Lack of correlation between different measurements of proprioception in the knee
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urrent methods of measurement of proprioceptive function depend on the ability to detect passive movement (kinaesthesia) or the awareness of joint position (joint position sense, JPS). However, reports of proprioceptive function in healthy and pathological joints are quite variable, which may be due to the different methods used. We have compared the validity of several frequently used methods to quantify proprioception.

Thirty healthy subjects aged between 24 and 72 years underwent five established tests of proprioception. Two tests were used for the measurement of kinaesthesia (KT1 and KT2). Three tests were used for the measurement of JPS, a passive reproduction test (JPS1), a relative reproduction test (JPS2) and a visual estimation test (JPS3).

There was no correlation between the tests for kinaesthesia and JPS or between the different JPS tests. There was, however, a significant correlation between the tests for kinaesthesia (r = 0.86). We conclude therefore that a subject with a given result in one test will not automatically obtain a similar result in another test for proprioception. Since they describe different functional proprioceptive attributes, proprioceptive ability cannot be inferred from independent tests of either kinaesthesia or JPS.

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Proprioception is the sum of kinaesthesia and joint position sense. Kinaesthesia is defined as the awareness of joint movement and is dynamic. Joint position sense (JPS) is restricted to the awareness of the position of a joint in space and is a static phenomenon. Proprioception can also be defined as the cumulative neural input to the central nervous system from specialised nerve endings called mechanoreceptors. These are located in the joint capsules, ligaments, muscles, tendons, and skin. Some of these receptors (for example, Pacinian corpuscles) are stimulated in the initial and terminal stages of the range of movement of joints as well as during rapid changes in velocity and direction (kinaesthesia). On the other hand the Ruffini end organ-like receptors and Golgi tendon organ-like receptors have been associated with a response to the relative position of muscles and joints (joint position sense). However, in the literature the terms kinaesthesia, joint position sense and proprioception are often used synonymously.

Depending on the type of proprioceptive test used, different results have been observed in the same subject groups. For example, Barrett2 showed that JPS was significantly improved by reconstruction of the cruciate ligaments. MacDonald et al.,3 however, found that in patients with reconstruction of the anterior cruciate ligament (ACL) proprioception did not improve when measured by a kinaesthesia test. Barrett, Cobb and Bentley4 found an improvement in JPS after total knee replacement while Skinner et al.5 were unable to find any such improvement using a different JPS test and a kinaesthesia-based test.

In a series of studies Skinner et al.5 used the same testing device for a healthy control group and the results differed by as much as 100%.6-9 Various authors have made definite conclusions about overall proprioception using only either JPS tests or kinaesthesia tests.2,4,10-20 Because of these contradictory results, the question arises as to whether overall proprioceptive ability can be ascertained by a single method. Our aim therefore was to compare frequently used tests of proprioception and to evaluate the correlation between them.

Patients and Methods

Thirty healthy volunteers (12 women, 18 men) with a mean age of 41 years (sd 13.5; range 24 to 72) participated in the
study. None had a history of injury to the lower limb or vestibular or neuromuscular disorders. The subjects were tested using their dominant leg for five different tests of proprioception.

In all five tests visual clues were eliminated using a blindfold. For JPS1 and KT1 the subject’s leg was allowed to hang freely over the side of the table at a distance of 5 to 10 cm proximal to the popliteal fossa. Soft-cast compression splints (soft scotch-cast; 3M Healthcare, St Paul, Minnesota) were fitted above and below the knee. Elastic bandages were applied over the soft scotch-cast as tightly as possible to neutralise cutaneous sensation (Fig. 1). For JPS2, JPS3 and KT2 the subject’s leg was fitted in an adjustable splint (Fig. 2). To neutralise the slight vibration

Fig. 1
Photograph of the testing device used for JPS1 and KT1: (1) motor; (2) motor control box; (3) vibrator; (4) compression splint; (5) wire; (6) on-off switch of the control box.

Fig. 2
Photograph of the testing device used for JPS1, JPS3 and KT2: (1) motor; (2) motor control box; (3) vibrator; (4) adjustable splint; (5) wire; (6) electrogoniometer; (7) on-off switch of the control box.
created by the testing motor a vibration device was fitted on
the splint for tests JPS1, KT1 and KT2. In a pilot study we
also found that patients very often could tell whether
movement occurred by the slight vibration of the starting
stepper motor rather than the movement itself. In order to
eliminate this clue the vibrator was used which is a recom-
manded procedure for measurement of proprioception.3
Furthermore, the present results compare well with those in
the literature and we therefore can confidently conclude
that the slight vibrations at the splint (and not at the skin)
did not significantly affect the results and conclusions.
Additionally, in KT1 and KT2 tests the auditory clues were
eliminated by using industrial earmuffs with music playing.
Joint position sense test 1 (JPS1). This test measured the
ability to reproduce passively the position of the lower leg
using a slow-speed motor (Proprioception 2000; Automated
Motion Systems, Perth, Western Australia) for reposition-
ing (Fig. 1).8,12,18 Starting at a free-hanging position of 90°,
the motor moved the subject’s leg at a rate of 12°/s to three
randomly selected angles between 60° and 80°, 30° and 55°
and 5° and 25° of flexion. The leg was held in this position
for a few seconds and the subject was asked to concentrate
on its position. The knee was returned to the starting
position and then moved again by the motor at a speed of
5°/s. When the subject thought that the leg was in the same
position as before, he or she stopped the motor by using the
on-off switch of the motor control box. The absolute angu-
lar error was measured. This procedure was repeated nine
times, three times for each angle, and a mean value of
angular error was recorded for each subject.
Joint position sense test 2 (JPS2). This test measured the
ability of a subject to reproduce the knee angle using
a hand-held electrogoniometer as a visual analogue mod-
el.2,4,10,13-15,20-22 Starting at a free-hanging position of
90°, the examiner moved the dominant leg by raising the
splint to angles of 17°, 34°, 50° and 67° of flexion. An
electrogoniometer was attached to the splint and recorded
the position of the leg to an accuracy of 0.05°. The
subject was instructed to concentrate on the location of
the leg while maintaining the position for a few seconds.
The leg was then returned to its original position. The
subject then represented the perceived angle of flexion by
the hand on a visual analogue electrogoniometer (Fig. 3).
This procedure was repeated 12 times, three times for
each angle, and the mean angular error was recorded for
each angle.
Joint position sense test 3 (JPS3). This test measured the
reproduction of a knee angle using the contralateral leg as
the gauge.8,25 The subject’s splinted leg was moved to four
angles of 17°, 34°, 50° and 67° of flexion. After a few
seconds the leg was returned to its original position. The
subject then was asked to place the contralateral leg in the
same position as the tested leg before. An electrogoni-
ometer was attached to both legs to measure the angular
error. This procedure was repeated 12 times, three times for
each angle, and the mean angular error was recorded for
each subject.
Kinaesthesia test 1 (KT1). The threshold of detection of a
passive leg movement was measured.5,7-9,11,16,19,24 A wire,
wound up by the slow-speed motor, was attached to the
compression splint and moved the subject’s leg (Fig. 1).1
From a starting position of 60° of knee flexion, and with
the tension to counter gravity already applied, the serv-
ometro slowly pulled the subject’s leg into extension at
0.5°/s. The onset of the servomotor movement had a ran-
dom delay which varied between 5 and 60 s after the
subjects were prepared for the task. The subject was given
a control box with an on-off switch to stop the motor when
a change was perceived in the position of the tested leg.
The linear movement of the wire was measured and conver-
ted to angular deflection.8 This procedure was repeated
ten times and the mean threshold angle to detect passive
movement was recorded for each subject.
Kinaesthesia test (KT2). This test was similar to KT1 in
that the awareness of movement of the joint was measured.
In contrast to KT1, the subject’s leg was fitted into an
adjustable and not a compression splint (Fig. 2).25,26 Addi-
tionally, an electrogoniometer was attached to the splint
and recorded the position of the leg with an accuracy of
0.05°. This procedure was repeated ten times and the mean
threshold angle was recorded for each subject.
Statistical analysis. Descriptive statistics (mean and stand-
ard deviation) were used to determine the performance of
all subjects in each proprioceptive test. Pearson correlation
tests were used to determine the relationships between the
measures of proprioception. In addition, subjects were
ranked according to their performance in each of the tests
and rank-correlation coefficients of the different tests were
calculated.

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There are various tests for kinaesthesia and JPS in the literature all of which have conclusions regarding the overall proprioceptive ability.\textsuperscript{1,6,8,13,23,26} Our main findings were that there is no significant correlation between the kinaesthesia and JPS tests, or between the different JPS tests. This suggests that there is no single test which quantifies proprioception. Instead, each assesses one facet of proprioception only and does not represent the overall functional ability.

The lack of correlation between the kinaesthesia and the JPS tests agrees with a study by Fridén et al.\textsuperscript{27} They evaluated proprioception in 16 patients at different times after acute injury to a knee ligament by using two tests for JPS and one for kinaesthesia. Loss of proprioception was found in the kinaesthesia test but not in the JPS tests. This lack of correlation may also explain several contradictory results in the current literature. For example, Barrett\textsuperscript{2} found that proprioception was significantly improved by reconstruction of the cruciate ligaments after using a joint position visual estimation test, but MacDonald et al.\textsuperscript{3} found no such improvement using a kinaesthesia test. Skinner et al.\textsuperscript{3} measured proprioception in a group of patients before and after total knee replacement using a JPS and a kinaesthesia test. They were unable to find a difference in proprioception between knees with osteoarthritis and those with a prosthesis. On the other hand, Barrett et al.\textsuperscript{3} used a joint position visual estimation test and found that knee replacement improved joint proprioception.

No conclusions can be drawn as to which test is the most sensitive for detecting possible changes in proprioception. Some investigators prefer the threshold tests to the JPS tests because previous results for kinaesthesia measurements are more constant than for JPS tests.\textsuperscript{27} For example, a loss of proprioception after injury to the ACL was found in all six studies which used kinaesthesia tests,\textsuperscript{8,11,24,25,27,28} but in only three of eight studies employing JPS tests.\textsuperscript{2,8,24,27,29} Likewise, our study showed a good correlation only between the two threshold tests. This could be because the difference in the testing device between these two tests was minimal.

Nevertheless, even the small methodological change such as using a tightly-fitted compression splint (KT1) to diminish cutaneous sensory information significantly influenced the threshold angle. Hence, information from other sensory pathways may explain contradictory findings such as a reported threshold angle of 2.4° for elderly patients after knee arthroplasty\textsuperscript{11} and 2.7° for young dancers.\textsuperscript{6} Also, when apparently the same tests were used by different authors opposing results may be explained by minor methodological changes. For example, Barrack et al.\textsuperscript{7} found a significantly higher kinaesthesia threshold angle in subjects with injuries to the ACL while Wright et al.\textsuperscript{30} found no difference after ACL injury using the ‘same’ proprioceptive tests.

Proprioception depends on the cumulative neural input to the central nervous system from mechanoreceptors.\textsuperscript{1,31}
located in the muscles, ligaments, joint capsules, tendons and skin. Most JPS tests also involve efferent pathways. The lack of correlation between different JPS tests may be due to some of the final measurements being dependent upon both the function of the knee being tested and also on the sensory input from the other leg (JPS3) and the visual-cognitive-spatial ability (JPS2). The JPS1 was the only JPS test which was independent of secondary sensory inputs, suggesting that JPS1 may be the most objective JPS test.

Finally, we only used healthy subjects. Most researchers use these tests to distinguish between normal and pathological conditions. Our conclusions may not apply to pathological conditions and this needs further investigation.

Our study and others have assessed the conscious perception of joint position and/or movement. However, the symptom of instability suffered by patients after joint injury does not reflect the conscious perception of where the joint is in space, but the reflex control of its activity by its musculature. 32,33 Therefore the measurement of JPS or kinaesthesia is not necessarily the right approach to reveal a neurological defect after joint injury. Tests of muscle coordination such as standing balance may be of more value in assessing instability after ligament injury. 34

We conclude that there remains no comprehensive method for measuring proprioception. The results of studies which use only either JPS tests or kinaesthesia tests must be interpreted with care. Furthermore, the terms proprioception, kinaesthesia and JPS should not be used synonymously.

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References


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