

Osteoarthritis and Proprioception: What Does the Literature Reveal?

Ray Marks

Ray Marks, Department of Health, Physical Education, Gerontological Studies and Services, School of Health & Professional Studies, City University of New York, York College; and Department of Health and Behavior Studies, Columbia University, Teachers College, the United States

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Correspondence to: Ray Marks, Department of Health and Behavior Studies, Teachers College, Columbia University, NBox 14, 525W, 120th Street, New York, NY 10027, the United States.

Email: rm226@columbia.edu

Telephone: +1-212-678-3445

Fax: +1-212-678-8259

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ABSTRACT

BACKGROUND: Osteoarthritis, a common disabling degenerative disease of freely moving joints, is often accompanied by high levels of persistent pain, as well as significant impairments of function and functional capacity. This comprehensive literature review specifically explores the extent to which there is support for the idea that subnormal proprioception, a sensory modality involved in mediating reflex and coordinated movements, is an important feature of the osteoarthritis disease process, and hence worthy of efforts to detect this abnormality at the outset of the condition, as well as to intervene

to heighten or normalize joint proprioception in symptomatic cases.

METHODS: All English language peer reviewed published data pertaining to the topic of osteoarthritis and proprioception were sought. Pertinent clinical studies as well as intervention studies on this topic were then reviewed systematically with respect to their findings and study conclusions and reported in narrative form.

RESULTS: Although a considerable number of studies published over the last 45 years were found to support a role for impaired proprioception in the pathology of osteoarthritis, this conclusion is not universal. Moreover, even though many forms of intervention can heighten proprioception, these interventions do not always result in the desired proprioceptive improvements, especially in the presence of severe osteoarthritic dysfunction.

CONCLUSIONS: Further research to more definitively examine the influence of proprioception in the osteoarthritis disability cycle, and at what point intervention may be more useful than not, using agreed upon terminology, methodology, outcome attributes, and careful sampling, is indicated.

Key words: Disability; Kinesthesia; Osteoarthritis; Position Sense; Proprioception; Rehabilitation

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BACKGROUND

Osteoarthritis, a widespread highly disabling joint disease predominantly affecting older adults is strongly associated with varying degrees of pain, joint dysfunction, and often, progressive joint instability. Attributed to the ongoing destruction of multiple joint structures, including the articular cartilage lining the joint, the bone located beneath the cartilage lining, the surrounding ligaments, joint capsule, tendons, nerves and muscles, attempts to delineate risk factors that underpin the disease have focused on many possible determinants. Among these factors, the role of proprioceptive feedback to and from

the central nervous system and the periphery^[1], in addition to the role of proprioception in optimizing the biomechanical and anatomical features of the joint, has been examined.

This body of evidence that proprioception, a term used to encompass the ability to sense movement and position, muscle forces and effort, control limb movement, as well to effect balance control and stability, may be subnormal in adults with varying forms of osteoarthritis, although quite substantive, is not conclusive at all however, despite more than 45 years of research.

Thus even though Barrack *et al*^[2] presented quite compelling evidence that osteoarthritis may produce more significant deficits in proprioception at the affected joint than those of healthy age matched adults more than 20 years ago, and these findings were somewhat independently supported in 1991 by Barrett *et al*^[3], Refshaug^[4] concluded proprioception is not consistently impaired by joint pathology. Rather, Refshauge argued that any proprioceptive deficit that may arise among persons suffering from osteoarthritis may be quite variable and may affect some- but not all aspects of movement. This idea was not consistent with findings that proprioceptive deficits potentially indicative of joint capsular damage or ligament damage or both were found not only on the affected side of osteoarthritis cases, but also in the unaffected side. Moreover, in both cases, proprioception was significantly more deficient in those with osteoarthritis than those of age matched healthy subjects^[2].

In light of the fact that osteoarthritis, the most prevalent disabling disease has no known cure, and that there is a strong possibility that a proprioceptive deficit may predispose an aging individual or at least some aging individuals to osteoarthritis, or to its progression, or both, it seems an updated attempt to carefully examine the extent of the support for or against proprioception deficits in the osteoarthritis disability cycle is both timely and important given the immense burden of the disease. To arrive at meaningful conclusion, the present author thus elected to examine and summarize all the relevant literature on this topic published to date in the English language peer reviewed data bases, including their findings, and conclusions.

The key question was the same as that proposed by Barrett *et al* in 1991- to what extent, does a lack of ‘good’ proprioception exist among osteoarthritis sufferers, and does evidence of this deficit, where it exists, predispose to the development of degenerative change or more severe disease outcomes?

In extending this question, the implications of the data for the clinician were assessed.

METHODS

To obtain the desired information, an extensive review of the current literature in this field published over the last 45 years using PUBMED, and The Science Citation Index Cumulative data bases was implemented. The key words: *osteoarthritis* and *proprioception*, as well as others listed in Table 1 were used. The studies were downloaded for analysis if they were published in the English language as full reports, and dealt primarily with osteoarthritis in general, and/or its association with proprioception. All forms of publication deemed acceptable were carefully examined, and categorized as positive studies supporting a role for proprioception in the osteoarthritic disease cycle, versus negative studies, and intervention studies. After examining the contents of the articles, it was decided to report the results in narrative form only as this body of research was found to be largely fragmented and methodologies and samples were generally not comparable (Table 2). The clinical

studies were reviewed critically however, in an effort to arrive at valid conclusions. Excluded for the most part were animal based studies, since these may not replicate the human disease process, balance related studies, and surgically oriented studies, since cutting the skin and muscle may cause a lesion of the proprioceptive pathway even if this is initially normal. Most articles on proprioception that did not examine osteoarthritic cases were excluded from this review.

RESULTS

Number of studies

Considering the immense numbers of publications housed on PUBMED, [71,000+] incorporating the key word osteoarthritis that were published between 1969 up until May 20, 2017, the present search showed that either the attribute of proprioception has not been readily studied as an associated topic in this chronic health condition, despite its possible importance in the context of pathogenesis, prevention, and treatment, or that the topic does not reach the stage of publication, especially if it yields negative results. Moreover, although osteoarthritis affects joints other than the hip and knee, the search revealed very little work has been published on the theme of proprioception in the context of other vulnerable joints. In addition, when trying to extract salient data to answer the present review questions using the topic words menu, many articles were found to be

Table 1 Table depicting numbers of publications according to key words listed in the PUBMED and Web of Science Data Bases between 1969-May 20, 2017.

Source	Key Words	Yield
PUBMED	Osteoarthritis and proprioception	425
	Knee osteoarthritis + proprioception	318
	Hip osteoarthritis + proprioception	81
	Ankle proprioception + osteoarthritis	28
	Lumbar osteoarthritis + proprioception	13
	Shoulder osteoarthritis + proprioception	11
	Cervical osteoarthritis + proprioception	8
	Elbow osteoarthritis + proprioception	4
	Temporomandibular osteoarthritis + proprioception	2
	Wrist osteoarthritis + proprioception	2
Web of Science	Osteoarthritis and proprioception	418
	Knee osteoarthritis + proprioception	370
	Hip osteoarthritis + proprioception	82
	Ankle osteoarthritis + proprioception	53
	Hand osteoarthritis + proprioception	19
	Shoulder osteoarthritis + proprioception	18
	Elbow osteoarthritis and proprioception	10
	Wrist osteoarthritis + proprioception	5
	Cervical osteoarthritis + proprioception	4
	Lumbar osteoarthritis + proprioception	4
Temporomandibular osteoarthritis + proprioception	2	

Specific proprioception related studies and general publications on the topic are numerous as well and include:

- Anesthesia related studies [66 publications]
- Anatomical and histological related studies [137; and 61 publications, respectively]
- Animal studies [3791 publications]
- Balance studies [1826 publications]
- Clinical-observational, comparative, performance-based, prospective, intervention studies [1896 publications]
- Computational studies [174 publications].
- Denervation studies [60 publications]
- Neurophysiological studies [194 publications]
- Pre and post surgical studies [299 publications]

completely unrelated to the present topic, thus the number of viable papers on the present topic does not exceed 100. When considering a report on this topic, authors may want to note that PUBMED may present more relevant reports than the five combined data bases employed by Web of Science.

But very few focus on any linkage to osteoarthritis.

Rationale favoring the role of impaired proprioception in osteoarthritis

The rationale for hypothesizing that there is a clinically relevant association between proprioception and osteoarthritis stems from a variety of anatomical, clinical, and animal studies that have revealed that all synovial or freely moving joints and the surrounding tissues, skin, tendons, and musculature are supplied by a broad array of neural sensory and motor receptors^{5,61}. These neural components, often termed joint proprioceptors or mechanoreceptors, and which comprise one segment of the pathways governing movement, normal reflexive responses, and sensibility, are important structures in the context of joint health, because they are responsible for monitoring and effecting appropriate muscular responses in the face of the many variations in joint loading that occur during day to day activities. In particular, when functioning optimally, these specialized receptors help protect joints against excess damage due to sudden perturbations or excess loading under dynamic conditions⁷¹.

Conversely, it is theorized that the presence of any structural or functional deficit in the afferent inputs from these joint sensory receptors may impact the entrainment of optimal three dimensional joint muscle interactions, joint stability, the ability to absorb shock, and the ability to carry out those timely and precise movements necessary for maintaining joint integrity. Thereafter, regardless of whether subnormal afferent inputs from a joint arise as a direct result of damage or as a result of inherent abnormalities, or both,

the presence of sustained subnormal neuromuscular responses is expected to foster disruption of the integrity of the articular cartilage lining the joint⁸¹, as well as pain, functional limitations, muscle insufficiency, a propensity to trip on an obstacle⁹¹, and further mechanoreceptor damage¹⁰¹.

In accord with this theory, Wodowski *et al*¹¹¹ concluded proprioceptive mechanoreceptors serving the joint are hence of paramount importance when trying to fully comprehend the origin of the functional problems of the osteoarthritis patient, as well as the disease itself. Cabuk *et al*¹²¹ similarly agreed that impaired proprioception was undoubtedly a possible local mediating factor in both the onset and progression of osteoarthritis based on a study of cadavers with and without knee osteoarthritis. While this was not an in vivo study, the fact that this group found the numbers of mechanoreceptors in cases with knee osteoarthritis to be low in the posterior and anterior cruciate ligaments of 30 specimens extracted from human subjects with the disease when compared to those extracted from human cadavers with no osteoarthritis damage of the knee is hard to ignore. In retrospect, it was proposed that since mechanoreceptors convey important information on joint position and force related constructs, their loss would potentially affect proprioception adversely, thus heightening the risk for osteoarthritic joint damage and pain.

In accord with Cabuk *et al*¹²¹, Moraes *et al*⁸¹ similarly showed there is indeed a distinct difference between the characteristics of the hip joint mechanoreceptors among those with and without hip joint osteoarthritis, suggesting that the disease is associated with changes in the hip joint proprioceptive pathways. Although the findings were hard to interpret, this group showed that when the densities of the nerve endings at the hip were examined with regard to those with arthrosis and those without arthrosis, the mechanoreceptors of those without arthrosis were found to be more pronounced.

Table 2 Summary of a Diverse Proprioceptive Measurement Approaches and Findings Among Osteoarthritis Cases.

Study	Modality Tested	Finding
Barrack <i>et al</i> [2]	Knee position sense	Joint position sense declines more significantly in OA cases
Baert <i>et al</i> [61]	Knee joint position sense	Proprioception deficits only occurred in established knee OA
Bayramaglu <i>et al</i> [62]	Reposition sense	Subjects with bilateral OA have same reposition sense as controls
Bennell <i>et al</i> [47]	Non-weightbearing knee position sense	Pain does not affect joint position sense and does not impact knee OA disability
Cammarata <i>et al</i> [18]	Detection of passive movement	There are proprioceptive differences between subjects with and without knee OA
Chen <i>et al</i> [37]	Joint motion detection threshold	Poor proprioception correlated with function in knee OA patients
Cuomo <i>et al</i> [30]	Shoulder position sense	Proprioception was decreased in patients with advanced shoulder arthritis
Felson <i>et al</i> [21]	Active knee position sense	Proprioception acuity correlated with knee pain and severity, not radiography
Garsden <i>et al</i> [51]	Passive joint position sense and kinesthesia	Chronic pain correlates directly with joint position sense in OA patients
Grigg <i>et al</i> [69]	Hip joint position and movement sense	Hip joint position sense is retained in patients following hip replacement
Hall <i>et al</i> [63]	Knee joint proprioceptive acuity	Subjects with knee OA performed similarly to health controls
Hassan <i>et al</i> [39]	Postural sway	Subjects with knee OA display reduced knee proprioception
Hortobagyi <i>et al</i> [25]	Ability to reproduce passive position sense	Joint position sense is impaired in knee OA, especially in extension
	Knee reposition sense	
Hewitt <i>et al</i> [41]	Movement detection	Movement detection was impaired in cases with severe knee OA
Holla <i>et al</i> [35]	Perceived change in position of the OA knee	Proprioception moderates relationship between muscle strength and activity
Levinger <i>et al</i> [32]	Lower limb proprioception using matching task	Lower limb proprioception did not improve post knee replacement
Lund <i>et al</i> [17]	Joint position sense;threshold to detection motion	There is an increased threshold to elbow + knee movement detection in knee OA
Mahmoudian <i>et al</i> .[29]	Proprioceptive weighting	Early knee OA may lead to proprioceptive reweighting
Mohammidi <i>et al</i> [81]	Passive position sense + active reproduction	Women with knee OA have reduced proprioception compared to controls
Peixoto <i>et al</i> .[56]	Passive joint positioning followed by active	Age does not affect proprioception in elderly women with knee OA
Roberts <i>et al</i> [22]	Threshold to detection of slow passive motion	Poorer knee proprioception was related to lateral cartilage lesions
Shanahan <i>et al</i> [45]	Mechanical vibration and postural responses	Adults with knee OA have disturbed triceps surae muscle inputs
Shakoor <i>et al</i> [14]	Knee joint position sense in sitting	Asymmetries in proprioception occur in unilateral hip OA
Williamson <i>et al</i> [19]	Accuracy of continuous leg tracking movement	There was a relationship between OA and reduced leg movement accuracy

Additional support for the premise that osteoarthritis and proprioceptive factors may be interrelated was further supported in another anatomically albeit clinically oriented study where Van der Esch *et al*^[13] assessed proprioceptive accuracy at the knee in the context of meniscal abnormalities. The study results showed proprioception correlated with both the numbers of abnormal meniscal regions ($p < 0.01$) as well as the extent of these abnormalities ($p = 0.02$). Of import was the finding that this observed associated decline in proprioception in the damaged knees was not confounded by muscle strength, joint laxity, pain, age, gender, body mass index, or duration of knee complaints, suggesting that structural damage to the meniscus housing the mechanoreceptors was the salient cause.

In a more definitive clinically oriented study, Shakoor *et al*^[14] who examined proprioception at a non-osteoarthritic set of joints found evidence of early alterations in proprioceptive acuity at the contralateral knee in cases with unilateral hip osteoarthritis. Their findings implied that rather than a local issue consequent to osteoarthritis, a generalized proprioceptive problem may underpin the development of osteoarthritis in some cases. Thus, a case for poor proprioception as a causative factor for osteoarthritis, rather than as a reactive disease factor was raised. Earlier, in 2008, Shakoor *et al*^[15] also found vibratory sense, a proprioceptive modality regulated by muscle spindle afferents to be less acute in both the upper and lower extremities of hip osteoarthritis subjects compared with controls, suggesting a general impairment of proprioception may be an important disease determinant.

This idea that people with osteoarthritis may have a generalized neurosensory problem, rather than a local problem, was also somewhat supported by Alfekey *et al*^[16] who found lumbar proprioception to be deficient in cases with chronic knee osteoarthritis. Similarly, Lund *et al*^[17] who found an increase in threshold to detection of passive motion in both the knees as well as the elbows of cases with knee joint osteoarthritis also indicated the disease may be associated with a generalized defect in proprioception, rather than joint specific related deterioration, as did Cammarata *et al*^[18].

Williamson *et al*^[19] meanwhile, found older adults without osteoarthritis performed tracking movements more proficiently than older adults with osteoarthritis in one of two test conditions, plus a relationship between the presence of osteoarthritis and the extent of the prevailing motion inaccuracy of the affected limb. Lubiatowski *et al*^[20] concluded however, that severe osteoarthritis at the elbow requiring surgery was specifically associated with a localized deficit in proprioception, irrespective of age, or any general proprioceptive problem, as a result of surgery, but this could not be proven to any degree.

Although Felson *et al*^[21] did not examine the potential for proprioception as a distinct causative factor, this group did find that knee osteoarthritis cases with poor proprioception were more likely to experience pain and physical functional limitations than those with no deficit. This finding did suggest however, that at a minimum, a possible indirect linkage between the extent of joint dysfunction and prevailing proprioceptive sensibility appears to exist. Roberts *et al*^[22] too suggested there is a relationship between the extent of joint damage in anterior cruciate ligament injuries, cartilage damage and proprioceptive acuity that should not be ignored. As well, Cammarata *et al*^[18] found having poorer proprioception at the knee was indeed associated with a decline in joint stiffness, and proposed that this could destabilize the joint along with inherent joint protection mechanisms, thus possibly impacting the onset and/or progression of

the osteoarthritic process.

Unsurprisingly, Slupek *et al*^[23] found considerable proprioceptive and sensorimotor system performance deficits, as recorded in an arthroplasty group, compared to a control group and implied that this deficit may not only contribute to the more rapid progression of a degenerative joint disease, where it exists, but to an increased risk of falling and further injury. In agreement, Collier *et al*^[24] found knee proprioception does seem to be impaired in cases of advanced knee osteoarthritis when assessed in the form of passive motion detection. Moreover, proprioception appeared to be more impaired in the more severely damaged knee among bilateral cases of the disease.

One explanation as to why excess joint damage might ensue in the face of impaired proprioception is the fact that proprioceptors are involved in mediating movement response time, as well as movement magnitude. In this respect, Hortobagni *et al*^[25] found osteoarthritic cases with knee pain needed 67% more time to complete four functional tasks, and produced 82% more proprioception errors (all $p < 0.05$) using a repositioning task compared to controls. About 80% of this error was due to overshooting the target and 68% of the overshooting error occurred at 2 of the 5 least flexed knee joint positions. The patients had 89% more errors in accurately matching target forces during submaximal quadriceps contractions and in the same tasks, and produced these forces with 155% more variability (all $p < 0.05$). As a whole, they would be expected to have a decreased ability to absorb shock or to function physically under challenging weightbearing conditions.

Shanahan *et al*^[26] similarly found 30 cases with knee osteoarthritis to have significantly larger relative joint repositioning error scores than controls (OA: $2.7 \pm 2.1^\circ$, control: $1.6 \pm 1.7^\circ$, $p = 0.03$). Chang *et al*^[27] too, found the knee frontal plane sensorimotor control system to be compromised in persons with medial knee osteoarthritis, while research by Riskowski *et al*^[28] has indicated individuals with poor proprioception would tend to experience a higher rate of loading during walking than those with optimal proprioception, which might provoke an increased risk for lower limb joint damage.

Mahmoudian *et al*^[29] who investigated whether weighting of proprioceptive inputs would be altered in persons with early and established knee osteoarthritis did find cases with both early and established disease to be significantly more sensitive to triceps surae vibration than their healthy counterparts. This observation suggested that cases with knee osteoarthritis might place increased reliance on ankle inputs for postural control in the early disease stages, but that the increased neural integration challenges that might arise during complex weight-bearing tasks in these individuals might adversely place excess demands on postural control mechanisms, potentially provoking a fall. As well, although compensatory and initially beneficial, with more reliance on ankle proprioceptive input for postural control than is normally desirable, alterations in loading patterns at the ankle joint may produce loading challenges that exceed the threshold of safety of the related joints.

In short, while not conclusive, the diverse evidence collected over the last few decades shows proprioception can be altered in adults with osteoarthritis, there may be individuals who acquire osteoarthritis due to inherent or acquired proprioceptive problems, and those with osteoarthritis and poor proprioception may incur more serious outcomes over time than those with no such deficit. Conversely, proprioception at an osteoarthritic joint can be heightened significantly, and when proprioception is improved, function at an osteoarthritic joint may also improve, even in advanced disease cases^[30].

In contrast, the presence of any persistent proprioceptive deficit

associated with an osteoarthritic lesion may be expected to hasten functional performance declines^[19]; increase postural sway and poor balance^[31], and movement inaccuracy^[19]. In addition, falls risk may be heightened^[32,33], the energy cost of walking may increase^[34], activity levels may decline^[35]; and symmetrical limb loading may be impaired^[36]. Muscle strength^[37] and endurance^[34] as well as posture; postural control^[38,39], and recovery following postural perturbations^[40] may all be affected negatively as well. In turn, these factors can impact joint protection mechanisms negatively, as well as joint proprioceptive mechanisms adversely and significantly.

Possible determinants of proprioception in the osteoarthritis patient

According to the available research, possible causes of poor proprioception in cases with osteoarthritis include inherent proprioceptive deficits, problems with mechanoreceptors caused by osteoarthritic joint pathology^[17], joint instability^[41], pain^[26], joint effusion^[42], and inflammation. Age, obesity and muscle strength capacity, along with muscle fatigue^[44], plus differences in the organization of the motor cortex^[45] may be additional factors impacting the extent of any prevailing deficit in proprioceptive sensibility^[31], as may the extent of any associated ligamentous laxity or damage^[46], capsular damage or contracture^[8], and certain medications^[9]. Surgery to improve joint status may also have the effect of increasing proprioceptive challenges^[2]. As well, diabetes and/or associated cardiovascular comorbidities, and depressed states-common in osteoarthritis cases- may all impact proprioception independently and negatively. Eliminating some of these potential causes, rather than targeting proprioception alone, may hence have far-reaching outcome benefits.

Disagreements in the literature

Studies that fail to support an osteoarthritis-proprioceptive linkage include those by Bennell *et al*^[47] who found no meaningful association between measures of knee joint position sense and pain and disability among 220 cases of knee osteoarthritis. However, their non weightbearing tests of position sense may have excluded positions where proprioception is especially impaired^[25], the angles tested may have been those where proprioception is not well correlated with pain^[48], and the extent to which pain or impaired proprioception might be related may have been more demonstrable if participants were divided into those with best and worst sensorimotor function^[49]. In addition, the use of cutaneous cues to prompt the subjects may have altered the nature of the recorded outcome, the quality of data from self-reported surveys may have been suboptimal, and factors such as muscle strength were not examined. Moreover, walking speed over a 7.5 m walkway, coupled with a single balance test, and no practice trials for the timed get up and go test may have obscured possible relevant associations that occur in daily functional settings and with activities, such as ascending or descending stairs.

In other related research, a further conundrum exists because while osteoarthritis is found to increase the propensity to trip on an obstacle^[9], and falls experienced after knee joint replacement surgery may represent the persistence of impaired lower limb proprioception^[32], others found falls risk was unaffected by the presence of hip or knee osteoarthritis^[36]. Yet others have argued dynamic balance training does not improve stability in osteoarthritis subjects^[50].

In other research realms, while some have found generalized proprioceptive deficits in osteoarthritis cases, as well as poorer position sense in both legs in subjects with unilateral

osteoarthritis^[51,52], as well as elbows and knees of knee osteoarthritis cases^[17], and that impaired proprioception is not the result of local joint damage^[53], others found proprioception deficits are localized solely to affected joints not to other joints^[26,54], or are not implicated at all even in advanced osteoarthritis surgical cases^[55].

As well, even though Sharma *et al*^[53] concluded that among factors placing individuals with knee osteoarthritis at greater risk for poor functional outcomes was proprioceptive inaccuracy, laxity, and muscle weakness, a finding supported by Chen *et al*^[37], Peizoto *et al*^[56] found no significant association between measures of proprioceptive acuity and muscular performance at the osteoarthritic knee. In addition, this group noted no influence of age on these measured variables among elderly women with knee osteoarthritis, which was somewhat contrary to findings of Barrack *et al*^[2].

While Weiler *et al*^[57] discounted the value of proprioceptors completely, and went as far as suggesting the complete removal of joint receptors during joint replacement surgery because they might have an adverse effect on maximal proprioceptive performance, in another report, Barry and Sturnicks^[58] concluded proprioceptive training for osteoarthritis is not warranted because proprioception is not deficient in people with knee osteoarthritis. However, not only does proprioceptive training enhance proprioception in the osteoarthritis population, but it is also accompanied by clinical and functional improvements^[54]. In addition, in the Kumar *et al* study used by Barry and Sturnicks^[58] to arrive at their conclusions, no assessment of joint position sense was conducted to rule out any possible conflicting observations, and their method of assessing threshold to detection of movement, which was conducted in the seated position, may have been too insensitive for detecting inherent proprioceptive deficits. Their conclusions that cases with knee osteoarthritis are able to walk with the same stability as healthy controls fails to explain the high rates of falls in people with knee osteoarthritis^[60], and their failure to detect any proprioceptive differences between control subjects was inconsistent with findings by Hewitt *et al*^[41].

Baert *et al*^[61] in contrast to Weiler *et al*^[58] similarly concluded that there are no significant differences in proprioceptive accuracy in cases with early osteoarthritis compared to healthy controls, as did Bayramoglu *et al*^[62] for cases with mild to moderate knee osteoarthritis measured by an angle reposition error test conducted in sitting. Hall *et al*^[63] similarly reported no differences in active knee position sense between 4 groups of subjects with radiographic knee osteoarthritis, even though those with more established disease were shown to produce higher repositioning errors compared to early onset cases (+ 29%, $p = 0.033$) and healthy controls (+ 25%, $p = 0.068$). Earlier, Bayramoglu *et al*^[62] too found no problems among knee osteoarthritis cases with mild to moderate disease as far as repositioning error goes, but this group did not include more severely affected cases in their analysis. They did not test the threshold to detection of passive knee motion of subjects, nor did they ask subjects to reproduce measured flexion angles. They could not explain why the right knees of more severe bilateral knee osteoarthritis cases were worse than those of the left knee.

Explanations for literature inconsistencies

Possible reasons for variable report findings include, but are not limited to the fact that the measures of proprioception discussed in different publications do not all assess the same proprioceptive attribute^[64], and even if they do, the mode of measurement was not truly replicated in any study to any degree. The nature of the joints assessed, the degree of joint stability, pain, inflammation,

and muscle status was also not necessarily consistent within and across comparative studies. As well, it is impossible to ascertain if the proprioceptive testing paradigms employed in negative studies were sufficiently sensitive to detect the presence of any specific proprioceptive deficit if this existed.

Erroneous or discrepant conclusions in the prevailing data base could also stem from tests that are not sufficiently challenging, nor designed to test a specific receptor that might be damaged. The role of compensatory processes, as well as any inadvertent introduction or obliteration of cutaneous cues and others either present or not present in normal activities may likewise produce ambiguous results, as may the comparison of differing modes of testing^[65,66] tests that occlude vision and auditory information that would be intact in actual real life situations as discussed by Proske^[5], and variable sample characteristics within and between study groups.

In short, the variable ages of samples, the extent of any medication intake, comorbid health status, cognitive status, level of fitness, plus variations in what is considered a proprioceptive test, are all factors that could introduce challenges in efforts to reconcile and interpret data from differing proprioception tests that have been conducted in osteoarthritic samples^[24,64].

In addition to the diverse array of findings noted above, which preclude any meaningful synthesis, it is highly challenging to arrive at any consensus concerning osteoarthritis and proprioception since control samples or limbs examined in some studies may have been pre arthritic, there may have been inherent proprioceptive deficits that were not identified as being linked to the disease, and/or other distinctive attributes that can influence proprioception may have been operative, but were not uniformly sought, documented, or identified as relevant. Prevailing measurement errors^[67], possible subject distraction during tests due to pain and anxiety, problems pressing an on-off button in a timely way^[2], muscle fatigue or soreness, eliminating active muscle contraction during one or more phases of position sense tests^[2], may be other confounding factors^[67]. Others include failure to test proprioception at multiple ranges of motion^[25], in functional positions^[2], and in the absence of prior exposure of subjects to exercise interventions. Differing assessment tools^[68], and the use of young osteoarthritis subjects with moderate joint damage^[25], rather than those with more severe joint disease may too have influenced the interpretation of the prevailing findings.

Highly confusing too are the terms employed to define and assess proprioception in cases of osteoarthritis. Extracted from the current literature the Box below shows some of the diverse assessment and analytic approaches reportedly employed in the context of osteoarthritis. Confusion reigns because all can potentially yield different outcomes even among the same individual and each potentially stresses unique aspects of the sensorimotor pathway (See Box 1).

In addition to these considerable variations in the mode of defining proprioception, in general, the diverse approaches employed to measure position sense acuity-one of the most common approaches-can be highly confusing in its own right to synthesize. Indeed, these variations include, but are not limited to- the extent of or the use of any verbally applied cues, the use of self-selected cues, physically imposed cues, and the nature of the test starting position and mode of restraint. As well, the use of intact skin sensation versus efforts to neutralize skin sensation, along with the extent of vision or muscle contraction that prevails during testing may produce discrepant findings. Additional variables that are seldom standardized across studies are the limb(s) and/or joints or angles tested, the order of testing, the plane(s) of motion tested, the number of test-retest

repetitions required, and the extent of practice and rest periods. Moreover, even where similar position sense tests are conducted, outcomes reported may be quite diverse and hard to interpret because attributes such as the absolute angular error, modular error, variable error, directional error, and constant error-each have potentially different clinical and explanatory implications.

Movement detection or threshold perception test results may likewise prove challenging to synthesize if conducted at different speeds, speeds unlikely to resemble those used in functional situations or if these are too slow to produce a localized sensation^[1]. Tests may also differ if generated by technology versus manual approaches. The various planes of motion tested, as well as differing test ranges, and frequencies with which tests are conducted adds further confusion in arriving at a clear conclusion, even if the test joint in question is the same. The differential use of practice movements, rest periods, methods of calculating deficits such as computing the threshold measure approach may all likewise produce invalid or diverse results^[41]. Variable methods of generating the initial sensory stimulus, along with variable subsequent instructions and measurement devices method for recording test responses further preclude adequate synthesis of the prevailing data. Unfortunately, even if proprioceptive accuracy appears normal when tested with one of these two key modalities, the findings may not be consistent across the different modalities^[51]. Thus, unless researchers and clinicians examine both attributes in a thoughtful way, and are aware matching motion tasks may be performed more accurately than position tasks, and that joint sensitivity often differs depending on joint site, proprioceptive deficits that do prevail may go undetected or arise as a result of ecologically invalid test procedures^[85-87].

DISCUSSION

Although the neurophysiologist Sherrington discussed the importance of joint receptors in the context of proprioception more than a century ago, and the additional importance of muscle and tendon receptors in mediating proprioception followed, the role of these receptors in the context of disturbances in joint function has not been widely examined when compared to other aspects factors that may impact or be impacted by joint damage.

Box 1 Nature of Differing Proprioception Measurement Concepts and Approaches Documented in the Literature

Ability to detect spatial position without vision [62]
Active joint position sense [17]
Balance
Detection of passive movement [69]
Estimation of the ability to move the joint accurately [69]
Extent of passive movement [69]
Passive joint position sense [1,84]
Hunting perception [43]
Joint motion sense [1,30]
Joint reposition sense using passive cues and active reproduction [25]
Kinesthesia [41]
Movement accuracy
Movement sense
Proprioceptive acuity, accuracy
Proprioceptive weighting [29]
Reaction time
Threshold to detection/sensation of slow passive movement [19]
Vibration sense [29,50]

This is surprising given the possibility that movement or reflex response abnormalities may reduce the protective features of a joint, exposing it to damage and osteoarthritic joint changes. In turn, osteoarthritic joint damage may conceivably alter the structure and/or the function of either joint or muscle proprioceptors or both. Cognitions implicated in proprioception may also be affected in those with intractable pain, and/or symptoms of depression as a result of osteoarthritis, the most common condition affecting synovial joints.

Moreover, since proprioceptors serving one joint may also be linked to neural structures in remote body areas, it is conceivable, the presence of osteoarthritis damage at one joint can lead to heightened risk of the disease at other joints, or altered proprioception at a distant joint^[83]. Conversely, the presence of a general deficit in proprioception, a modality determined in part by genetics, might explain both the presence of generalized osteoarthritis in some persons, as well as the tendency for some older adults to develop osteoarthritis, as well as for the disease to spread from one side of the body to another, or from one joint to another on the same body side, or a distant site as shown schematically in Figure 1 below.

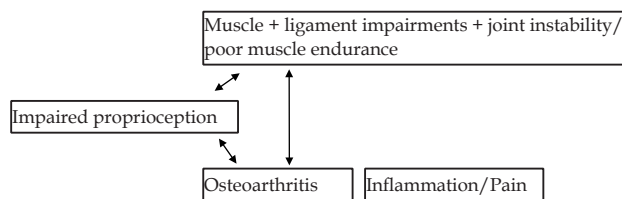


Figure 1 Schematic representation of possible cycle of deleterious impacts associated with osteoarthritis and impaired proprioception.

Yet, not all authors support a role for poor proprioception in the genesis of osteoarthritis and its pathology^[21], even though poor proprioception may increase the risk for osteoarthritis or heighten its progression^[2,17,34] and may foretell the development of osteoarthritis^[12,52]. Indeed, no firm conclusions for purposes of intervening to prevent or reduce osteoarthritis disability attributable to poor proprioception can be forthcoming at this time, despite findings by some of defects in the ability to perceive joint angular positions accurately in response to passive or active movement cues in the absence of vision, as well as deficits in motion detection or both^[2,26,27,89].

Even if proprioception is found impaired, whether this is a result of damage or dysfunction of the joint and/or muscle sensory receptors^[26], ligament dysfunction, unremitting pain^[70], joint effusion and/or joint inflammation^[71], or an inherent deficit in neural processing^[84], is impossible to discern, despite the possible clinical utility of this information. The secondary impact of impaired proprioception on pain and activity limitations as outlined by Knoop *et al*^[72], as well as the coordination between balance and movement initiation^[70], also remains controversial, even though this interacting pathway of problems may be highly relevant in efforts to understand the progressive nature of the disease, and what intervention(s) may prove favorable or unfavorable in this regard.

Those who advocate for a causative role include Barrett *et al*^[3] who found a steady decline in knee joint position sense with age in subjects with normal knees and those with osteoarthritis at all ages, which did not reach the accuracy of age-matched patients with normal knees after surgery. As well, Fuchs, Thorwestern, and Niewerth^[73] showed reduced proprioceptive capabilities to be present in patients with degenerative knee arthritis in both the operated and the contralateral leg, while Porter *et al*^[84] found significant associations between pain and function scores of knee osteoarthritis cases who had

worse knee and shoulder proprioception than age matched controls. The presence of poor knee proprioception also predicted self reported knee instability in knee osteoarthritis cases over a two year period^[82] and those with symptomatic evidence of postural instability incurred more pain than those with no proprioceptive impairment^[90]. However, others do not concur, firstly that proprioception is associated with osteoarthritis, and secondly, even if it is, there is no consensus on its impact on the disease and its progression^[74].

Consequently despite quite compelling data, efforts to clearly understand the etiology and pathogenesis of osteoarthritis from the perspective of proprioception, must await further research, even if a case can be made for an association between the presence of impaired proprioception^[75] and osteoarthritis joint damage^[79]. As well, efforts to intervene to offset the onset of osteoarthritis in vulnerable adults, and to minimize osteoarthritis disability through a proprioceptive lens must also await future work.

To this end, empirical evidence shows a number of promising strategies, and that more rather than less may be gained by careful examination of proprioception functions as routine clinical tests in the context of preventing or treating osteoarthritis. While some literature is negative in this respect, and additional negative findings may have been inadvertently omitted due to publication bias-an attempt was made to capture all peer reviewed literature on the topic.

As osteoarthritis is the single most important rheumatological cause of worldwide disability, and has no known cure, efforts to overcome any current methodological study limitations in the present data base, more predictive longitudinal studies, as well as basic studies, studies that employ advanced electrophysiological instruments, and especially robust replication studies that employ optimal proprioceptive measurement approaches and metrics of analysis, and that are deemed functionally relevant with high predictive validity in the context of osteoarthritis may help to produce more solid conclusions.

In particular, careful sampling, studies of multiple osteoarthritic joint sites, and increased efforts to control for correlates of proprioception such as age, gender, body mass, fatigue, medication use, physical activity levels, diabetes, speed and plane of motion, plus muscle strength, endurance capacity, and atrophy, as well as medical histories in well designed sufficiently powered comparative and prospective are sorely needed. Along with these suggestions, recommended are dedicated efforts to test and report on the reliability, sensitivity, normal variability, and precision of the proprioceptive methods employed, efforts to extend the test repertoires, and efforts to conduct more comparative studies that can help to differentiate related proprioceptive mechanisms. Concerted efforts by researchers to adopt standardized proprioceptive test approaches among different laboratories is additionally recommended in efforts to minimize differences in results attributable to outcome measure differences or attributes measured as outlined by Wind and Zoethout^[76], a group who found 13 studies that used 24 different hip proprioception measures.

According to Collier *et al*^[24], seeking more precise information on variables that influence proprioception, and identifying patients with osteoarthritis likely to have poorer proprioception than desired from the earliest point in time, may prove especially valuable to both clinicians and patients, especially if surgery is contemplated. Indeed, sufficient research shows this information concerning an osteoarthritic patient's proprioceptive capacity is not merely academic, but should be intensively sought, because this, rather than radiographic assays alone, could have tremendous far reaching implications in the context of preventing and/or attenuating the disability associated with the

disease as stated by Wodowski *et al*^[11]. Moreover, efforts to improve proprioception may help to reduce pain, falls prevalence post knee replacement surgery, and further injury and disability^[32].

In sum, in light of the aging populations' increased susceptibility to developing osteoarthritis, and the immense global burden of the disease, the role of proprioception in the osteoarthritis disability cycle, should be further explored despite a lack of consensus in this regard. Sufficient data further suggests that concerted efforts by researchers in the field to better understand basic proprioceptive mechanisms, and to test the theory that deficient proprioception in general, can potentially heighten the risk for incurring a joint injury, as well as progressive joint damage is likely to prove immensely helpful in reducing the disease burden. Understanding what neural substrates and other factors need to be specifically targeted to achieve optimal clinical and surgical outcomes in the event proprioception is impaired in the osteoarthritis patient also needs to be uncovered.

Since numerous motor functions predictably impacted by abnormalities of proprioception can potentially be improved by an array of non-invasive approaches, and others aimed at reducing excess joint damage might prove valuable, the role of these strategies in the armamentarium against disabling osteoarthritis should be specifically examined.

CONCLUSION

In 1997 Sharma and Pai^[53] stated the relationship between sensory input and protective or damaging muscle activity had been minimally evaluated in the context of osteoarthritis, despite its possible benefits to the patient and clinician. However, even though the nature of this premise has garnered some support since that time, more research in this realm is clearly indicated to further our the role of sensorimotor mechanisms in the disease process.

In particular, more efforts to clearly clarify the clinical criteria for study inclusion and exclusion, and to employ sensitive measurement tools, along with careful co-factor analyses is highly indicated. In addition, reliable and universally agreed upon measurement tools and approaches will help to delineate if sensorimotor structures are implicated in osteoarthritis, and if so, what these are. Prospective studies to examine if proprioceptive deficits can lead to more severe disease or heighten the disease risk, as well as more research to examine proprioception at joints other than those directly affected by osteoarthritis may also be helpful in improving our knowledge base in this area.

In the interim, efforts to routinely measure proprioception among osteoarthritis cases as well as among those at risk for this condition are likely to be more helpful than not in efforts to intervene accordingly and in a timely manner to minimize osteoarthritis disability. Indeed, this line of inquiry does seem highly promising as outlined by Mohamed and Abdullah^[77] who found that in the absence of adequate proprioceptive input, onset of muscle activities of the quadriceps muscle in cases with knee osteoarthritis was greatly affected, along with the patient's level of activities, especially during sit to stand activities. Indeed both Sharma^[78], Hagert *et al*^[79], Esch *et al*^[82] and others have intimated that proprioception should not be discounted as a possible and highly salient mechanical precursor of some forms of osteoarthritis and its symptomology^[52,88]. In addition, osteoarthritis at one joint might impact proprioception at another joint, indirectly mediating future damage at the affected joint^[83]. Hence, further research to establish a more definitive role for proprioception in the context of osteoarthritic joint disease is not only highly desirable, but is destined to have far reaching conservative and

surgical intervention implications^[80].

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