Impaired Limb Position Sense After Stroke: A Quantitative Test for Clinical Use

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Objective: A quantitative measure of wrist position sense was developed to advance clinical measurement of proprioceptive limb sensibility after stroke. Test-retest reliability, normative standards, and ability to discriminate impaired and unimpaired performance were investigated.

Design: Retest reliability was assessed over three sessions, and a matched-pairs study compared stroke and unimpaired subjects. Both wrists were tested, in counterbalanced order.

Setting: Patients were tested in hospital-based rehabilitation units.

Patients and Other Participants: Reliability was investigated on a consecutive sample of 35 adult stroke patients with a range of proprioceptive discrimination abilities and no evidence of neglect. A consecutive sample of 30 stroke patients and convenience sample of 50 healthy volunteers, matched for age, sex, and hand dominance, were tested in the normative-discriminative study. Age and sex were representative of the adult stroke population.

Main Outcome Measures: The test required matching of imposed wrist positions using a pointer aligned with the axis of movement and a protractor scale.

Results: The test was reliable (r = .88 and .92) and observed changes of 8° can be interpreted, with 95% confidence, as genuine. Scores of healthy volunteers ranged from 3.1° to 10.9° average error. The criterion of impairment was conservatively defined as 11° (±4.8°) average error. Impaired and unimpaired performance were well differentiated.

Conclusions: Clinicians can confidently and quantitatively sample one aspect of proprioceptive sensibility in stroke patients using the wrist position sense test. Development of tests on other joints using the present approach is supported by our findings.

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PROPRIOCEPTION-BASED abilities, such as locating one’s limb without looking, directing a limb to a given point, judging the weight of an object lifted, and appreciating the compressibility of an object, are important abilities in their own right, yet they are often impaired after stroke.1-7 Loss of limb position sense, for example, is reported to occur in 36% to 54% of stroke patients.8-10 Impairment is typically on the contralateral body side to the lesion, but may also be present ipsilaterally.11-13 Severity of loss varies from a scarcely measurable defect to complete lack of discrimination.1,4-10

Impairment of these abilities is often devastating for the individual. The loss has a negative impact on activities such as safety, postural stability, and motor function that require proprioceptive information.2 Patients often adopt unusual positioning of the affected limb, which may be uncomfortable and damaging,2,5 and prevalence of shoulder-hand syndrome has been associated with impaired proprioception.6 Even patients who have made a reasonable motor recovery may be unsafe in a domestic situation because of impaired proprioception.12 A negative association with motor recovery has also been reported. Limb position sense has a strong correlation with motor recovery of the hemiplegic arm,13-15 and is a reliable prognostic sign for the extent of long-term motor recovery.16 Quality of motor control, including control of slow, goal directed movements,16-21 multijoint movement sequences,21-22 accurate aiming, reaching, and tracking movements,23,24 prehension,25 and correction of ongoing movements,26 are most likely to be affected.21,22,27,28 In addition, proprioception appears to be important in novel motor tasks and in motor learning.26-32 Stroke outcome studies that have included measures of proprioceptive impairment also found loss of this ability to be of prognostic importance in relation to selfcare, likelihood of discharge home, and period of rehabilitation.10,31-34 Thus, the importance of the impairment is clearly evident.

ASSESSMENT OF POSITION SENSE IN THE UPPER LIMB

Various methods of assessing proprioceptive sensitivity may be employed in clinical settings. They include assessment of position discrimination, weight discrimination, force discrimination, thickness discrimination, detection and discrimination of imposed movements, detection of direction of movement, and discrimination of movement patterns.7,19,30,35 Appreciation of limb position, rather than detection of movement alone, is commonly impaired after stroke,5,23 and is frequently assessed by clinicians. It has been argued that only when an awareness of both movement and position is required, versus movement alone, can tests be regarded as specific for proprioceptive mechanisms.19 Attempts to assess "total proprioceptive sensitivity" have failed, given the apparent specificity of proprioceptive functions.30,35

Methods for assessing appreciation of limb position fall into several major categories, according to presentation of the target position by the examiner and indication of the perceived location by the subject. Typically, testing involves movement at a single joint, although tests involving combined movement of several joints of the limb may also be used.23 Commonly employed methods require different motor and cognitive abilities,
with a consequent impact on their suitability for use with stroke patients.

Three commercially available, quantitative tests of proprioceptive sensibility of the upper limb are the Kinesthesia Test, the Kinesthetic Acuity Test, and the Kinesthesiometer Test. The Kinesthesia Test requires subjects to actively reposition the limb by using a sheet with location markers. Yet, motor and memory demands of the task are problematic for many stroke patients. Furthermore, only limited retest reliability data exist for adults, and this reliability was shown to be poor. A need for adult norms has been indicated.

The Kinesthetic Acuity Test requires a subject to discriminate, with vision occluded, the height of two inclined runways on which his/her forearms are rested. The subject’s hands are placed around pegs at the base of the runways and moved concurrently up the runways by the examiner. Although motor and memory demands are eliminated and adult reliability and normative data are available, the test focuses on kinesthetic acuity between limbs rather than within one limb. This presents a problem in the assessment of stroke patients who may have ipsilateral as well as contralateral impairment. In addition, the range of angle separations recommended, ie, 3° and 5°, is likely to be too narrow for the stroke population, and problems with sensitivity of the test have been identified.

The Kinesthesiometer Test consists of a horizontally moving trough, on which the forearm rests, with the pivot of movement occurring at the elbow. The subject is required to actively reproduce an active or imposed movement of the elbow within the flexion-extension range. The response is read from the base of the device, which is calibrated in degrees of rotary movement and compared with the target position. Limited normative data are available for adults and retest reliability is relatively high (r = .82) for imposed movements of the forearm. The method has the advantage of being quick, simple, and consistent with clinical testing methods. The response, however, requires active movement by the subject, which is often not possible after stroke. The authors also report that subjects used auditory cues of the moving apparatus and timing cues of the length of movement to help judge distance moved.

Alternative methods of assessing limb position sensibility include quantitative limb matching tasks in which subjects are required to point to their visually occluded limb position on either side of a marked board, limb matching using infrared light emitting diodes and photographs, or use of a goniometer and scaling methods. The primary restriction to application of limb matching tests after stroke is the motor control required to match the position. Although imposed movements have been used, the method poses a further confounding effect by incorporating both upper limbs when ipsilateral impairment may be present after stroke. Scaling tests have potential for use with stroke patients when an imposed position is used but the use of an internal scale imposes memory and conceptual demands that could be problematic.

Although some proprioceptive discrimination tests are quantitative and have supportive validity and reliability data, these measures are not currently available in a format suitable for use with the stroke patients. Furthermore, clinicians currently employ measures that are not quantitative, lack objectivity, sensitivity, and criteria of normality, and are often confounded by other impairments. Typically, the limb is manually guided to test positions, often only two to five positions are sampled at a joint, and positions are not quantified. Verbal responses include only a few choices, such as up, down, and straight and are therefore relatively insensitive. Imitation response tests are subjectively judged and may be confounded by the presence of ipsilateral impairment. Limited attempts have been made to quantify positions or response error in clinical studies. Movements are still guided by the clinician, however, and quantification is usually only approximate. Thus the ability to quantify impairment, assess magnitude of change, objectively evaluate treatment effectiveness, and provide scientific documentation of outcome for consumers is currently compromised, particularly in patients who show less than obvious impairment and changes in impairment. A need for more quantitative and sensitive measures of proprioception is therefore apparent.

Additional problems include poor reliability and lack of standardized assessment and recording procedures. Dickenson noted extremely divergent results on tests of reliability for a range of proprioceptive measures. Garraway et al reported total inter-rater agreement of only 35% for measures of proprioceptive impairment after stroke. More recently Lincoln and associates found poor inter-rater reliability using a standardized sensory assessment form that included appreciation of joint movement, direction of movement sense, and joint position sense. Test procedures were reported to be consistent with common clinical practice, but were more detailed and standardized. Based on data reported, inter-rater reliability for tests of proprioception averaged only .22 across the eight joints tested. Furthermore, agreement between standardized test items and routine medical tests of proprioception was very poor, with a mean correlation of .09. Retest reliability was higher, .53 on average. Yet, all proprioceptive correlations were lower than for all other somatosensory measures.

Our purpose in this investigation was to develop a test that can quantitatively and reliably sample limb position sense in stroke patients. Knowledge of wrist position was selected because it is commonly impaired after stroke and is important in daily tasks such as grasp and release activities. Furthermore, since knowledge of limb position affects performance of everyday tasks, it is important to know the nature and severity of the underlying impairment to select the most appropriate form of treatment and to evaluate its effectiveness. The test therefore needed to provide a defined scale with good resolution, allow identification of the degree of impairment (ie, normal ability to severe impairment), be suitable for use with stroke patients, and be reproducible with potential for broad clinical application. The preceding review of existing quantitative measures indicated that externally imposed positions, avoidance of imitating or matching the position with the other limb, and use of an external pointer as a method of indicating a response were desirable. Supportive reliability data and objective, norm-based criteria of abnormality are also important for confident monitoring of change and interpretation of test scores, especially given the potential for variability in performance and for ipsilateral impairment in addition to the classical contralateral deficit. An “unaffected” ipsilateral side cannot be assumed or used as a standard of normality.

RELIABILITY STUDY

Methods

Subjects. The sample comprised 35 adult stroke patients who presented with a range of somatosensory discrimination skills (normal ability, mild, moderate, and severe impairment), as suggested clinically and defined by the developed Wrist Position Sense Test (WPST). Each gave voluntary, informed consent. The study was approved by ethics committees of our university and participating hospitals and conformed to guidelines of the National Health and Medical Research Council on human experimentation. Subjects were medically stable, had adequate comprehension of instructions and perceptual ability for assessment, were free of unilateral spatial neglect based on clinical
observation and standard neuropsychological assessments of shape cancellation,45 line bisection4 and tactile maze,55 and had no peripheral neuropathy. During selection WPST scores were checked to ensure the full range of proprioceptive discrimination skills was sampled. This range was achieved naturally within the sequential selection process adopted. The sample had a mean age of 54 years, with a range of 21 to 79 years (13 years, SD). Twenty-eight subjects were men. The right hand was affected in 14 subjects and the left hand in 21. Subjects were tested 2 or more weeks after stroke to minimize potential influence of transient sensory10 or rapid spontaneous change.57

**Apparatus.** The WPST quantified ability to indicate wrist position following an imposed movement. Test stimuli comprised 20 predetermined wrist angles in the flexion-extension range. An equal number of positions within the inner and outer ranges of flexion and extension were presented. The test device (fig 1) comprised protractor scales on the lid and base of the box-like apparatus, with scale markings at 1° intervals, splints for the forearm and hand, and a curtain. The forearm splint was fixed in a central position aligning forearm and hand. The hand splint was attached to a lever, allowing free wrist movement. A pointer, aligned with the axis of wrist movement and attached to the top of the box above a protractor scale, enabled subjects to indicate perceived wrist position. The axis of movement of the response pointer exactly matched that of the test lever and angle calibrations were made according to the protractor scales. A small roller inserted into the base of the lever permitted smooth movement and a felt cloth under the lever eliminated noise created by movements.

**Procedure.** Following standard instruction the examiner administered wrist movements to defined test positions in a predetermined random sequence using the lever (fig 2). The subject’s wrist was carefully aligned with the axis of movement of the lever. The examiner attempted to move the lever with a constant velocity. Subjects indicated perceived wrist angle by aligning the pointer on the top protractor scale with an imagined line linking the middle of the wrist to the index finger. The subject’s vision of his or her wrist position and of the examiner’s lever manipulations were occluded by the apparatus. A pretest wrist position ascertained comprehension of instructions and adequacy of visual acuity and visuo-spatial skills. The angle indicated by subjects was compared to angle of the lever to determine error. Average absolute error over the 20 positions was the index of proprioceptive discrimination ability. Testing took approximately 5 minutes.

The hand contralateral to the lesion site, identified by computed tomography and medical history (the “affected hand” in clinical observation), was tested in three separate sessions using the WPST apparatus and procedures described above. Presentation order was reversed for Session Two. Although reliability is typically investigated over two test sessions,58 three sessions permitted investigation of error associated with lack of test familiarity at the first assessment. Testing was conducted at 24-hour intervals (range, 24 to 72 hours) in a quiet room by the first author. Rests were permitted as required.

**Data analysis.** Test-retest reliability coefficients58 were calculated for Sessions One versus Two and Two versus Three. Standard errors of measurement (SEM) and 95% confidence intervals for estimating a single value59 and for estimating change in values from one session to another56 were also calculated to obtain metric indexes of combined random and systematic error. The test-retest regression was examined for deviations from the expected slope and intercept parameters of one and zero60 to investigate systematic errors. Scattergrams around the lines of best fit were also examined for linearity and uniformity in deviations from the regression line.

**Results**

Reliability coefficients, SEMs, and corresponding confidence intervals for estimating a single value and change in values across test sessions are presented in table 1. Scattergrams (fig 3) revealed a spread of scores across the full range of the WPST scale and suggested that the data were well represented by a linear model. Statistical analysis of slope and intercept values indicated no significant differences from the expected values of one for slope and zero for intercept in the regression of Sessions One and Two. However, significant differences were found for slope ($t(33) = 4.59, p < .001$) and intercept ($t(33) = 3.91, p < .001$) for Sessions Two and Three. Some subjects with low average error at Session Two scored with a slightly higher error for Session Three (fig 3B) while those with high error scores at Session Two had lower scores at Session Three, resulting in a slope effect. These results suggest a regression towards the
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Table 1: Test-Retest Reliability and Associated Error of Measurement

<table>
<thead>
<tr>
<th>Sessions Compared</th>
<th>r</th>
<th>SEM Individual Score</th>
<th>95% Cl Individual Score</th>
<th>Mean Error Change*</th>
<th>SEM Change Score</th>
<th>95% Cl Change Score</th>
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<td>1 &amp; 2</td>
<td>.92</td>
<td>2.7°</td>
<td>±6.5°</td>
<td>.13</td>
<td>3.7°</td>
<td>±7.5°</td>
</tr>
<tr>
<td>2 &amp; 3</td>
<td>.88</td>
<td>2.9°</td>
<td>±6.0°</td>
<td>.03</td>
<td>4.6°</td>
<td>±9.3°</td>
</tr>
</tbody>
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Abbreviations: r, reliability coefficient; SEM, standard error of measurement; CI, confidence interval.

* Mean changes in error scores were not significantly different from zero.

Two-tailed. All comparisons based on n = 35.

NORMATIVE STUDY

Methods

Subjects. Fifty stroke patients who met selection criteria outlined for the reliability study were sampled. The group was heterogeneous and included subjects with and without proprioceptive loss, according to clinical examination. All subjects who met selection criteria and agreed to participate were included. Ages ranged from 21 to 79 years (52 years, mean; 12.6 years, SD). Thirty-four men and 16 women were tested. Six subjects were left-hand dominant and six had inconsistent hand preferences according to the Annett questionnaire. Subjects were categorized into five-year age subgroups. The sample included 33 subjects from the reliability study.

The normative sample comprised 50 subjects without history of neurological dysfunction or impairment of sensibility in upper limbs. Each subject was individually matched with stroke subjects by age (within 5-year categories) and sex. Ages ranged from 23 to 77 years (52 years, mean: 13 years, SD). Similarly to the stroke group, 34 men and 16 women were tested. Five subjects were left handed and three had inconsistent hand preference.

Apparatus. Testing was conducted with the WPST.

Procedure. Both hands were tested. In the stroke sample 25 subjects were tested with the “unaffected” hand first and 25 with the affected hand first. Classification of affected and “unaffected” hands was based on clinical symptoms and computed tomography. Despite evidence of impairment on the side ipsilateral to the lesion, the common terminology “unaffected hand” will be adopted to distinguish between the limbs. Data for the dominant and nondominant hands of unimpaired subjects was also collected in counterbalanced order.

Data Analysis. Distribution properties of dominant and nondominant hands of unimpaired subjects and affected and “unaffected” hands of stroke subjects were examined with histograms. Criteria of abnormality, defined as the 95th and 100th percentiles of the unimpaired normal sample, were determined and confirmed with reference to stroke distributions. The zone of uncertainty around these criterion values was obtained to quantify error of measurement. This zone was constructed using the average one-tailed confidence interval obtained from the reliability study (ie, 4.8°), as interpretation of scores will mostly involve unidirectional decisions (eg, Is a patient’s performance in the normal range, indicating that treatment need not be initiated, or existing treatment may be withdrawn?). Differentiation of impaired and unimpaired performance was also investigated by comparing: the affected hand of stroke subjects with the comparable hand of unimpaired subjects; the “unaffected” stroke hand and matched subject’s unimpaired hand; and affected and “unaffected” hands of stroke subjects. If the affected hand of the stroke subject was the dominant hand, then the dominant hand of the matched unimpaired subject was selected as the comparable hand for analysis. Differences between stroke and unimpaired subjects and between the dominant and nondominant hands of the unimpaired normal sample were investigated with the Wilcoxon matched-pairs signed-rank nonparametric statistic, as paired difference scores distributions appeared to deviate from normality. Age related differences in performance were investigated using analysis of variance.

Results

WPST scores had a mean error of 6.1° and standard deviation of 1.8° (range 3.1° to 10.9°) for the combined data of the unimpaired sample. All scores were less than 11° (fig 4). Thus, the conservative, 100th percentile criterion for abnormality was defined as 11° average error and the zone of uncertainty was
The Wrist Position Sense Test is a quantitative, standardized measure of a person’s ability to judge wrist position following imposed movements. This ability is important in its own right and is by definition one aspect of proprioceptive sensibility. Although it has been suggested that ‘kinesthetic acuity’ is probably of greater functional value when subjects are active rather than passive, we chose the method of imposing a movement of the limb because the motor impairment that is commonly experienced after stroke would likely confound actively positioned testing. The WPST is suitable for use in clinical settings and with a wide range of stroke patients. It minimizes subject and experimenter bias, eliminates reliance on motor abilities, provides high resolution, allows repeated measurement over time, and has empirically demonstrated high reliability and ability to discriminate impaired performance.

Stability over time was indicated by high test-retest reliability coefficients. Reliability scores achieved were within recommended ranges, while still achieving high resolution. More importantly, the error of measurement appears adequate for clinical monitoring. The SEM for estimating an individual score, represents less than 7% of the maximum proprioceptive error score that was obtained, is only 1.0% of the full scale available, and is substantially less than the often severe impairments observed (40° to 45° average error). The average SEM for estimating a genuine change from one session to another was ±8.4°, which is small enough to clearly monitor progress in most patients. Intervention studies have indicated improvements of the order of 10° to 20° average error.

Reproducible test scores can be expected for the full range of wrist position sense abilities, because there were no systematic differences in reliability of scores at varying points of the scale. Although scores did not appear to be influenced by the level of familiarity with the tests or amount of practice on them, there was a slight tendency for high error scores to decrease with testing. Despite this suggested tendency, the stability of the measure has been demonstrated in the repeated baseline testing of a series of single case time series experiments.

The WPST showed its discriminative validity by clearly identifying impaired performance relative to normal standards. Although there was no predefined, independent measure of abnormality for stroke subjects, the proportion of subjects showing impairment and the distributions of scores across affected and unaffected hands were consistent with prior knowledge of the typical stroke syndrome and prevalences previously obtained. Similar methods of testing have been used in physiological investigations, supporting the conclusion that the WPST can validly differentiate impaired position sense at the wrist. Moreover, normal discrimination performance in stroke patients can be confidently identified relative to normative standards obtained.

Norm-based criteria of abnormality were objectively defined to facilitate interpretation of WPST scores. This was particularly important given the potential for impairment in the “unaffected” limb and the common clinical practice of using this limb as a point of reference. The conservative criterion of abnormality was 11° in the opposite hand, which was +8.4°, is small enough to clearly monitor progress in most patients. Intervention studies have indicated improvements of the order of 10° to 20° average error.

Competing explanations for test performance of stroke subjects do not appear plausible. The possibility of nonsensory factors, such as motor impairment and memory problems, influencing the scores was minimized in the design of the WPST. Imposed limb positions were used and subjects indicated limb position while still in the position. Selection criteria controlled for neglect, inadequate comprehension, and visuo-perceptual impairment. Furthermore, many stroke subjects with impaired scores in the affected hand concomitantly demonstrated scores well within the normal range for the “unaffected” hand, which reduces the plausibility of impairment of attention and cognition.
as explanations for the impaired scores of the affected hand. Also, 12 of the 15 subjects with impaired ipsilateral scores did not have concentration, memory, or language impairment that might have influenced performance, as was reported following detailed testing by a qualified neuropsychologist (9 cases) or by rehabilitation specialists and allied health professionals (3 cases). Fluctuation of attentional processes was reported by the neuropsychologist in three subjects. Even in these subjects, however, it is debatable whether the impairment would be sufficient to substantially affect the 5-minute WPST test.

Findings from the reliability and normative-discriminative studies appear generalizable to the wider population of stroke patients. Stroke subjects in the reliability study had limb position sense scores spread across the full range possible and significant change would not be expected within the test-retest time interval sampled. Standard test procedures were employed and testing of affected and "unaffected" limbs was counterbalanced. The discriminative study stroke sample was sequentially selected from three major rehabilitation hospitals, providing a representative sample of the sub population of patients who present for rehabilitation. Also, in both studies the age range was comparable to that of the adult stroke population, particularly those involved in rehabilitation.55,66 Although more men than women were included, this was consistent with reported higher incidence of men.56 Age was not significantly associated with level of performance in the normative sample, a finding at variance with the literature. A decline in proprioceptive sensitivity, including static limb position sense, has been demonstrated with advancing age in comparable age range samples.57,68 The contrary results of the present study may, however, be influenced by the combination of a relatively small sample size and observations that the decline in sensitivity is not universal, there being wide individual differences in the extent of involvement.56,69

The WPST measures the ability to discriminate relative positions at the wrist. It does not attempt to assess the contribution of different receptor types or to isolate discrimination of limb location relative to limb movement, nor does it attempt to measure other dimensions of proprioception. The test does, however, provide a quantitative, reliable, norm-referenced measure of the capacity to indicate wrist position following an imposed movement, thus advancing existing clinical measure. In considering the clinical application of the test it is recognized that the WPST only samples one body location. This is a general problem in testing limb position sense, as it is only possible to sample body parts. Yet, in clinical settings it is usually important to investigate limb position sense at several body locations.

The extent to which WPST scores generalize to other body locations, to other measures of proprioception, or to other somatosensory abilities is unknown at present. Research suggests that the presence and severity of somatosensory impairment, including impairment of limb position sense, varies across body locations after stroke45,49 and is influenced by factors such as lesion site and extent of bilateral innervation. Organization of the somatosensory system is also highly specific. Each population of receptors coding kinesthetic information relays information about one small specific part of the body.35,70 Furthermore, "calibration" within the system is highly specific, as evidenced by findings that recalibration affects only the moving body part involved in discordance and does not transfer to other joints.35 In combination, these findings suggest that specific scores obtained at the wrist cannot be generalized to other body locations. Furthermore, given the apparent specificity of proprioceptive abilities previously noted,35,39 clinicians may need to separately

![Fig 5. Frequency distribution of wrist position sense error for (A) affected hand of stroke sample, (B) corresponding hand of neurologically unimpaired sample; (C) "unaffected" hand of stroke sample, (D) corresponding hand of neurologically unimpaired sample.](image-url)
assess other aspects of proprioceptive sensibility such as weight discrimination and appreciation of compressibility. The extent of generalization to other somatosensations, such as tactile discriminations that are conducted through the same dorsal column-medial lemniscal system and contribute to knowledge of limb position, is also likely to be limited. For example, Roland2 reports differential impairment in discrimination of kinesthesia (measured by the capacity to appreciate change in limb position with contracting muscles) and diserniination of texture, size, and shape. Development of other proprioceptive measures and investigation of the nature and specificity of proprioceptive impairment following stroke is required.

In conclusion, the WPST can be used with stroke patients in clinical settings to measure wrist position sense. Because knowledge of wrist position is important in daily activities and is frequently impaired following stroke, it is recommended that the test be used as a quantitative clinical tool to measure degree of impairment and treatment outcome related to wrist position sense. The measure is standardized, able to objectively discriminate impaired performance relative to normative standards, and can reliably measure small changes over time. In addition, it is anticipated that subjects who demonstrate presence of impaired position sense in the wrist task would also show impaired location of limb position at other joints of the upper limb. Nevertheless, since it cannot be assumed that the degree of impairment obtained at one joint will be similar to that obtained at another, it is recommended that a number of joints be measured in clinical settings to obtain a profile of limb position sense in the upper limb. Development of parallel forms of the WPST is therefore indicated. Interobserver reliability also requires investigation to ensure the same phenomenon is assessed and communicated by different clinicians. To facilitate accurate, reliable testing of a range of patients sustaining neurological damage to the peripheral or central nervous system, further reliability and matched normative studies, similar to those conducted for the stroke sample, would also be useful.

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