Concise Report

A novel device for the measurement of proprioception in the hand

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Background. Together with visual information, awareness of limb position and movement is essential for limb coordination. A proprioceptive deficit has been demonstrated in a number of rheumatological disorders. There is a lack of a portable device for measuring hand proprioception in the field.

Methods. A compact portable device for measuring joint position sense in the metacarpophalangeal joint of the index finger of either hand was constructed. This device was manually operated and required the subject to match the position of the hidden finger with a surface-mounted silhouette. Reliability studies were performed over three consecutive days in 12 normal volunteers.

Results. Intrasubject variability [95% confidence interval (CI)] was 0.86° (0.04–1.76) between days 1 and 2, and 1.23° (1.04–3.50) between days 2 and 3. The intraclass correlation coefficient (95% CI) between all 3 days was 0.92 (0.85–0.96). Average proprioceptive error (95% CI) in the sample population was 5.72° (1.23–10.2) over the 3 days. This value was 5.94°, 5.79° and 5.42° on days 1, 2 and 3, respectively. No difference was found between sexes but dominant hands gave smaller errors (mean dominant error 5.11°, mean non-dominant error 6.35°; t = −3.4, P = 0.002).

Conclusions. This report describes a new portable device for measuring proprioception in the hand. Reproducibility was shown to be good on an individual and group basis. These results are promising and warrant larger age- and sex-related studies. The ease and portability of the device make it ideal for use in epidemiological studies of rheumatological disorders involving the hands, including joint hypermobility.

Key words: Proprioception, Joint position sense, Kinaesthesia, Measurement, Validation.

Awareness of limb position and movement is essential for coordination in the absence of visual stimuli. A deficiency in joint position sense has been implicated in the pathogenesis of a number of upper limb rheumatological disorders [1, 2], though its role in disease progression is poorly understood. Ferrell et al. demonstrated impaired position sense in fingers with rheumatoid arthritis, hypothesizing that chronic inflammatory joint disease leads to altered proprioceptive sensation [3]. Deficient finger proprioception has also been seen in individuals with the benign hypermobility syndrome [4], though the authors questioned whether the disturbance was a cause or effect of the laxity. From studies of knee joints, Sharma et al. hypothesized that the progression of osteoarthritis may be due to increased joint loading from age-related declines in proprioception, a view supported by studies showing bilateral proprioception deficits in unilateral knee osteoarthritis [5]. More recently, proprioceptive inaccuracy has also been identified as a strong predictor of poor physical function in patients with knee osteoarthritis [6]. Despite these associations, there have been no large-scale epidemiological studies to establish the exact relationship between proprioception and disease progression.

The only widely acknowledged clinical test of finger proprioception is the ‘up or down’ test undertaken at the distal interphalangeal joint during the peripheral neurological examination. Although simple, this is only designed for recognizing proprioceptive loss from gross sensory deficit [7]. Physiological studies have identified separate movement and position sensations in the index metacarpophalangeal (MCP) joint, with movement sensation dependent on rate of joint rotation [8]. Therefore, much of the recent research on position sense has eliminated movement sensation by displacing joints below the sensory threshold, at an angular velocity of <2°/min [8–10]. Such tests can last up to 6 h per patient, so are highly impractical for large-scale studies. Also, other authors argue that examining dynamic motion better simulates joint activity during functional tasks [11].

Further study of an easily accessible joint is needed to gain insight into hand proprioception in normal, hypermobile and diseased populations. This effort has been hampered by the lack of a quick and reliable method of testing finger position sense. We describe the design and validation of a device for the easy quantification of joint proprioception in the hand.

Methods and materials

Apparatus

Existing methods of examining proprioception in finger joints [3, 12, 13] and other joints [11, 14–16] were considered during development. The method chosen requires a subject to observe a target angle (a finger silhouette) and actively match the position...
with a hidden index finger. Proprioceptive acuity is determined as the average error over a range of angles. The central position in the index MCP joint and the crucial role of the index finger make this joint ideal for representation of hand function.

The apparatus, termed the proprioceptometer, was designed and constructed in conjunction with the Bioengineering Division of the Academic Unit of Musculoskeletal and Rehabilitation Medicine, University of Leeds. The apparatus measures 270 x 260 x 170 mm (length, width, height) and weighs just over 2 kg. The design allows symmetrical use in either hand for any size and shape of hand. With the hand in place, the device isolates the index finger, allowing full flexion and extension of the MCP joint while splinting the distal interphalangeal and proximal interphalangeal (PIP) joints into extension (Fig. 1). The remaining fingers and hand are held in the midline underneath, away from rotation of the index. The wrist is Velcro-strapped to a height-adjustable platform. A lid is placed on the top of the device with the thumb pointing up through a hole. A surface-mounted finger silhouette rotates above the index MCP joint indicating the target angle.

**Examination**

A relaxed subject sits on a chair and is asked to lean over the device to look through to their hand. The storage box maintains the apparatus at a height of 420 mm. The subject is asked to maintain their forearm in the mid-line with their wrist straight (Fig. 2). Each examination session consists of four tests, two for each hand. The first test is undertaken with the subject able to see their finger movements through a transparent 180° protractor (0.5° accuracy) in the lid (the visual test). This promotes familiarity with the apparatus, encourages the subject to lean over to reduce parallax error and allows compensation for remaining parallax afterwards. The subject is asked to watch the finger silhouette and match its position with their index finger. The examiner reads the achieved angle on a hidden examiner’s scale (0.5° accuracy). The finger silhouette is moved in a predetermined order to all 10° intervals between −10° (extension) and 50° (flexion) once only, excluding 0°. Between each 10° interval the silhouette is moved back to 0°, thus covering the same total angular displacement regardless of order. The subject will therefore be asked to achieve 10 position matches per test (five at 10° angles and five at 0°).

After this initial test, a non-transparent protractor sheet is inserted into the lid and the test is repeated in a different predetermined order (the non-visual test). This represents the true test of proprioception, the subject using position sense alone to match the finger silhouette angles.

**Reproducibility**

A study of reliability was conducted over three consecutive days at the same time each day to prevent diurnal variations in joint laxity [17]. The order of right or left hand tested first was alternated between subjects and days. A single examiner undertook all experiments on all subjects, eliminating potential variability from using separate observers [18].

**Sample population**

Twelve healthy adult volunteers with no history of hand injury or pathology were recruited for a study of reproducibility. The sample comprised of six male individuals, average age 21.2 yr (range 20–23 yr), and six female individuals, average age 22.0 yr (range 20–24 yr), each sex with five right-handed and a single left-handed
individual. Ethical approval was obtained for these non-invasive examinations and all volunteers gave informed consent.

Analysis
Overall matching error for each test was calculated by combining average errors of 10° intervals and 0° matches. Visual test values were subtracted from non-visual test values to adjust for parallax, representing proprioceptive acuity for a given hand on a given day. Reproducibility between days was analysed on an individual level using the intraclass correlation coefficient and on a group level using paired two-sample for means t-tests, with statistical significance at \( P < 0.05 \). Statistical analysis was performed using Microsoft® Excel 2000 data analysis and SPSS for Windows.

Results
Examination
A complete examination with explanation took around 15 min, short enough to maintain concentration and avoid discomfort. Differences between right and left tests and between tests undertaken first and second in a session were found to be statistically insignificant (\( P > 0.05 \)). Also, the difference between average errors at 10° intervals and errors at 0° was statistically insignificant, suggesting that use of these values equally was appropriate.

Reproducibility

Intrasubject reproducibility. The reproducibility of the device was firstly analysed on an individual subject level. A subject’s proprioceptive acuity on a given day was compared with the equivalent value on the next. Comparisons between days 1 and 2 were considered most demonstrative of test–retest reproducibility. The average variation [95% confidence interval (CI)] in proprioceptive acuity between days 1 and 2 was 0.86° (0.04–1.76). Individual reproducibility between days 2 and 3 showed greater variation, with an average difference of 1.23° (1.04–3.50). Variability analysis was undertaken by calculating intraclass correlation coefficients between all days. The average measure intraclass correlation coefficient (95% CI) between all days was 0.92 (0.85–0.96), and was 0.96 (0.90–0.98) between days 1 and 2 and 0.86 (0.67–0.94) between days 2 and 3. These results show little variation with repeated tests, and therefore very good reproducibility.

Intersubject reproducibility. Results for all 12 subjects were grouped with respect to dominance and sex for an analysis of group reproducibility. The average proprioceptive acuity (95% CI) in the sample population was 5.72° (1.23–10.2). On days 1, 2 and 3, this value was 5.94° (1.63–10.25), 5.79° (1.91–10.67) and 5.42° (1.07–9.77), respectively. These gradual improvements were not statistically significant by paired t-test (\( P > 0.05 \)). Dominant hands performed consistently better, with values of 5.54°, 5.41° and 4.39° compared with 6.32°, 6.18° and 6.45° in the non-dominant hands on days 1, 2 and 3, respectively. Using data from all three days, average errors were 5.11° in the dominant and 6.33° in non-dominant hands, a difference that was statistically significant using the paired t-test (\( t = -3.4, P = 0.002 \)). There were no statistically significant differences between the sexes.

Discussion
Research findings
This report represents the initial study of finger proprioception using the novel proprioceptometer, a device that adopts a unique approach to examining position sensation in the hand. Reproducibility studies conducted on 12 individuals over 3 consecutive days show good test–retest reproducibility of proprioceptive acuity by intraclass correlation. Reproducibility was better between days 1 and 2 compared with days 2 and 3 by group analysis. A reasonable explanation for this is the proximity of successive tests, as intense use of the apparatus in a short time could result in a practice effect. In the clinical setting, retests would not be taken so closely together.

Previous studies of the index PIP joint have contributed greatly to the understanding of finger proprioception [3, 8–10, 19, 20]. Mallik et al. measured a median modular proprioceptive error of 8.4° in the index PIP joints in a control group of 12 individuals [4]. The present study has measured an average proprioceptive acuity of 5.71° in the index MCP joint in a group of comparable size. These differences are most likely due to differences between joints, the younger sample population in the present study and the inclusion of kinaesthetic sense with the proprioceptometer. Mallik et al. used computer-controlled apparatus to test finger proprioception below the sensory threshold [4]. This apparatus has been used in other studies by the same research group [3, 9, 10, 19, 20]. This apparatus would be the most suitable alternative for comparison with the proprioceptometer. Such studies would be valuable in further validation of the new device and method.

Future study
This initial study used 12 individuals, a control sample size comparable to existing studies of finger proprioception [4]. Young and healthy individuals were used to eliminate the age-related finger proprioception deficits previously seen by other authors [9]. The promising results of this study warrant additional studies using larger samples from age- and sex-related subgroups. These would demonstrate true group-related differences and give further support to the suitability of the apparatus in epidemiological use. Though not statistically significant, the practice effect will also need investigation. If the initial visual test to promote familiarity contributes to this, changes in the method may be required. Variability when using different examiners has been seen in previous joint studies [18]. This will need investigation before undertaking large epidemiological studies that will involve more than one examiner. Despite a design that accommodates any size or shape of hand, patients with significant deformity may have difficulty using the apparatus, especially those with severe rheumatoid arthritis. Therefore, suitable structural adaptation of the design may be needed for such studies, though the method should remain the same.

Clinical application
The proprioceptometer offers potential to clinical and epidemiological research. The ability to quantify proprioceptive changes will allow continuous measurement of proprioception in the progression of degenerative and inflammatory arthritis. Proprioception might also be studied in poorly understood conditions, such as the focal dystonias described in musicians [21] and hypermobility. The versatility of the device would allow collection of data from large numbers of individuals in out-patient clinics and even the industrial setting. In the neurological setting, stroke patients have previously shown significant impairment of wrist proprioception [22]. These authors encourage the development of methods to quantify proprioception in the hand. If proprioceptive changes were implicated in specific conditions, the ability to quantify these changes would allow the assessment of hand function before and after medical intervention; for example, physiotherapy and occupational therapy following hand injury.
Conclusion

The system of measuring finger proprioception using the apparatus developed at Leeds has wide potential for further joint study, offering many benefits over existing methods. This initial study is promising and warrants larger age- and sex-related studies. The device is extremely portable and can reliably quantify index MCP joint proprioception in around 15 min. These factors support the proprioceptometer as the most appropriate apparatus for measuring hand proprioception as part of clinical and epidemiological studies.

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References