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Proprioception in the nearly extended knee

Measurements of position and movement in healthy individuals and in symptomatic anterior cruciate ligament injured patients

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Abstract Proprioception of the knee was measured in 19 healthy individuals to evaluate whether there were any differences between extension and flexion movements from two different starting positions. The threshold before detecting a passive movement, visual estimation on a protractor of a passive change in position (30° angular change) and active reproduction of the same angular change were registered. The reference population was tested twice to study normal variation and reproducibility, followed by the evaluation of 20 patients with chronic, symptomatic and unilateral anterior cruciate ligament (ACL)-deficient knees. In the normal population no differences were found between the right and the left leg, men and women, or measurements made at the first and at the second test occasion. The thresholds from a starting position of 20° were lower for extension than for flexion. When comparing the thresholds for extension between the 20° and the 40° starting position, lower values were found in the more extended position. The thresholds for flexion were lower from the 40° starting position than from the 20° starting position. The active reproduction of an angular change of 30° was more accurate during flexion (30°–60°) than during extension (60°–30°). There were no differences in the reproduction tests or in thresholds from the 40° starting position between the patients and the normal group, but the patients had higher thresholds from the 20° starting position, in movements towards both extension 1.0° (range 0.5°–12.0°) and flexion 1.5° (range 0.5°–10.0°) than the normal group 0.75° (range 0.5°–2.25°) (P = 0.01) and 1.0° (range 0.5°–3.0°) (P = 0.06), respectively. Thus, information of passive movements in the nearly extended knee position was more sensitive towards extension than towards flexion in threshold tests and the sensitivity improved closer to full extension, which implies a logical joint protective purpose. In this nearly extended knee position, which is the basis for most weight-bearing activities, patients with symptomatic ACL-deficient knees had an impaired awareness in detecting a passive movement. There were no differences in the more flexed position or in the reproduction tests between the patients and the normal group, and reproduction tests in the present form seem less appropriate to use in the evaluation of ACL injuries.

Key words Proprioception · Anterior cruciate ligament

Introduction

Sensory information is essential for proper joint function during both activities of daily living and sports. Several morphological studies have verified sensory receptors of various types around and within the knee joint including the anterior cruciate ligament (ACL) [30, 31, 40]. Afferent activity has been registered upon stimulation of the ACL both in animal studies [22] and in patients [29]. Neurophysiological experiments have shown that the compound afferent information is complex, and the relative contribution from muscle receptors, joint receptors and cutaneous receptors on joint position sense (JPS) and movement sense (MS) has not been clarified [9, 21, 22, 39]. Some studies suggest that the different receptor types are probably complementary in providing sensory information, where each type of receptor modifies the function of the other [6, 17]. Basic characteristics of sensory afferents have been documented in repeated studies: an increased impulse generation near the extremes of physiological joint motion [7, 8, 10, 17, 18, 33] and an increased awareness when a higher velocity during passive displacement of the joint is used [9, 10, 15].

Defects in proprioception as a consequence of different anatomic lesions has to our knowledge only been studied after ACL injuries, which are often associated with additional intra-articular lesions, and the relationship between the sensory defects and knee function has yet to be evaluated. The morphological changes in different tissues of the knee after experimentally created defects in proprioception have been described [13], and Gupta [19] suggested that permanent disturbances of the sensory system might predispose to further injuries and progressive joint deterioration. Whether temporary or partial defects in proprioception in humans will affect immediate knee function or lead to knee joint degeneration or whether the defect proprioception seen in patients with arthrosis [1, 5, 26] is secondary to the degenerative process need further studies. Established methods to measure proprioception include the threshold to detection of a passive movement and the reproduction of a passive or active positioning of the limb [1, 5, 9, 11, 12, 21, 24, 25, 28, 32, 38]. Proprioceptive deficits in humans have been reported with ageing [1, 4, 24, 32], in ballet dancers [2], in arthrosis [1, 5, 26], in ACL deficiency [3, 4, 12, 34] and after ACL reconstruction [4, 11, 25, 27].

An enhanced proprioception has been reported in ballet dancers [2], after an ACL reconstruction [11] and when an elastic brace was used [4, 25].

In most previous studies measurements have not been performed in the range of motion utilised by ordinary weight-bearing activities and, despite the description of flexion-type receptors and extension-type receptors [7], mainly in movements towards extension.

Some patients with an ACL injury have a severe disturbance in proprioception [3], and a better correlation to functional outcome after an ACL reconstruction has been reported when the patient's proprioception was measured than when traditional scoring systems and laxity testing were used [4].

A sensation of "insecurity of the actual position of the knee and rate of change in position" is not infrequently reported by patients after a recent knee injury (unpublished observation), and this sensation of not knowing where the knee is positioned, especially during standing and walking, has also been described after meniscal surgery [35]. A joint incongruence during simple weight bearing in some patients with ACL deficiency has been registered on lateral radiographs [14], and both the subjectively experienced difficulty in controlling limb positioning and this objective finding have not been adequately explained.

The aim of this investigation was to characterise normal individuals and ACL-injured patients in movements towards both extension and flexion over the range of motion utilised during standing and walking activities. The sensitivity to detect a passive movement (TE/TF) and the ability to reproduce an angular change both actively (AR) and by visual estimation on a protractor (VE) were registered. The reproducibility of the recordings was evaluated in the normal population by repeated measurements after 1 month. The patients with symptomatic and unilateral ACL deficiency were analysed with both the uninjured limb as an internal control and with the reference population as an external control.

Patients and methods

The *normal population* consisted of 19 young and healthy volunteers, 14 men and 5 women. Their mean age was 25 years (range 20–37 years). None of them had any history of significant injuries of the lower limbs, any general disease that might interfere with peripheral or central neural function or any unphysiological limitation in range of motion. Since an effect of training has been found in ballet dancers [2] and after immobilisation [36], all subjects were asked to estimate their activity level according to the Tegner scale [37]. The highest score among the subjects was 7, equal to competitive sports such as tennis or basketball, and the lowest score was 2, equal to walking on uneven ground. The median score was 5, equal to heavy labour and jogging on uneven ground.

The *patients* were selected from the waiting list for an ACL reconstruction. All had a positive pivot-shift and had experienced giving-way episodes after their primary injury. Associated meniscal tears were common. They all felt insecure and had a sensation of not being able to trust the knee in strenuous situations. There were 14 men and 6 women with mean age of 26 years (range 18–39 years). Mean time from injury was 3.6 years (range 1–16 years). The median Tegner score was 4 (range 2–9). None of them had suffered any injuries or subjective complaints from the contralateral knee.

The *apparatus* used (Fig. 1) was a platform placed on the floor. An electrical engine with a wire was mounted at one short end. This wire was connected to a movable sled, shaped like a "T" and acting as a leg support. A plastic splint for positioning and fixation of the distal limb and foot was attached to it. The sled was fixed in the centre of the plate with a metal bar, and a pull in either direction on the wire would make it turn like the hand of a clock along the natural arc of extension or flexion of the knee. The knee joint

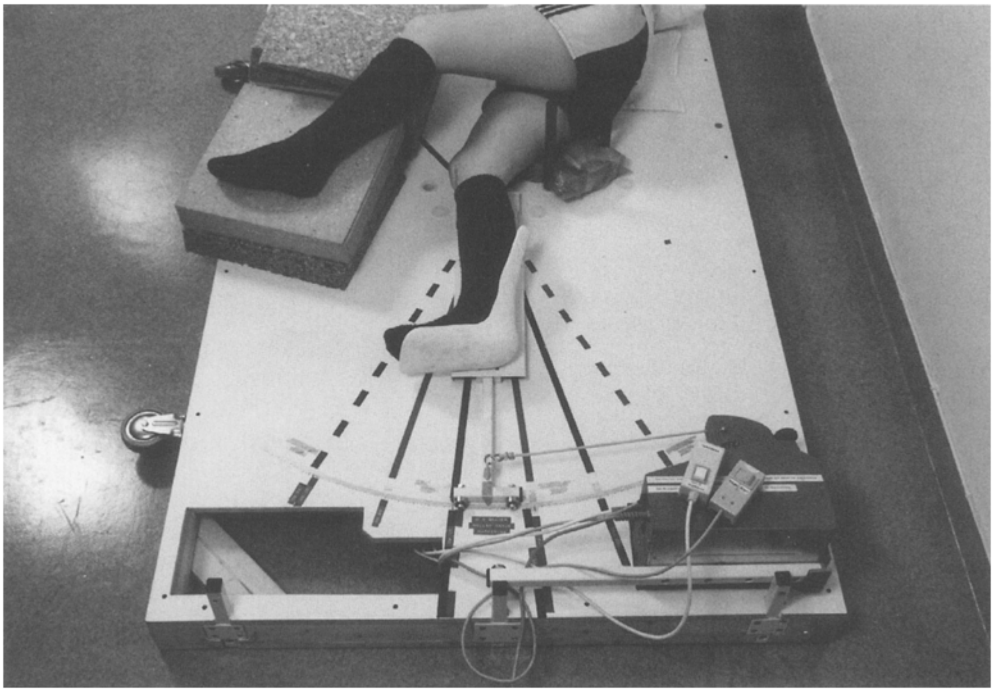

Fig. 1 The three different tests were performed while lying on the side on a specially designed platform

was carefully positioned in the rotatory centre, and the use of ball bearings meant that all movements of the sled could be made with almost no friction.

The subject was positioned on his or her side, with the lower foot placed in the plastic splint. Two bars mounted on the plate served as guidemarks for placement of the thigh and trunk in a standard position, with the hip joint in semiflexion. The upper thigh rested on rubber pillows, and pillows were also placed under the hips and back to help the subject relax during the test. Care was taken to eliminate any external cues to limb movement except those from the knee joint and surrounding structures. To neutralise cutaneous sensation they all wore short pants and a thick woollen sock, and the knee had no contact with the underlying plate. The positioning did not allow visual checking of the leg, and auditory impulses were prevented during the threshold trial by earphones with a sound imitating the engine.

The *threshold measurements* were performed towards both flexion (TF) and extension (TE) from two starting positions, 20° and 40°. The subjects were told to concentrate and respond verbally to a clear sensation of movement or change in position of the knee or the lower limb. The examiner then turned on the tape recorder and started the engine, which was calibrated to an angular velocity of 0.5°/s. The onset of the engine had a random delay, varying between 5 and 15 s, after the subjects were told to be ready. When the subjects responded, the engine was stopped, and the movement was registered in degrees. The median value of three consecutive trials was used for statistical analysis.

In the *visual estimation test* (VE) the subjects were told to concentrate on the starting position and remember it. The position was 60° in the extension trial and 30° in the flexion trial. The engine was then started and moved their legs 30° at a speed of 0.5°/s. The leg was fixed in that position while the subjects were told to concentrate on the new position and relate it to the starting position. On a specially designed protractor, shaped like a leg on a plastic circle, they were given the starting position and told to move the plastic leg to the position they felt their own leg had. This trial was repeated three times, and the medians of both the real value and the absolute error from the exact value were registered.

The *active reproduction test* (AR) used the same starting positions as the VE test. However, this time the engine was disconnected, and the examiner moved the leg 30° at a speed of about 10°/s. Upon reaching the final position the leg was held still for a few seconds while the subjects were told to memorise the position. The leg was then returned to the starting position with the same speed by the examiner, and the test person was told to repeat the movement using his or her own muscle force. The medians of both the real value and the absolute error from the exact value in three consecutive trials were registered.

The three different tests were made on both the left and right legs, by reversing the apparatus arrangement, and each normal individual was tested twice with an interval of 1 month between the measurements.

Mean values and standard deviations were calculated for the normal population, where the real values in the reproduction tests were used. Some individuals had extreme recordings in both the threshold and reproduction tests, and since the absolute deviation from the set 30° angular change in the reproduction tests was used for comparisons, median values were calculated. The Wilcoxon signed-rank test was used for within group comparisons and the Wilcoxon rank-sum test for between group comparisons. Nonparametric 95% confidence intervals were calculated for the difference between measurements 1 and 2 in the normal population. Statistical analyses were performed using Minitab 10 and SAS 6.10 program packages.

Results

In the normal population there were no differences between the sexes or right and left knees or between persons with a moderate activity score (eight persons averaging 6 or 7 according to the Tegner scale) and individuals with a low score (seven persons averaging 2 or 3) in any of the three tests. When further comparisons were made, men

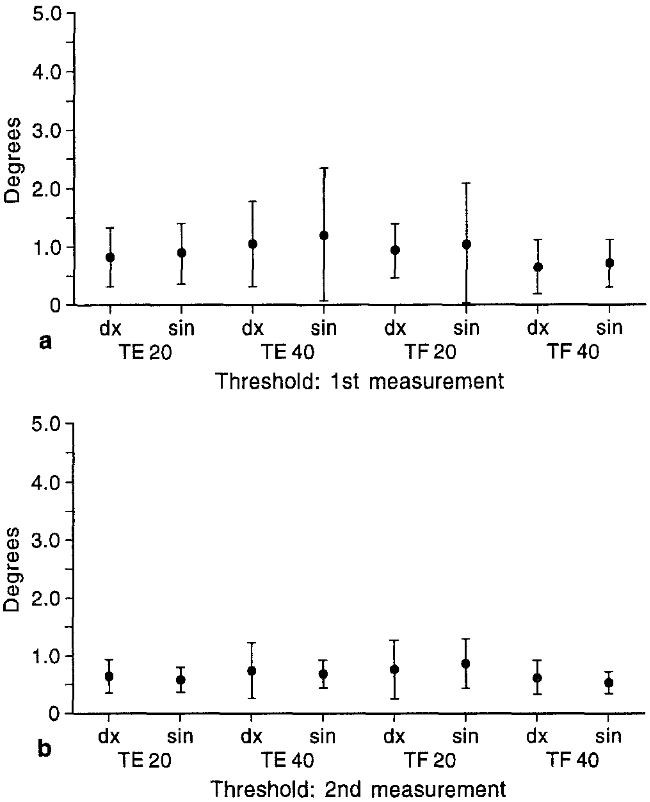

Fig. 2 Threshold values in degrees (mean ± SD) from both the 20° and 40° starting positions towards extension (*TE*) and towards flexion (*TF*) for both the right (*dx*) and left (*sin*) knee at **a** initial testing and **b** after 1 month

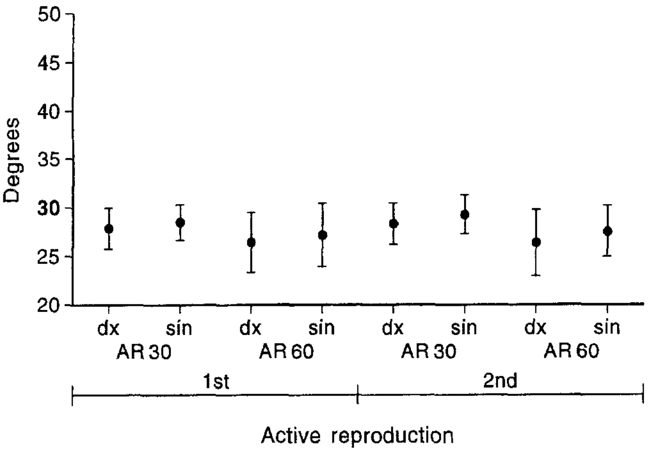

Fig. 3 Active reproduction of a 30° passive angular change (mean ± SD) from both the 30° (*AR30*) and the 60° (*AR60*) starting positions for both the right (*dx*) and left (*sin*) knees initially (*1:st*) and after 1 month (*2:nd*)

and women as well as right and left limbs were therefore analysed as one group (n = 38). When measurements at the first and second (1 month later) test occasions were compared, no differences were found for any of the three tests. In both the threshold and reproduction tests there were, however, trends towards lower recordings after 1 month (Figs. 2–4), probably as a sign of some learning effect, and analyses of each of the three tests were therefore made separately on both test occasions. The 95% confidence intervals for the difference between measurements 1 and 2 are given in Table 1.

When the thresholds for extension and flexion (Fig. 2) were compared from the 20° starting position, the threshold for extension tended to be lower than that for flexion: 0.75° (range 0.5°–2.25°) vs 1.0° (range 0.5°–3.0°) (NS) on the first test occasion, and was significantly lower: 0.5° (range 0.5°–1.25°) vs 0.75° (range 0.5°–2.25°) (P = 0.004) at the second measurement.

The threshold for flexion was, on the other hand, lower than that for extension when compared from the 40° starting position: 0.5° (range 0.5°–2.25°) vs 0.75° (range 0.5°–4.0°) (P = 0.002) in the first measurement, and with a tendency, 0.5° (range 0.5°–1.0°) vs 0.75° (range 0.5°–1.75°) (NS), in the second measurement.

When comparing the thresholds for extension between the 20° and 40° starting positions, a lower value was found in the more extended position in the first measurement,

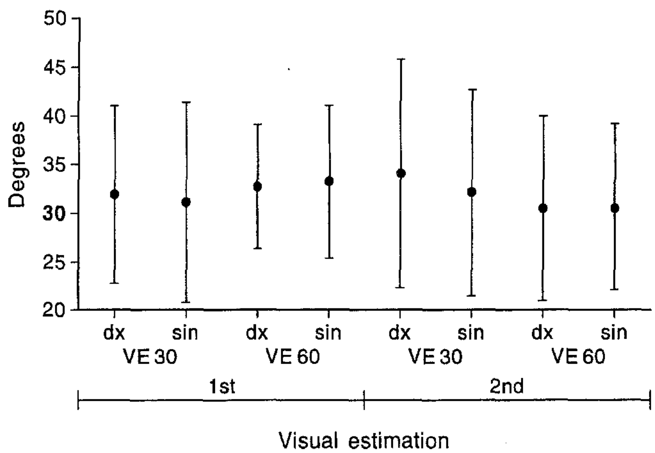

Fig. 4 Visual estimation on a protractor of a 30° passive angular change (mean ± SD) from both the 30° (*VE30*) and the 60° (*VE60*) starting positions for both the right (*dx*) and left (*sin*) knees initially (*1:st*) and after 1 month (*2:nd*)

Table 1 Difference with 95% confidence intervals (deg) between measurements 1 (initial) and 2 (after 1 month) in the normal population

Type of test		Difference	Confidence interval
TE	20	0.13	0–0.38
	40	0.25	0–0.63
TF	20	0.13	0–0.25
	40	0.00	0–0.13
AR	30	0.50	–0.13–1.38
	60	0.25	–0.62–1.25
VE	30	0.13	–2.25–2.25
	60	–0.25	–2.38–2.00

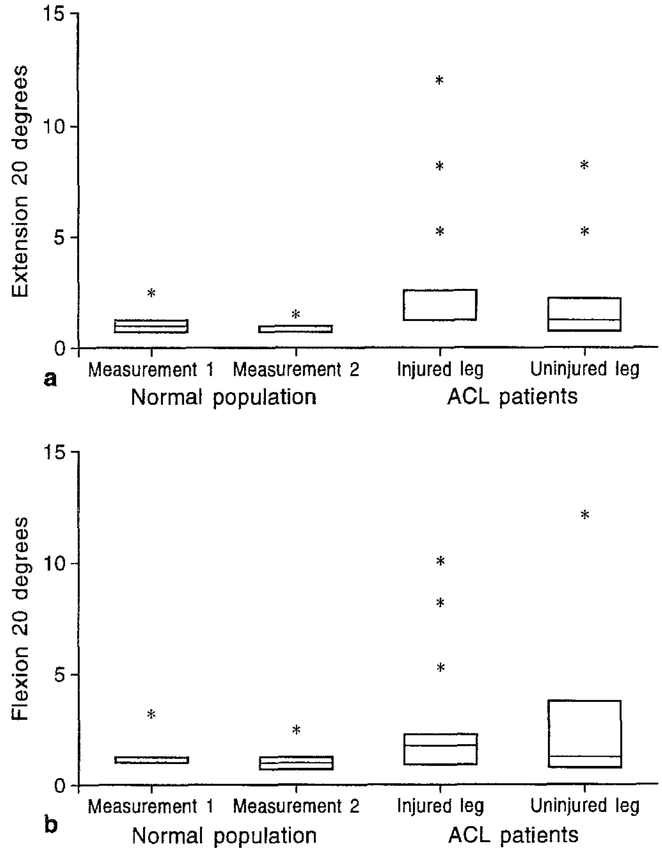

Fig. 5 Boxplots of threshold measurements (deg) from the 20° starting position towards both extension (**a**) and flexion (**b**). In the normal group, at initial testing (measurement 1) and after 1 month (measurement 2). In the ACL-injured patients, both the injured and uninjured leg. Median values given as a separate *line through the box* or as the *bottom line of the box*. The box includes the first to third quartile. *Asterisk* denotes outliers

0.75° (range 0.5°–2.25°) vs 0.75° (range 0.5°–4.0°) (P = 0.03), and with the same tendency in the second measurement, 0.5° (range 0.5°–1.25°) vs 0.75° (range 0.5°–1.75°) (NS).

The thresholds for flexion were lower from the 40° starting position than from 20°; 0.5° (range 0.5°–2.25°) vs 1.0° (range 0.5°–3.0°) (P = 0.0005) in the first and 0.5° (range 0.5°–1.0°) vs 0.75° (range 0.5°–2.25°) (P = 0.007) in the second measurement.

A difference was found when an active flexion movement was performed from 30° to 60° as compared with an extension movement from 60° to 30° (Fig. 3). In the first measurement the flexion reproduction median error was 2.0° (range 0.5°–16.0°) compared with 2.5° (range 0.25°–7.25°) (P = 0.07) for extension, and in the second measurement the figures were 1.5° (range 0.0°–4.75°) and 2.75° (range 0.75°–7.75°) (P = 0.0006), respectively.

The visual estimation of a passive angular change from 30° to 60° and from 60° to 30° on a protractor showed larger individual variations (Fig. 4) and was significantly less accurate than the active reproduction of the same angular changes. No differences were found between movements towards extension and towards flexion. Active reproduction tended to underestimate the angle change whereas the estimation on a protractor tended to overestimate it (Figs. 3, 4).

The patient group was compared with the average of the right and left knee in the first measurement of the normal population. When the injured side was compared with the normal population (Fig. 5), higher thresholds from 20° towards both extension (TE 20) 1.0° (range 0.5°–12.0°) vs 0.75° (range 0.5°–2.25°) (P = 0.01) and towards flexion (TF 20) 1.5° (range 0.5°–10.0°) vs 1.0° (range 0.5°–3.0°) (P = 0.06) were found.

No differences were found in thresholds from 40° either towards extension (TE 40) or towards flexion (TF 40). In the reproduction tests no differences were found between the patients and the normal individuals, either from 30°(AR 30 and VE 30) or from 60°(AR 60 and VE 60). When the injured side was compared with the uninjured limb, no differences were found in any of the tests, but there was a tendency towards higher values in all tests on the uninjured side compared with the normal group.

Discussion

Sensory measurements of the knee in humans have traditionally been performed in one direction, either in a sitting [1, 9, 11, 24, 32] or in a supine position [5, 12, 38]. In these positions it is possible to measure threshold values for movements towards both flexion and extension [25] produced by an engine and also to move the lower leg passively or actively into the chosen position for a reproduction trial, but there will be an uncontrolled effect from gravity varying between different starting positions. This will lead to a disturbance of the direct relationship between muscle tension and joint movement, depending on the direction of the movement compared with gravity: in a sitting position with semiflexion of the knee, flexion movements are assisted by gravity, while extension movements are counteracted. Since it has been shown experimentally that a muscle contraction with resultant joint torque changes the neuronal afferent discharge rate from the joint [17], comparisons of flexion and extension movements might be compromised. Testing in a lying on the side position would make such comparisons possible with a minimal effect from gravity.

The different starting positions in this study were chosen to be within the working range of the knee during ordinary weight-bearing activities where a sensation of not feeling the knee has been described [35], and also to cover the flexion range from 20° to 40° in which some patients with chronic and symptomatic knee injuries have an impaired ability to keep their joint congruent during simple weight bearing [14]. The different starting positions were also chosen to exclude the most extreme joint positions in order to make patient positioning and the testing procedure more precise. Measurements closer to terminal extension might otherwise, due to variations in the physiological range of motion (some individuals have a hyperextension and some a few degrees of extension lag), lead to a different tension in the muscles, the capsule and the ligaments between individuals. The same types of tests as in previous studies were used, and a slow velocity was chosen to make sure that the patients could not detect a sudden onset of motion and to make testing more difficult than if a higher velocity had been chosen [9, 10, 15].

When the different starting positions were compared in this study, lower thresholds were found in movements towards extension from a more extended position than from a less extended position, which was also found in ACL-injured patients [25]. These findings are in accordance with neurophysiological experiments showing an increased afferent impulse generation near the extremes of joint motion [7, 8, 10, 17, 18, 33]. The results imply a logical joint protective purpose since the higher sensitivity occurred closer to the terminal joint position, which if exceeded might lead to injuries. It seems from this study that this increase in awareness starts at some distance from the most extreme joint position.

In the active reproduction tests, differences were found between movements towards extension and towards flexion. In the first measurement the flexion reproduction median error was 2.0° (range 0.5°–16°) compared with 2.5° (range 0.25°–7.25°) for extension ($P = 0.07$). In the second measurement the flexion reproduction median error was 1.5° (range 0°–4.75°) compared with 2.75° (range 0.75°–7.75°) for extension ($P = 0.0006$), and thus, the hamstrings seem to be superior to the quadriceps in performing a more precise movement. A difference between the quadriceps and the hamstrings regarding their relation to proprioception has previously been suggested in a study on patients with an ACL lesion, where a positive correlation between the hamstrings/quadriceps strength ratio and proprioception was found [12].

The visual estimation of a passive movement (VE) was assessed as the most difficult of the tests by the examinees. After having moved their lower leg 30° at a speed of 0.5°/s, the majority of them commented spontaneously that they had no clue at all where the leg was positioned. They all felt the sensation of movement, but some did not even know if the movement was extending or flexing their knee, and thus, the individual variations were large. This method seems less appropriate to use as a single measure of proprioception, which has also been reported by others [16].

In patients with an ACL injury, Barrack et al. [3] have found a significantly higher threshold in the injured limb than the normal contralateral limb, in a group of 11 patients, and a severe defect in 7 of them. Barrett [4] reported defect accuracy in a visual analogue test in 10 ACL-deficient and 45 ACL-reconstructed patients compared with a control group and a better correlation to the subjective functional outcome than laxity testing and knee scores. Corrigan et al. [12] found an increased threshold and active reproduction error in 20 ACL-deficient patients compared with 17 normal and healthy subjects. Co et al. [11] reported no significant differences in reproduction error between a normal population, and the injured limb and the contralateral normal limb in 10 patients with an ACL reconstruction. In the threshold measurements both limbs of the patients were more accurate than the control group and the ACL-reconstructed limb less accurate than the patient's own contralateral limb. Harter et al. [20] found no difference between the injured and uninjured knee in a group of 51 patients after an ACL reconstruction, whereas Newberg [27], also with the uninjured knee as internal control, observed defects after ACL reconstruction in a group of 35 patients in reproduction tests. In a study on 12 patients after an ACL reconstruction, where the uninjured knee served as the internal control, the thresholds on the injured side were found to be higher than in the uninjured limb in movements towards both flexion and extension near terminal extension but not in more flexed positions [25].

The inconsistency in the results might be due to differences in the populations and to differences in the type of tests applied, where some probably measure a position sense in reproduction tests, whereas others probably measure more of a movement sense in threshold tests, and consequently the underlying neurophysiological mechanisms might vary between the studies. One can only speculate about the relative importance of impulses from cutaneous, muscular, tendinous and articular afferents.

Associated soft tissue, menisci and chondral lesions are frequent after an ACL injury, and these may also effect proprioception and thus add to the inconsistency. However, in all five reports on thresholds, including this one, defects have been reported after an ACL lesion, but in only three of the eight studies on active or passive reproduction, so it seems reasonable to assume that the primary and predominant effect after an ACL lesion influences the sensitivity to detect a passive movement. This is in accordance with Lephart et al. [25], who suggested that threshold tests at slow velocities maximally stimulate joint receptors, while the effect on muscle receptors is minimal, in contrast to both active and passive reproduction tests which are thought to stimulate both muscle and joint receptors. A possible effect from compensatory mechanisms on the diverging results from reproduction tests has been suggested [20], and there might be more severe disturbances in some patient populations than in others. The diverging results might, however, also be affected by methodological and statistical issues, since testing procedure reproducibility has only occasionally and briefly been reported in the few existing studies on ACL patients. If the real error in a reproduction test is used, the group mean has a tendency towards zero, while if the absolute error is calculated, normality is affected which was previously reported [16]. In the threshold tests in this study, there were some extreme recordings in the groups (Fig. 5), and thus, in order to avoid false differences in the relatively small populations studied, parametric testing should not be made without careful consideration. Since most previous studies have used T-statistics, this adds to the difficulty in the correct interpretation.

The decreased awareness near extension, previously shown in patients after an ACL reconstruction with the uninjured leg serving as the internal control [25] and in the present study in patients with chronic and symptomatic ACL deficiency compared with an age-matched reference population, might be a contributing factor to both the subjective sensation of insecurity during standing and walking as well as the radiographically recorded joint incongruence during single limb stance.

In conclusion, information of passive movements in the nearly extended knee position was more sensitive towards extension than towards flexion in threshold tests, and the sensitivity improved closer to full extension, which implies a logical joint protective purpose. The hamstrings were superior to the quadriceps in performing a precise motor task as measured by an active reproduction test. The findings indicate that posterior structures have an important role in the fine-tuning of knee joint motion in this functionally important range of motion. In the nearly extended knee position, which is the basis for most weight-bearing activities, a group of patients with symptomatic ACL-deficient knees had an impaired awareness in detecting a passive movement. There were no differences in a more flexed position or in reproduction tests between the patients and the normal group; therefore, reproduction tests in the present form seems less appropriate to use in the evaluation of ACL injuries.

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