		Not appliciable

Table 3: Measurement properties Joint Motion Sense (JMS)

	Move direction	Outcome	Device	Methods of assessment: Subject position	Starting angle (°)	Testing velocity (° / sec)
Grigg 1973	Abduction	TD° calculated from correct number of stimuli detected	Mechanically driven, custom made testing arm, analogue angle indication	Supine	Neutral	0.15
	Abduction	AD° when detecting movement		Supine	Neutral	0.6
Karanjia 1983	Flexion, Extension	Detection of 20 movements in correct direction	Manual movement, monitored by a linear potentiometer (Tektronix DC amplifier) and storage oscilloscope, fixed to an arm	On hetro lateral side	10-15, 45 -50 flex., 10-15, 45-50 ext.	0.5 and 2.0
Eakin 1992	Extension	TD° calculated from linear displacement of truck	Mechanically moved, custom made footrest-truck	Standing	60 Flexion	0.5
Refshauge 1995	Flexion, Extension	TD°, TD% TDmm of at least 70% of stimuli	Mechanically moved, electromagnetic vibrator, displacing rod, a oscilloscope	On hetro lateral side	10 Flexion	0.1, 0.5, 5.0 and 12.5
Gelecek 2006	Abduction	TD° AD when detecting movement	Manual movement and goniometry (Guymon, Model 01129, Lafayette)	Standing	30 Abduction	0.5-1.0
Wingert 2009	Exorotation, Endorotation.	Detection of 10 movements in correct direction	Mechanically moved ,Custom made, semi-goniometeraxis	Semi-reclined	45 Flexion	0.5
Benjaminse 2009	Abduction, Adduction	TD°, AD when detecting movement	Mechanically moved, Sixteen 14mm markers, software collection and export of hip angles, The Biodex System 3 Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc, Shirley, New York)	On hetro lateral side	15 Abduction	0.25
	Flexion, Extension			Supine	45 Flexion	0.25

TD° = threshold detection in degrees; AD = angular displacement

Table 4: Measurement properties Passive Joint Position Sense (P-JPS)

					Methods of assessment				
	Move direction	**Outcome**		**Device**	**Subject position**	**Starting angle**	**Target angle (°)**	**Testing velocity (° / sec)**	**Other**
Grigg 1973	Abduction.	Accuracy in judging angles in *r*	Correspondence of judgment with testing angle	Mechanically driven, custom made testing arm, analogue angle indication	Supine	Neutral	0.5 - 15	2.0	Judging of angles was related to a standard of 7,5 degree abduction
Eakin 1992	Extension	RE in °	AD between testing and target angle calculated from linear displacement of truck	Mechanically moved, custom made footrest-truck	Standing	60° flex.	35°, 40°, 45°, 50°, 55 ° flex.	0.5	
Stender 1994	Flexion	RE in °	AD between testing and target angle	Manually movement, handheld goniometry, yardstick	Supine	Neutral	20°,40°,60 ° and 80° flex.	?	
Pickard 2003	Abduction	RE in °	AD between testing and target angle	Manual movement, The 3Space Fastrak (Polhemus Navigation, Vermont) motion analysis system	Supine	10° add.	10° abd.	5	
Gelecek 2006	Abduction	RE in °	AD between testing and target angle	Manual movement and goniometry (Guymon, Model 01129, Lafayette)	Standing	Neutral	30° abd.	?	

RE = reposition error; AD = angular displacement

Table 5: Measurement methods Active Joint Position Sense (AJPS)

	Move direction	Method (A / P / O)	Measurement instrument		Methods of Assessment			
			Device	**Angle measurement/ other**	**Subject position**	**Starting angle (°)**	**Target angle (°)**	**Other**
Grigg 1973	Abduction	O	CM testing arm in transversal plane	CM analogue angle indication	Supine	Neutral	Variable	Target angle was presented as an index
Stender 1994	Flexion	O		Handheld goniometry	Supine	Neutral	20, 40, 60, 80	Reproduction of heterolateral hip with testing leg extended.
	Flexion	A		Handheld goniometry	Supine	Neutral	20, 40, 60, 80	Reproduction of angle presented on a picture
	Flexion	P	Manual movement	Handheld goniometry	Supine	Neutral	20, 40, 60, 80	
Ishii 1999, 2000	Abduction Flexion	A		Electro goniometry (Instrumented Spatial Linkage (ISL))	Standing	Neutral	30 abduction 30 flexion	6 reps with each test serving as an index for the next test
Pickard 2003	Abduction	A		The 3Space Fastrak motion analysis system (Polhemus Navigation, Vermont)	Supine	Full adduction minus 10% of total ROM	20 from start angle	
						20 from target angle	Full abduction minus 10% of total ROM	
Mendelsohn 2004	Flexion	P	Manual movement	Electro goniometry	Supine	Neutral	15, 30, 60 flexion	
Lin 2006	Extension	A	Constant resistance device (close chain)	Electro inclinometer,	Supine	60 flexion	?	90° flexion of the knee
Wingert 2009	Exorotation Endorotation	O	CM foam lined holder	CM analogue angle indication	Semi-reclined	45 flexion	?	
Benjaminse 2009	Exorotation Endorotation	A	CM Rotating disc	CM analogue angle indication	Standing	Neutral	Max endo and exo, minus 10% of full ROM	
	Abduction	A		16 14mm retroreflective markers, (Vicon Nexus software collection)	Standing	Neutral	15°	
	Flexion	A			Standing	Neutral	45°	

A: target angle performed actively; P: target angle performed passively; O: other; CM: custom made; ?: not reported

Table 6: Clinimetric properties

	JMS	P-JPS	A-JPS
Reliability	(26): 3 / +		(29): 3/- (26): 3/-
Agreement	(26): 2 /-		(26): 2/-
Content validity	(25): + (26): + (27): - (31): + (33): + (34): +	(25): + (27): - (28): + (35): -	(13,32): + (25): + (26): - (28): + (29): + (30): - (31): + (35): -
Construct validity	(27): 1/- (31): 1/+	(27): 1/- (28): 1/- (35): 1/?	(28): 1/- (29): 3/- (30): 2/+ (31): 1/- (35): 1/?
Floor Ceiling			
Responsiveness			(29): 3/-
Interpretability			

+ : positive rating; - : negative rating; ? : indeterminate rating

Figures

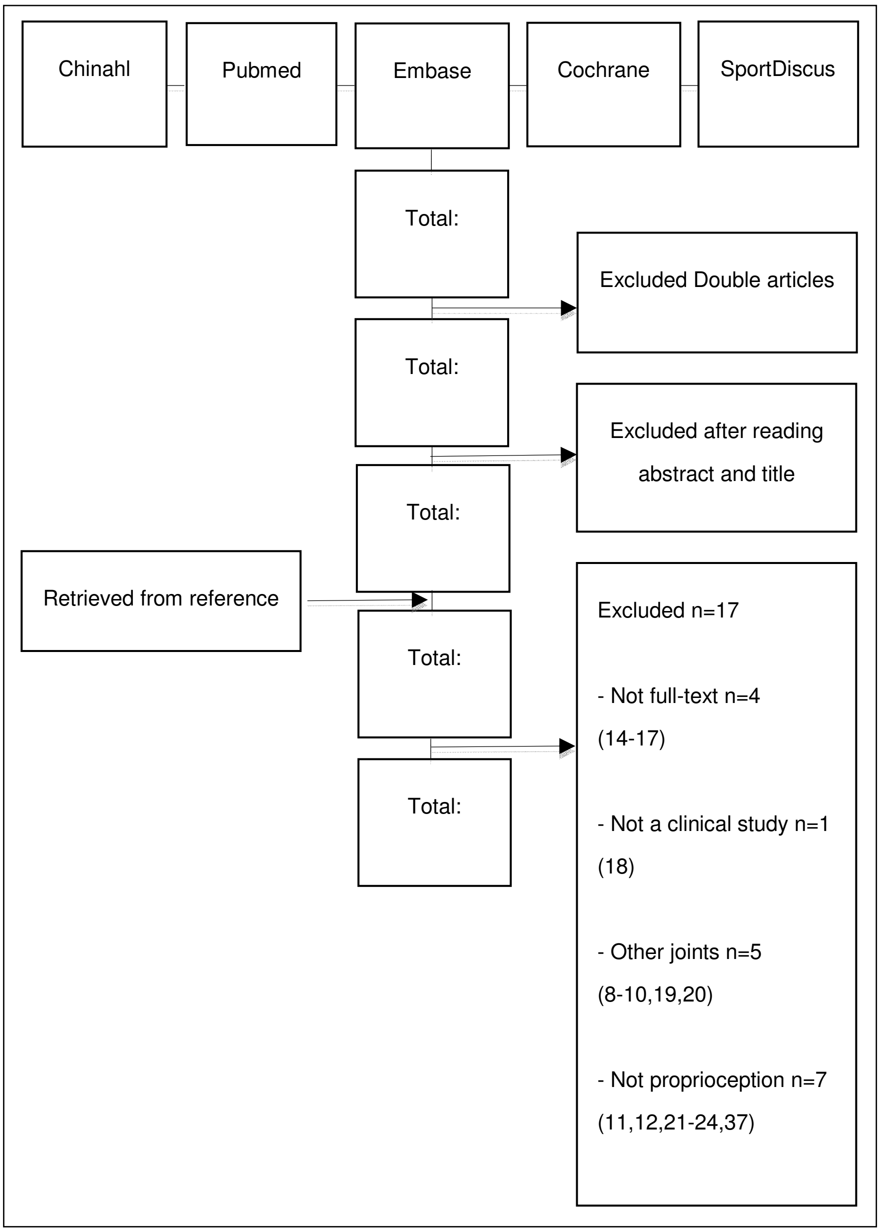

Figure 1: Flowchart of publication

Appendices

Appendix 1

Search Strategy Pubmed	
#1	hip[MESH]]
#2	hip joint[MESH]
#3	lower extremity[MESH]
#4	Thigh[MESH]
#5	Hip[tiab]
#6	Hip*[tiab]
#7	Cox[tiab]
#8	Cox*[tiab]
#9	“hip joint” [tiab]
#10	“hip joints”[tiab]
#11	“lower limb” [tiab]
#12	“lower limbs”[tiab]
#13	“Lower extremity”[tiab]
#14	“Lower extremities”[tiab
#15	“Lower extremit*”[tiab]
#16	Thigh[tiab]
#17	Thighs[tiab
#18	#1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #12 OR #13 OR #14 OR #15 OR #17
#19	Proprioception[MESH]
#20	Kinesthesis[MESH]
#21	Propriocept*[tiab]
#22	Proprioceps*[tiab]
#23	Propriocepc*[tiab]
#24	"joint instability"[tiab]
#25	"joint stability"[tiab]
#26	balance[tiab]
#27	balanc*[tiab]
#28	“postural sense”[tiab]
#29	“postural senses”[tiab]
#30	“postural balance”[tiab]
#31	"position sense"[tiab]
#32	"position senses"[tiab]
#33	"sense of position"[tiab]
#34	"senses of position"[tiab]
#35	"joint reposition sense"[tiab]
#36	"joint reposition senses"[tiab]
#37	"joint position sense"[tiab]
#38	"joint position senses"[tiab]
#39	"motion sense"[tiab]
#40	"motion senses"[tiab]
#41	"sense of motion"[tiab]
#42	"senses of motion"[tiab]
#43	"joint motion sense"[tiab]
#44	"joint motion senses"[tiab]
#45	"movement sense"[tiab]
#46	"movement senses"[tiab]
#47	Kinesthes*[tiab]
#48	Kinaesthes*[tiab]
#49	Kinesthet*[tiab]

#50	Kinaesthet*[tiab]
#51	"neuromuscular control"[tiab]
#52	"sensimotor changes"[tiab]
#53	equilibrium[tiab]
#54	stathetic[tiab]
#55	stathetic* [tiab]
#56	buckling[tiab]
#57	shifting[tiab]
#58	"given way"[tiab]
#59	"giving way"[tiab]
#60	#19 OR #20 OR #21OR #22 OR #22 OR #23 OR #24 OR #25 OR #26 OR #27 OR #28 OR #29 OR #30 OR #31 OR #32 OR #33 OR #34 OR #35 OR #36 OR #37 OR #38 OR #39 OR #40 OR #41 OR #42 OR #43 OR #44 OR #45 OR #46 OR #47 OR #48 OR #49 OR #50 OR #51 OR #52 OR #53 OR #54 OR #55 OR #56 OR #57 OR #58 OR #59
#61	(addresses[PT] OR biography[PT] OR case reports[PT] OR comment[PT] OR directory[PT] OR editorial[PT] OR festschrift[PT] OR interview[PT] OR lectures[PT] OR legal cases[PT] OR legislation[PT] OR letter[PT] OR news[PT] OR newspaper article[PT] OR patient education handout[PT] OR popular works[PT] OR congresses[PT] OR consensus development conference[PT] OR consensus development conference, nih[PT] OR practice guideline[PT]) NOT (animals[MeSH Terms] NOT humans[MeSH Terms])
#62	#18 AND #60 AND #61

Knee joint proprioception in the healthy elderly

- The association of joint motion sense with joint position sense -

Introduction

Osteoarthritis (OA) of the knee is one of the leading causes of limitations in daily functioning in the elderly (1). Limitations in activity are related to biomechanical factors, such as muscle weakness and deficient knee joint proprioception (1-3). Knee joint proprioception and activity limitations are weakly related (4). However, poor joint proprioception exacerbates the effect of muscle weakness on activity limitations (4). Although knee joint proprioception seems to be an important factor in activity limitations, research on joint proprioception is sparse.

Proprioception in the knee comprises joint motion sense (JMS) and joint position sense (JPS) (5). Both derive from afferent input of mechanoreceptors of the joint, skin, muscles and tendons (6). Although JMS and JPS are supposed to be part of the same afferent system, little is known about their association. Previous research has shown that JMS and active JPS (AJPS) are weakly associated (7) and JMS and passive JPS (PJPS) are not associated (8). Whether JMS and both active and passive JPS are different aspects or interchangeable components of joint proprioception is currently not known. Assessment of JMS has been studied using different methods and instruments of measurement (9-11). Studies involving assessment of JPS do not only vary in measurement procedure, but also in the selected biomechanical approach (e.g. weight bearing versus non weight bearing and active versus passive positioning of the joint) (12-14). These differences in measurement procedures and biomechanical approaches limit estimations on the relationship between JMS and JPS.

Assessment of JMS and JPS under equal environmental circumstances, with the same biomechanical approach and comparable indices of reproducibility would enable accurate estimation of their association. In a previous study JMS was assessed with high indices of reproducibility (11). To assess JPS by both active and passive repositioning tests is currently possible. However, the relationship between JMS and JPS is unclear.

The aim of this study is to investigate the relation between JMS, AJPS and PJPS in a population of healthy elderly. To accomplish this our objective is to examine JMS, AJPS and PJPS and assess their association in a healthy elderly population. Proposed biomechanical differences between JMS and JPS could be responsible for the absence of a relationship between JMS and JPS. Therefore, it is hypothesized that JMS and JPS are not related to each other. AJPS and PJPS are expected to be less different, therefore we hypothesized that AJPS and PJPS are related to each other.

Methods

Ethics

The ethics committee of the VU University Medical Center Amsterdam approved the study and the participants gave their informed written consent prior to inclusion in the study.

Subjects

Community based healthy voluntary participants were recruited from the Amsterdam area. Participants were employees of the Jan van Breemen Institute and relatives of the research staff. Volunteers were eligible for participation when they were aged 50 years or over and had adequate control of the Dutch language in written and spoken communication. Participants were excluded when they met one of the following criteria: (a) presence of prosthesis at the lower extremity, (b) steroid injection in the knee within two months prior to inclusion, (c) recent, < 1 year, history of a lower extremity fracture, (d) presence of neurologic and related neurologic disorders or orthopaedic disorders, (e) history of traumatic knee injury and (f) presence of osteoarthritis of the knee.

Measures

One researcher (SZ) recorded the demographic variables including sex, age, body weight, length, educational level and physical activity level. Lin et al. (15) suggested that the level of physical activity could be related to joint proprioceptive acuity. The physical activity level in the current study was assessed using the Short Questionnaire to Assess Health-enhancing physical activity (SQUASH) (16). The outcome of interest was whether participants did or did not perform moderate exercises for at least 5 times a week lasting 30 minutes or longer.

General procedure

JMS and JPS (both AJPS and PJPS) were measured in one session with a duration of approximately one hour. The device consists of a chair with a computer-controlled motor and transmission system and two attached free-moving arms (figure 1). Both angles and angular speed are adjustable using a digital control panel. Each arm supports the subject's shank and foot and moves in the sagittal plane. The joint of each arm is moved by a computer controlled stepper motor and a transmission system for angular displacement. The amount of angular displacement is recorded with a frequency of 60 Hz and presented in decimal degrees on a digital display. In the JMS test and passive JPS tests the foot is attached to the arm on a footrest with an air splint. In the active JPS test the participants' knee is resting on the footrest until actively reproduction of the testing angle is requested. The angular displacement is detected by a digital inclinometer that is attached to the participants' lower leg just below the tuberositas tibiae. An upward-bending tray is attached to the chair to prevent visual input of the moving knee. Two response-buttons are mounted on the tray. The seat of the chair consists of a gel pad to prevent any vibrating sensation and movement of the skin.

The measurement device provides a measurement of angular displacement, while minimizing visual and auditory stimuli, vibrations, cutaneous tension, and pressure cues to limb motion. Subjects were seated in a semi-reclining position with the back supported and the knee hanging over the edge of the seat, which is 5 cm proximal to the popliteal fossa. The knees were placed in 90° flexion and the hips in 70° flexion.

Although the measurement of JMS has proven to be reliable (11), some individual variability is expected. This variability might have a disturbing effect on the calculation of the correlations between the three types of joint proprioception. Use of the mean of multiple measures would reduce the disturbing effect of random variability and enhances a more genuine approximation of the score. Pilot testing revealed greater variability in the AJPS, compared to the PJPS measurements. Therefore the measurement of JMS and PJPS was repeated 3 times and the measurement of AJPS 9 times. Both moving arms and inclinometer were calibrated daily before testing commenced.

All participants received the same protocolized instructions given by the same researcher (EW). The measurement protocol was practiced and accordingly standardised, by test-piloting 5 volunteers. Data from these tests were excluded from the study results. Depending on the odd or even identification number the measurement started with the right or left leg respectively.

Joint Motion Sense (JMS)

JMS measurement consisted of a knee joint movement detection task. From the rest position (70° knee flexion), both legs were moved to a starting position of 45° knee flexion. Following a random delay, one knee was extended further with an angular velocity of 0.3°/second. Participants were instructed to push the response-button at the moment of definite detection of knee joint position change. After detection both legs moved back to the rest position. This procedure was repeated 3 times for each leg. The angular displacement between the starting position at 45° flexion and the position in the extension direction at the instance when the button was pushed was recorded as the measure of knee joint JMS (4). This means that a lower value (i.e., a small difference between the knee joint angle at onset of movement and the knee joint angle at the moment of detection of knee joint position change) indicates better joint proprioception.

Active Joint Position Sense (AJPS)

AJPS measurement also consisted of a position reproduction test. In this test the leg was passively moved to a test-angle of 30° of knee flexion. This position was maintained for 5 seconds to allow the participant to concentrate on the angle. Participants were not allowed to make muscle contractions to determine the position. Thereafter the leg was moved back to the starting position. The participant was then asked to reproduce the testing angle by extending the knee. By pushing the response-button the participant indicated that the testing angle was reproduced. The relative angular displacement in degrees between the testing angle and reproduction angle was recorded as the measure of knee joint AJPS. This means that a lower value (either positive or negative) indicates better AJPS.

Passive Joint Position Sense (PJPS)

PJPS measurement consisted of a reproduction task. First the leg was extended from 70° knee flexion to 60°, 45° or 30° with an angular velocity of 0.3°/second. When the position was reached the participant was told to concentrate on this position for five seconds. Then the leg was moved back to 70° knee flexion. After 1 second the same leg was extended again with the same velocity. The participant was instructed to push the response-button when he or she felt the testing angle was reproduced before reaching the maximum of 15° knee flexion. This procedure was repeated until for both legs three reliable measures were recorded for each of the three positions (60°, 45°, 30°). To minimize the learning effect, the researcher varied the order of measurement by random selection. The relative angular displacement in degrees between the testing angle and reproduction angle (degrees) was recorded as the measure of knee joint PJPS. This means that a lower value (either positive or negative) indicates better PJPS.

Statistical analysis

Sample size

The calculation of the required sample size was based on previous research on the correlation between JMS and JPS (7,8). Correlations between 0.29 ($p<0.025$) for AJPS (7) and $r= 0.07$ ($p>0.05$) for PJPS (8) were found in mixed populations of young and elderly healthy subjects. A correlation of $r= 0.29$ would be significant at a $p<0.05$ when the sample consisted of at least 50 subjects (17).

JMS and JPS

First, the mean angular displacement of JMS, AJPS and PJPS for the left and right knees was calculated separately. Secondly, in case of a normal distribution of the means, the Pearson correlation coefficients of the relationships between JMS, AJPS and PJPS for the left and right knees were separately calculated. Spearman rank correlation coefficient was calculated when the data were not normally distributed. Thirdly, in order to compare the left and right knee the means of JMS, AJPS and PJPS were compared with a paired sample t-test and their correlation was calculated under previous mentioned conditions. The influence of gender, age, BMI and level of physical activity on the relationships between JMS, AJPS and PJPS was calculated in post-hoc analyses.

Identification of outliers

Outliers were identified by visual trend analysis of all measurements and/or by the criteria of the statistical software (a deviation of ≥ 1.5 Inter Quartile Range [IRQ] per measurement). When the deviation could not be explained by any participant characteristic (e.g. BMI, age) or methodological variable (measurement sequence), the deviation was considered to be part of the random variability and therefore not excluded from analysis.

All analyses were performed using SPSS for Windows 15.0 (SPSS Inc., Chicago, IL, USA).

Results

Participants were recruited between January 2010 and April 2010. A total of 20 male and 26 female participants were included in the study. Characteristics of the participants are listed in table 1. Preliminary analyses of the data revealed no outliers. Therefore, all data were used in the analysis. The mean scores (±SD) of JMS, AJPS and PJPS are presented in table 1. In post hoc analyses the impact of age, gender, BMI and level of physical activity on proprioceptive acuity was calculated. Both age and BMI were dichotomized by using the median (age 58 years and BMI 26.8). Using an independent sample t-test no overall impact could be found. However, statistical significant differences were found for JMS between men and women for the right knee and for PJPS in 60º knee flexion for the left knee.

JMS, PJPS and AJPS within left and right knee

The correlations between JMS, PJPS and AJPS within the same knee were calculated with the Pearson correlation coefficient. The results are presented in table 2.

JMS, PJPS and AJPS between left and right knee

Paired wise comparison using a students t-test showed only a statistical significant difference for the mean JMS of the left and right knee ($p<0.05$). The correlations for JMS, PJPS and AJPS between the left and right knee are presented in table 3. Post hoc analysis showed no statistical significant influence of age, gender, BMI and level of physical activity on the correlations between the different joint proprioception types within knees and the correlation between knees.

Discussion

It was hypothesized that JMS and JPS are not related to each other within and between knees. Furthermore we hypothesized that AJPS and PJPS within a knee are part of the same construct and therefore related to each other. To our knowledge, this is the first study that measured all three aspects of proprioception in one study group. This study group existed of healthy participants, without knee complaints in the age of 50 to 72. Our results showed no association of JMS with JPS (either AJPS or PJPS) and a weak association of AJPS with PJPS. Age, gender, BMI or level of physical activity had no significant impact on the relationships between JMS and JPS. The present results suggest that JMS and JPS are representing different aspects of joint proprioception, even though they are part of the same afferent system. The weak association between PJPS and AJPS suggest that they are not interchangeable aspects of JPS.

Grob et al. (8) assessed both JMS and PJPS with a similar method in an elderly population. They found a comparable average mean for JMS (1,38°±0,41°). The mean for PJPS they reported however, is the average of multiple measures. Therefore comparing the association they found between JMS and PJPS with our findings is not possible. In addition, Grob and coworkers did not find a correlation between JMS and PJPS (r=0.07, p>0.05) and no difference between the left and right knee was reported. Skinner et al. (7) did not present any data on the means for JMS and AJPS. They found a higher correlation between JMS and AJPS (r=0.293, p<0.05) than in our study. Possibly, instrumented versus manually assessment and the presumed larger variability in proprioceptive acuity due to age range (20-82 years, compared to 50-72 years of the present study) might account for this. In a slightly younger population Takayama et al. (18) reported a absolute mean AJPS error of 1,8º (±1,2º). The contrast with the means of our study could be caused by slight variations in assessment method.

The association of AJPS with PJPS has not been subject of research before. Based on physiological characteristics, we hypothesized that AJPS requires activation of muscles that results in an increase in excitation of muscle spindles. Relative to PJPS, where the extremity is not moved actively, this would result in different cumulative afferent input. With their kinematic resemblance and physiological differences it was unclear whether AJPS and PJPS represent a different part of joint proprioception or are interchangeable. Our results show that although both measuring JPS, AJPS and PJPS represent unique aspects of joint proprioception.

The observed difference between the left and the right knee in this study was expected. Lund et al. (19) observed similar values for the left (1.57º) and right (1.47º) knee JMS. In accordance of Lund et al. (19) we did not use leg dominance as dependent variable. The predominant use of one side for specific tasks leads to an increase in sensitivity of the mechanoreceptors and therefore proprioceptive acuity (15). Nevertheless, consensus about the definition of dominance does not exist. For instance, both leg performances while kicking a ball (15) as well as the preferred side for one leg hopping (20) are mentioned as indices of dominance. Therefore, this variable was not taken into account in our analysis.

The change in PJPS between different angles has also been investigated previously (21,22). Although using a different assessment method and calculation of results with absolute error values, they also found the midrange angles to be less accurate than the more extreme angles. In midrange position the capsular structures are least strained (*i.e.* the maximum loosed packed position) (23) and the muscle length does not reaches the maximum length for both agonists and antagonists. We argue that when moving towards the more extreme angles either flexion or extension of the knee joint will increase the amount of strain on capsule, muscle, tendons and skin. The increase in strain enhances the probability that the mechanoreceptors' threshold for firing will be exceeded (5). On its turn, the increase in afferent input will enhance proprioceptive accuracy as we showed in our results.

Strength of this study is the measurement of three different types of proprioception as well as their association in a population of healthy elderly. This data can therefore serve as a possible age matched control group in research on patients with OA. Also all data collection was performed by instrumented assessment combined with a strict protocol to enhance reliability. Other measures to enhance reliability were the elimination of visual cues and learning bias and assessment by one researcher.

Limitations of this study are lacking knowledge on the reproducibility of assessment of PJPS and AJPS. Previous research using comparable instruments showed promising indices of reliability (PJPS ICC 0.57-0.67 (24) and AJPS ICC 0.89 (25)).

Despite daily calibration of the inclinometer used for AJPS assessment and a strictly standardized protocol the mean AJPS error exceeds the PJPS error of the same angle. Nevertheless, the variability of both methods was still comparable. Takayama et al. (18) found a absolute mean AJPS error of 1,8º (±1,2º). They used an electro-goniometer which was attached proximal and distal of the knee, whereas in our study the inclinometer was fixed distal of the knee. Movement proximal of the knee was not registered. This could have induced a systematical overestimation of the criterion angle in our study. The sample size might have been too small, resulting in lacking of statistical significance of the correlation between the various PJPS means. A larger sample would have allowed for more subgroup analyses, but would presumably not alter the conclusions presented here. Since only healthy participants were included in our study, our conclusions may not apply to pathological conditions. Therefore, further investigation in specific groups of patients is needed. To enhance applicability of these findings and facilitate future research on JMS, PJPS and AJPS the indices of reproducibility of the instrument we used should be investigated in both patients and healthy subjects.

Conclusion

We conclude that there is no association between joint motion sense and joint position sense. Although resembling, AJPS and PJPS are not interchangeable components of joint proprioception. Future studies on knee joint proprioception should take all three components into account. Further research should investigate whether associations in joint proprioception differ in populations with pathological conditions like for instance OA.

Acknowledgements

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Mr. van der Esch had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study design. Wind, Zoethout, van der Esch, Steultjens, Dekker.

Acquisition of data. Wind, Zoethout.

Analysis and interpretation of data. Wind, Zoethout, van der Esch, Dekker.

Manuscript preparation. Wind, Zoethout, van der Esch, Steultjens, Dekker.

Statistical analysis. Wind, Zoethout, van der Esch.

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Tables

Table 1. Characteristics of participants, N=46

Characteristic			Value: Mean ± SD	Value: Range
Gender, no. (%)	male		20 (43)	
	female		26 (57)	
Age, years			58,8 ± 5,5	50-72
Body Mass Index			26,4 ± 3,8	18,8-35,6
Height, meters			1,71 ± 0,07	1,59-1,92
Weight, kilograms			78,1 ± 12,5	55-109
Physical Active	yes		25 (54)	
	no		21 (46)	
Proprioception				
JMS† (degrees)		L	1,33 ± 0,71	
		R	0,97 ± 0,55	
AJPS (degrees)	30	L	9,07 ± 4,64	
		R	9,58 ± 4,79	
PJPS (degrees)	60	L	0,44 ± 2,51	
		R	0,28 ± 2,07	
	45	L	-3,80 ± 3,22	
		R	-3,87 ± 2,89	
	30	L	-2,64 ± 4,30	
		R	-2,49 ± 4,17	

JMS = Joint Position Sense; AJPS = Active Joint Position Sense; PJPS = Passive Joint Position Sense; all expressed in degrees, † statistical difference between sides ($p < 0.05$), L=left knee, R=right knee

Tabel 2. Correlations between JMS, AJPS and PJPS within knees*

		Left knee		Right knee	
		Correlation	*p*	Correlation	*p*
JMS - AJPS		-0,07	*0,664*	-0,03	*0,824*
JMS - PJPS	60	-0,11	*0,481*	0,08	*0,583*
	45	0,07	*0,649*	0,10	*0,504*
	30	-0,04	*0,777*	0,08	*0,599*
AJPS - PJPS	60	0,28	*0,059*	-0,03	*0,858*
	45	0,46‡	*0,001*	0,20	*0,195*
	30	0,42‡	*0,003*	0,31†	*0,039*

* JMS = Joint Position Sense; AJPS = Active Joint Position Sense; PJPS = Passive Joint Position Sense; † $P < 0.05$; ‡ $P < 0.01$

Tabel 3. Correlations between JMS, AJPS and PJPS* between left knees and right knees

		Between Left-Right knees	
		Correlation	*p*
JMS		0.72‡	*0.000*
AJPS		0.77‡	*0.000*
PJPS	60	0.68‡	*0.000*
	45	0.60‡	*0.000*
	30	0.49‡	*0.000*

* JMS = Joint Position Sense; AJPS = Active Joint Position Sense; PJPS = Passive Joint Position Sense; † $P < 0.05$; ‡ $P < 0.01$

Figures

Figure 1. Setup for the assessment of knee joint proprioception,
showing the measurement chair control mechanism,
air splints, and footrest (the moving component of the instrument).