Evaluation of cervical proprioceptive function: optimizing protocols and comparison between tests in normal subjects

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Evaluation of Cervical Proprioceptive Function

Optimizing Protocols and Comparison Between Tests in Normal Subjects

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Study Design. A test-retest design evaluated stability as well as within and between day reliability.

Objective. The study aimed to define optimum protocols for the cervical joint position error (JPE) and cervicocephalic kinesthesia tests and to investigate association between performances in the tests.

Summary of Background Data. The cervical JPE and cervicocephalic kinesthesia tests are proposed as measures of cervical proprioception. However, there has been little investigation of the number of trials needed to obtain stable and reliable estimates of performance. Both tests have potential limitations in reflecting the underlying construct of cervical proprioception and association between performances in both has not been investigated previously.

Methods. Head repositioning and head-tracking errors were measured using an electromagnetic-tracking system in 16 normal subjects, tested on 3 occasions over 2 days. The effect of different numbers of trial repeats was analyzed descriptively in terms of stability of measures obtained and by using intraclass correlation coefficients to assess reliability. Association between the tests was analyzed with the Pearson correlation coefficient.

Results. Stable estimates of performance were obtained when data from 6 or more trials was included. The greatest test-retest reliability was obtained with 5 or more trials in both the cervical JPE (intraclass correlation coefficients = 0.73–0.84) and cervicocephalic kinesthesia (intraclass correlation coefficients = 0.90–0.97) tests. Correlation analyses indicated no significant association between performances in the 2 tests (r = −0.476–0.228, $P > 0.05$).

Conclusion. Our finding that at least 6 trials were needed to optimize stability, and reliability of outcome measures has important implications for application of these tests. The lack of correlation between performances in the tests supports the suggestion that they are not comparable measures of cervical proprioception. Further planned studies will include a range of tests challenging different aspects of cervical proprioceptive contribution to sensorimotor control in different subcategories of neck pain patients.

Key words: cervical spine, proprioception, cervicocephalic kinesthesia, methods, reliability, correlation, movement. **Spine 2007;32:E692–E701**

Afferent proprioceptive information is important for sensorimotor control of posture and movement,[1,2] and altered proprioceptive function is associated with joint disease[3] and other musculoskeletal conditions.[4–7] The specific nature and clinical significance of this association remain unclear, but it is believed that understanding sensorimotor functional impairment is important for diagnosis and rehabilitation of spinal and peripheral joint problems.[8] A number of studies have investigated this relationship in neck pain patients, using various tests proposed to reflect cervical proprioceptive function.

A widely used measure of cervical proprioception is the joint position error (JPE) test, in which impaired ability to relocate neutral head position has been demonstrated in acute[9] and chronic[7,10–12] whiplash and in nontraumatic neck pain patients.[11,13] However, this test may give an incomplete measure of proprioceptive contribution to movement control.[7,14] First, only a static neutral head position is evaluated, and it is not clear how proprioception relates to ongoing control during repositioning motion. Also, it might be expected that neutral repositioning is a learned action, wherein the required motor action is predictable, and dependence on ongoing proprioception during movement could be limited. Recently, a new test of cervicocephalic kinesthesia (position sensation during movement) was proposed to overcome these limitations, and whiplash patients made greater errors when moving their head to track a slow, unpredictably moving visual target compared to healthy controls.[14] Although the face validity of this task suggests that it may overcome some limitations of the JPE test, the use of visual feedback in aiding performance cannot be isolated from the role of proprioception. Last, if both tests do similarly reflect the same underlying construct of cervical spine proprioception, correlation would be expected between the levels of performance in each test. This has not been evaluated to date.

Physical function measures should demonstrate stability (values remain consistent when calculated across different numbers of trials) in both performance accuracy (mean value) and precision or variability about the mean (standard deviation)[8] and also show acceptable test-retest reliability.[15] There has been little examination of these issues for either of the above cervical proprio-

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Figure 1. Experimental setup for the head-tracking cervicocephalic kinesthesia test. The distance from the head-mounted sensor to the screen center is 80 cm. The yellow cursor provides the visual target, and the green, ring-shaped cursor displays head position.

ception tests. For the cervical JPE test, most studies used 3 or 10 repeats for each motion. A recent study showed that for a spinal JPE test, increasing trial numbers to 6 or more improved stability and statistical power.[8] No studies have investigated the optimum number of trials to perform, for the cervical JPE or the cervicocephalic kinesthesia tests.

A few studies have addressed reliability of the cervical JPE test.[6,7,15–18] Two reporting intraclass correlation coefficients (ICCs)[8,16,17] demonstrated good reliability except for repositioning following cervical extension, in which the reliability was low. For the cervicocephalic kinesthesia test, analysis of a small subgroup of participants showed "acceptable" reliability.[14] The impact of varying trial numbers on test-retest reliability has not been reported for any proprioceptive function tests.

The primary aim of this study was to define optimum protocols for evaluating cervical spine proprioception using the JPE test and cervicocephalic kinesthesia test, in terms of the number of trials needed in healthy subjects to maximize stability and reliability. A secondary aim was to evaluate whether the 2 tests are comparable measures of the underlying construct of cervical spine proprioception in normal subjects by analyzing the level of correlation between performances in both.

Materials and Methods

A test-retest design was used to evaluate stability and combined within and between day reliability.

Sixteen healthy volunteers (6 men, 10 women), with a mean (SD) age of 26.5 (9.4), gave informed consent and participated in the study, which received institutional human research ethics approval. Each subject was tested on 3 occasions. Tests 1 and 2 took place consecutively on the same day. Test 3 took place 5 to 7 days later, at the same time of day to maintain consistent conditions. The same examiner performed all tests.

Equipment

Head repositioning and tracking were assessed using a Polhemus 3 space Fastrak electromagnetic-tracking system (Colchester, VT). Subjects were seated 80 cm in front of a PC monitor. A head-mounted receiver, positioned over the vertex, was fixed to a plastic head strap. A second receiver was secured over the spinous process of the T2 vertebra to monitor trunk movement (Figure 1).

For the cervicocephalic kinesthesia test, head sensor position was displayed by a cursor on the screen. Horizontal and vertical motion of this represented rotations in azimuth and elevation, respectively, maintaining a 1:1-relationship between angular head motion and cursor deviation. A second cursor provided the visual target for head-tracking tasks. Target trajectories were generated by scripts written in MatLab (The MathWorks Inc., Natick, MA).

Procedure

The cervical JPE test was carried out first, followed by the cervicocephalic kinesthesia test. A short training protocol preceded each. All trials were cued by a 2-second auditory tone, with recording commencing at the end of the tone. Training and test protocols are detailed in Table 1.

Cervical JPE Test

Subjects located their head in their perceived neutral position. They then made a full active movement in left rotation, right

Table 1. Details of the Training and Test Protocols Followed for the Cervical JPE and Cervicocephalic Kinaesthesia Head Tracking Tests

Test	Training Protocol	Test Protocol
Cervical JPE test	1 trial each for repositioning following left and right cervical rotation, flexion and extension 4 practice trials in total	10 trials for each repositioning movement Presented in pseudo-randomized sequence 40 test trials in total
Cervicocephalic kinaesthesia head tracking test	3 fixed curve trials each presented once 3 randomly generated curve trials 6 practice trials in total	3 fixed curve trials each presented 3 times 9 randomly generated curve trials All presented in pseudo-randomized sequence 18 test trials in total

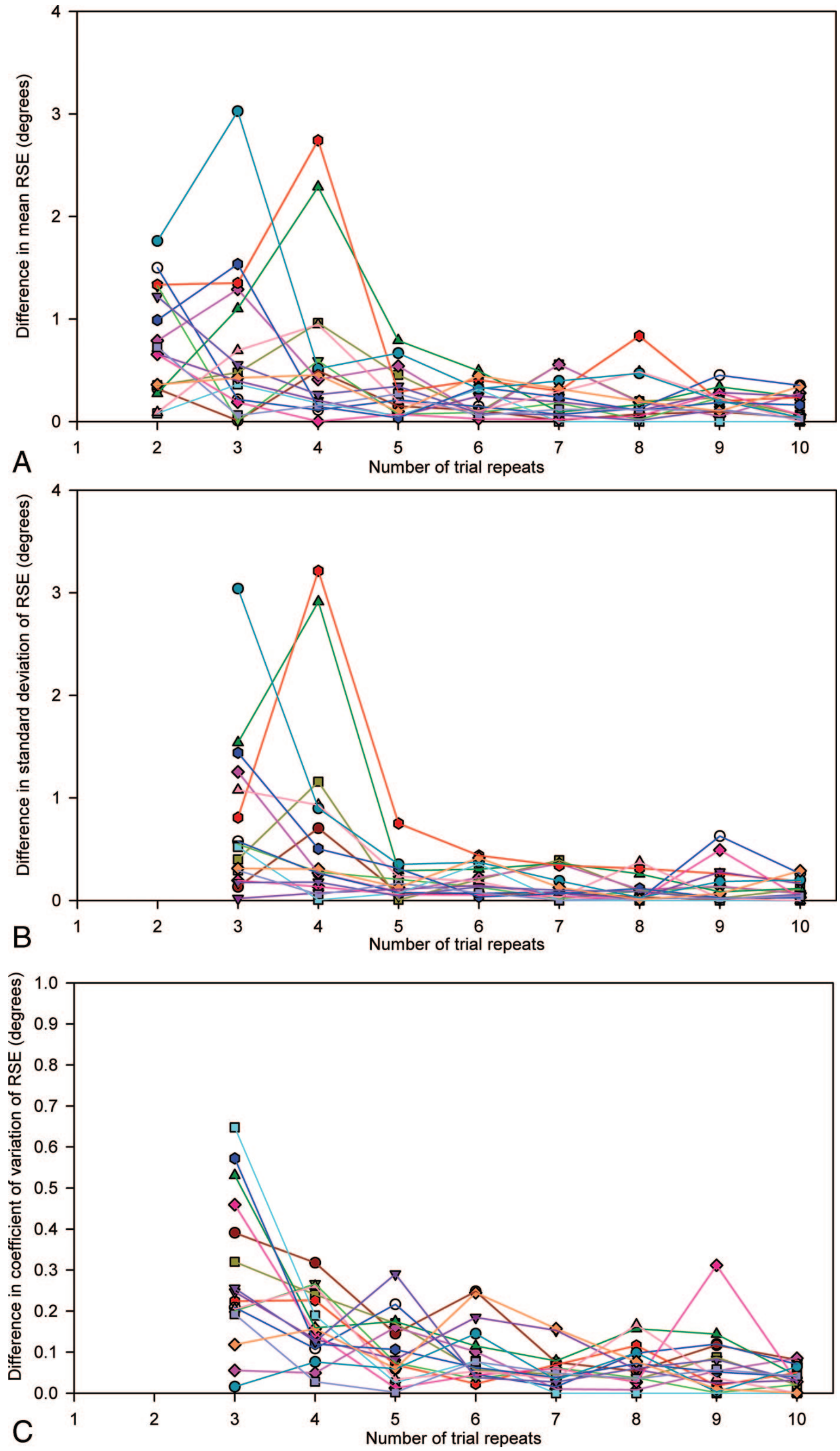

Figure 2. Effect of number of trials on stability of extension head repositioning for individual subjects in the cervical JPE test. The absolute difference between values derived from n and from n − 1 trial repeats is shown for **A**, mean RSE, **B**, standard deviation, and **C**, coefficient of variation. Each trace represents data for an individual subject (n = 16). B and C, no SD can be calculated for a single trial, so that the first-plotted difference is between 3 (*n*) and 2 (*n* − 1) trials.

rotation, flexion, or extension, with direction instructed verbally before each trial. Immediately afterward, they attempted to return to the initial neutral position. Vision was occluded throughout. Start and finish positions were electronically marked. Subjects were allowed to move their head before each trial. Root-squared error (RSE) (degrees) was calculated for the primary plane of motion as the difference between head sensor position at the start and end of the recorded segment of data, with any difference in T2 sensor position subtracted.

Cervicocephalic Kinesthesia Test

Preceding each trial, the stationary visual target was visible for 2 seconds, during which the subjects moved their heads to position the cursor over the target. Each trial lasted for 15 seconds, during

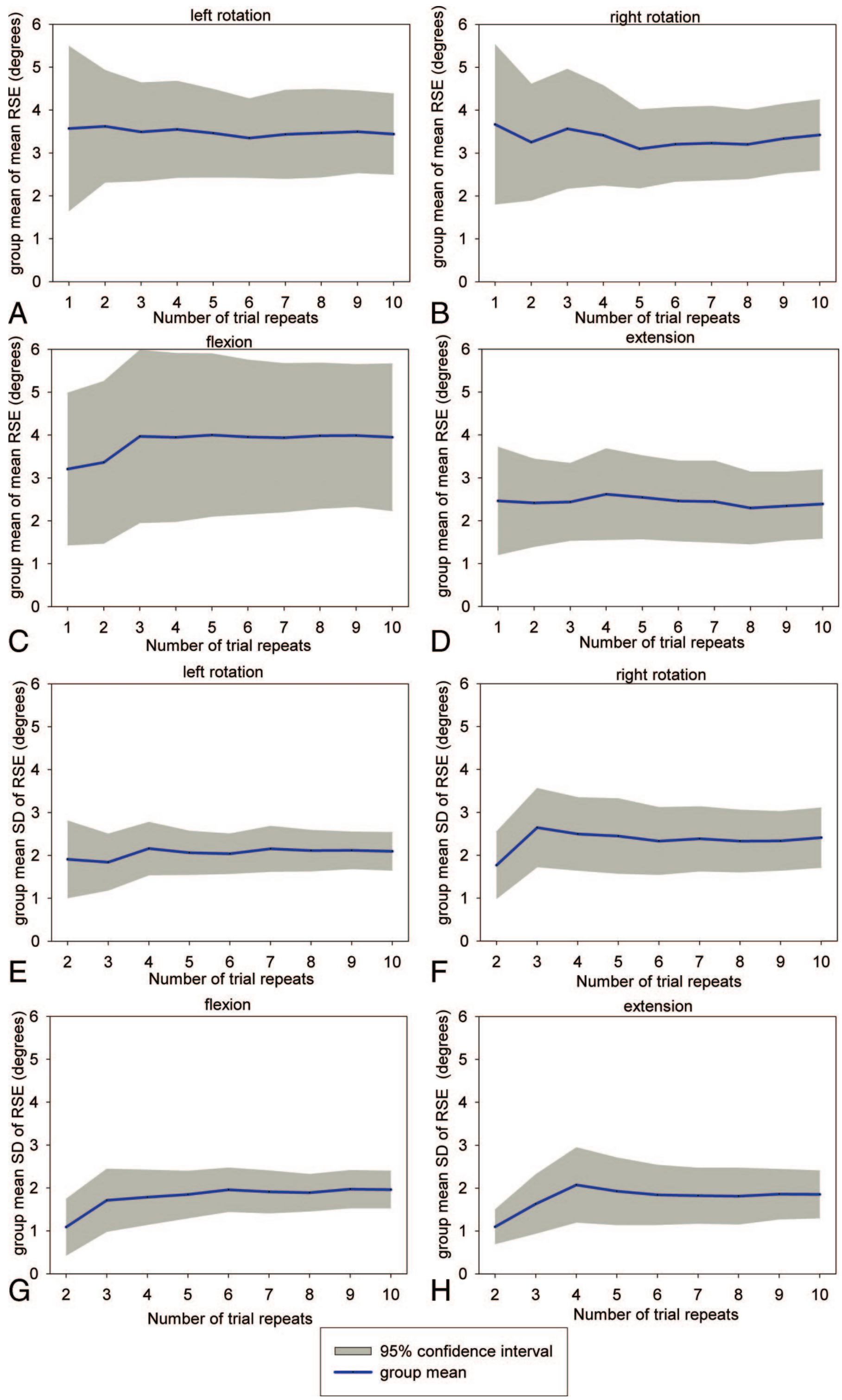

Figure 3. Effect of number of trials on stability of mean group head repositioning errors in the cervical JPE test. For each head-repositioning motion, the number of trial repeats are plotted against mean group mean RSE (**A–D**) or mean group standard deviation of the RSE (**E–H**). Gray shading indicates 95% confidence intervals.

which the subjects moved their heads to track the target with the head position cursor. Two types of target trajectory were presented in pseudo-randomized sequence.

Fixed Trajectory. In accordance with Kristjansson *et al* (2004),[14] 6 curved, unpredictable trajectories with constant velocity of 1° sec^{-1} were generated. Three were presented during pretest training and 3 as test trials (Table 1).

Random Trajectory. To evaluate whether the test could be carried out without preselection and repetition of trajectories, a unique trajectory was generated for each trial. These had variable velocity, with a maximum of 1° sec^{-1}.

Mean RSE (degrees) between the visual target and head position cursor was calculated across each trial.

Data Analysis

Scripts were written in MatLab to calculate errors for each repositioning and tracking trial. Data were analyzed for systematic differences across trials on test occasion 1, and across

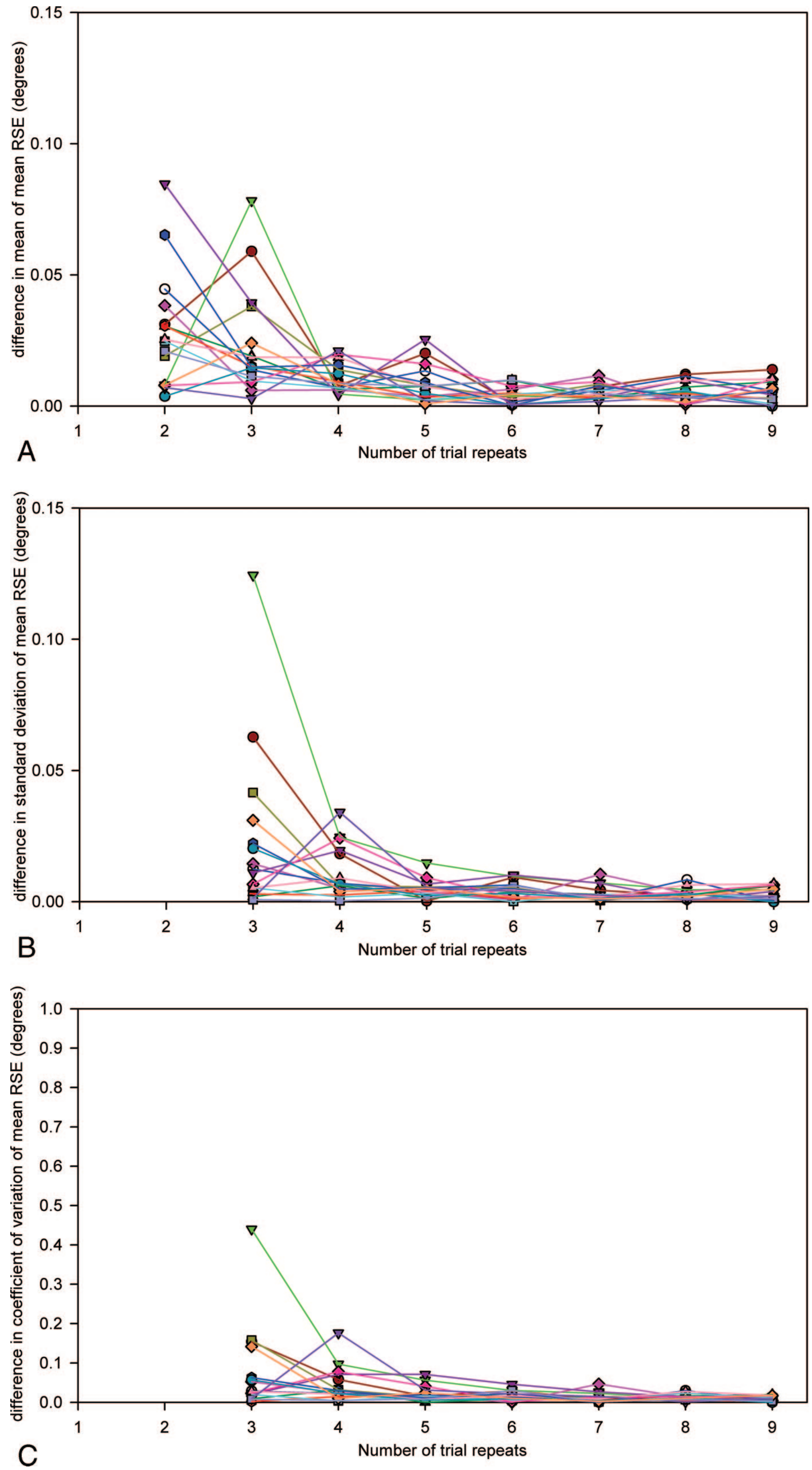

Figure 4. Effect of number of trials on the stability of random trajectory head tracking for individual subjects in the cervicocephalic kinesthesia test. The absolute difference between values derived from n and from $n - 1$ trial repeats is shown for **A**, mean of mean RSE per trial, **B**, standard deviation of mean RSE, and **C**, coefficient of variation of mean RSE. Each trace represents data for an individual subject ($n = 16$). B and C, no SD can be calculated for a single trial, so that the first-plotted difference is between 3 (n) and 2 ($n - 1$) trials.

occasions 1 to 3 with a series of repeated measures 1-way ANOVAs.

Stability was analyzed for individual subjects and group performance. Accuracy (mean) and precision (SD)[8] for repositioning error, and mean and SD mean RSE for head tracking, were calculated with inclusion of data from increasing numbers of trials from test occasion 1. Coefficients of variation were also calculated, enabling variability of tasks with different means to be compared. Plots of the effect of different numbers of trial repeats on these derived variables were analyzed descriptively. It was not appropriate to apply ANOVAs to

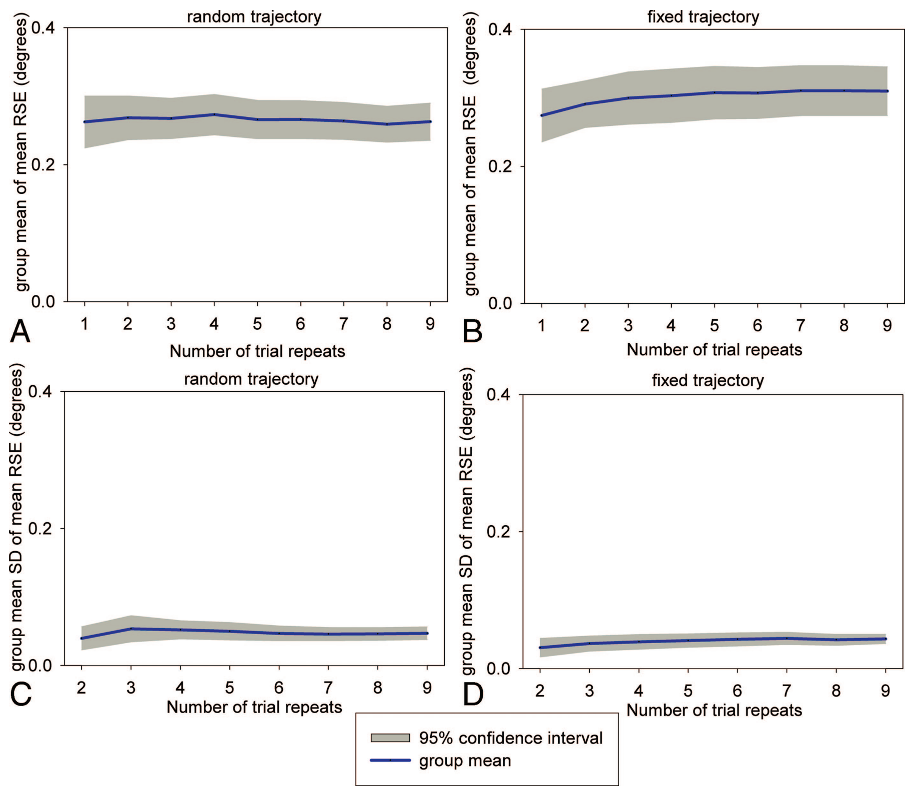

Figure 5. Effect of number of trials on the stability of mean group head-tracking errors in the cervicocephalic kinesthesia test. For random and fixed target trajectory head tracking, the number of trial repeats are plotted against mean group mean RSE (**A–B**) or mean group standard deviation of the RSE (**C–D**). Gray shading indicates 95% confidence intervals.

the effect of trials analysis. As different numbers of data values were used to derive each observation, their underlying variances are not homogenous, and the usual variance-covariance assumption for a repeated measures ANOVA is not met.[19,20]

Combined within and between-day reliability was analyzed by calculating performance across increasing numbers of trials on each test occasion, then computing ICCs (2,k) with 95% confidence intervals (CIs) on these.

Association between the subjects' performances in all tasks was analyzed using the Pearson correlation coefficient.

Results

For cervical JPE and cervicocephalic kinesthesia tests, repeated measures ANOVAs indicated no systematic differences in group performance across trials comprising test occasion 1 or between occasions 1 to 3 ($P > 0.05$).

Stability

For repositioning errors, the mean, SD, and coefficients of variation with inclusion of data from increasing numbers of trials are shown for individual subjects (Figure 2) and mean group performance (Figure 3). Figure 2 shows the differences between the estimates derived from increasing numbers of trials and illustrates that for extension repositioning, each parameter shows inconsistency when derived from few trials. For precision, fewer than 4 repeats tended to result in underestimation of the SD for subjects who showed poorer overall precision in performance. For most subjects, stable estimates were derived from 6 or more trials (differences approximate zero). The same trends were observed for effect of trials on extension and rotation repositioning (not shown). Figure 3 shows a similar pattern for mean group performance whereby accuracy and precision estimates for all movements generally reached stable levels with 6 trial repeats, coinciding with narrower CIs. The pattern for coefficients of variation (not shown) was similar to that of the SDs.

Analysis of the cervicocephalic kinesthesia test is shown for individual subjects (Figure 4) and mean group performance (Figure 5). Figure 4 illustrates that deriving data from approximately 6 or more trials resulted in relatively stable estimates for most subjects. Figure 5 shows that estimates of mean group performance similarly stabilize with 6 or more trial repeats, coinciding with narrower CIs.

Reliability

The effect of calculating ICCs from increasing numbers of trials is shown for cervical JPE and cervicocephalic kinesthesia tests (Figure 6). With 3 or fewer repeats, ICCs are lower for extension repositioning than for flexion and rotation. For all movements, 5 or more repeats resulted in the highest, most stable reliability estimates of between ICC (2,k) = 0.73 to 0.84. Taking ICC = 0.41 as a threshold minimum for "fair" reliability,[21] consideration of the lower bound of the CI for ICC values shows that all exceed 0.41 with 5 or more repeats.

For head tracking, ICC values of over 0.8, indicating "substantial" reliability[21] were obtained with 3 repeats. The highest, most stable estimates of ICC (2,k) = 0.90 to 0.97 were derived with 5 or more repeats. The lower bound Cl threshold of 0.41 was exceeded with a single-tracking trial.

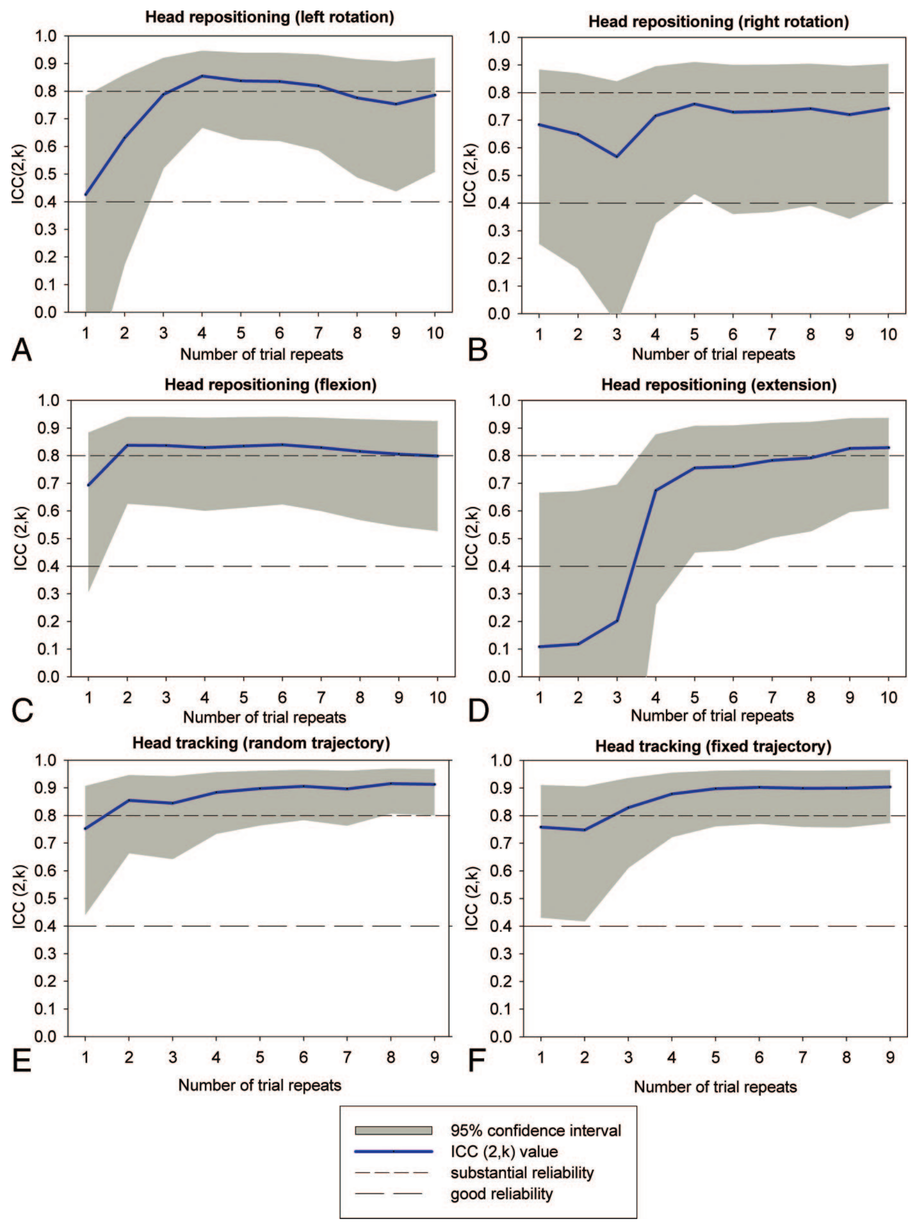

Figure 6. Effect of different numbers of trials on test-retest reliability for the cervical JPE and cervicocephalic kinesthesia tests. The number of trial repeats from which each estimate was calculated is plotted against the ICC value obtained from the mean RSE in each head-repositioning task (**A–D**) and mean of mean RSE for each head-tracking task (**E–F**). Ninety-five percentage confidence intervals are indicated by the gray-shaded areas. The dotted lines indicate the minimum threshold ICC values of 0.41 for fair reliability and 0.81 for substantial reliability.

Correlation Between Tests

Scatterplots revealed no nonlinear association between the tests. Pearson correlation coefficients for performance in cervical JPE and cervicocephalic kinesthesia tests using data from 6 trial repeats are shown in Table 2.

Within each repositioning movement, significant correlation ($r = 0.631–0.854$, $P < 0.01$) was shown between accuracy and precision. Comparing the movements, significant correlation ($r = 0.673$, $P < 0.01$) was shown between precision of flexion and extension repositioning. Correlation of accuracy between these motions approached the significance at the 0.05 level ($r = -0.492$, $P = 0.053$). No significant correlation was shown between any other pair of repositioning movements. Performance between random and fixed trajectory head-tracking conditions was significantly correlated ($r = 0.905$, $P < 0.01$).

When comparing the performance between the cervical JPE *versus* cervicocephalic kinesthesia tests, no significant correlations were found for any parameters or any conditions ($P > 0.05$).

■ Discussion

The aims of this study were to test the reliability and stability of 2 measures of neck proprioceptive function and to compare the performance in the 2 tests.

Systematic error effects should be investigated before interpreting reliability analyses, because high ICC scores are possible even with significant systematic effects present.[22] The absence of systematic effects indicated that our practice protocols were sufficient to remove the potential effects of learning. Similarly, it can be assumed that no fatigue effects occurred.

For head repositioning, the finding that the data from 6 or more trials of each movement direction were needed to achieve stable estimates of accuracy, precision, and coefficients of variation was consistent with the results reported by Allison *et al* (2003)[8] for repositioning of the

Table 2. Correlation Between Performance in the Cervical JPE and the Cervicocephalic Kinaesthesia Tests

	JPE Left Rotation Mean		JPE Right Rotation Mean		JPE Flexion Mean		JPE Extension Mean		Head Tracking Random Mean		Head Tracking Fixed Mean	
	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*
JPE left rotation mean												
JPE right rotation mean	0.216	0.422										
JPE flexion mean	0.102	0.707	−0.221	0.410								
JPE extension mean	0.080	0.770	0.056	0.838	0.492	0.053						
JPE left rotation SD	0.755	0.001*	0.143	0.598	0.215	0.424	0.093	0.733				
JPE right rotation SD	−0.026	0.925	0.854	0.000*	−0.118	0.662	−0.054	0.842				
JPE flexion SD	0.315	0.235	−.142	0.600	0.631	0.009*	0.425	0.101				
JPE extension SD	0.103	0.706	0.060	0.826	0.631	0.009*	0.848	0.000*				
Head tacking random mean	−0.053	0.846	−0.141	0.603	−0.001	0.997	0.228	0.396				
Head tracking fixed mean	−0.162	0.548	−0.262	0.327	−0.141	0.601	0.097	0.722	0.905	0.000*		
Head tracking random SD	0.022	0.935	0.033	0.904	−0.116	0.668	−0.347	0.188	0.229	0.394	0.072	.791
Head tracking fixed SD	−0.046	0.865	−0.476	0.865	0.140	0.605	0.146	0.588	0.443	0.086	0.467	.068

*Correlation is significant at the 0.01 level (2-tailed).
r indicates Pearson's correlation; *P* = probability.

thoracic and lumbar spine. This suggests that recent studies using 3 repetitions in the cervical JPE test may have used insufficient trials to ensure optimum evaluation of repositioning ability.[7,9,12,17] Less accurate estimates influence reliability, particularly if variance is affected, because this is the basis of indexes such as ICCs.[22] In agreement with this, we found that greater test stability coincided with higher ICC values. Poor reliability (ICC = 0.29) has been reported for head repositioning following cervical extension using 3 trials.[17] Here, extension repositioning similarly showed poor reliability (ICC = 0.20) with 3 trials, but with 5 to 6 trials, this increased to 0.76, illustrating how the test protocol can directly influence the reliability of the outcome measurement. Generally, ICCs influence correlation analyses and can also be used to adjust sample size and statistical power calculations.[22] Test protocols and their effect on reliability of the outcome measure thus should be important considerations for clinical studies.

The level of reliability considered acceptable varies widely in the literature, with lower limits for "good" reliability ranging from ICC = 0.61 to 0.81.[23–25] However, some sources recommend that only "substantial" reliability (ICC = 0.81–1.0) should be considered adequate.[21] Estimation of CIs around ICCs is advocated to avoid making false inferences about reliability.[21] Here, consideration of 95% CIs revealed that even with good ICC values obtained from 6 trials, lower CI bounds ranged only from fair to moderate reliability (0.36–0.62). Increasing the number of subjects further would be expected to improve CIs.

Results for head tracking showed that stable estimates of mean, SD, and coefficients of variation are obtained for individual subjects, and for the group, with 6 trials. With this protocol, reliability was substantial to excellent (ICC = 0.91 and 0.90), and the lower bound for the CIs fell within the "good" range (ICC = 0.78 and 0.77). This test has only been reported once previously, using fixed trajectories and a 9 repeat protocol.[14] Our work indicates that a shorter trials protocol produces highly reliable results. Comparable performance between randomly generated and fixed trajectories indicated that the preselection and repetition of trajectories[14] are not necessary.

For head repositioning, significant correlations between accuracy and precision for each movement direction suggest that both are comparable indexes of performance. This is in accordance with the proposals that both should be considered as metrics of proprioception in JPE tests.[8,26] Comparing different repositioning movements, an apparent discrepancy was found of correlation between extension and flexion, but not between left and right rotation. One possibility was lower variance in the latter 2 movements, however, examination of data did not indicate this. Another possible explanation is that differences in symmetry of cervical spine joint or muscle function might introduce greater differences between movements to the left and right in the transverse plane than between flexion and extension in the saggital plane. One previous study also found no significant correlations between rotation and extension repositioning in normal subjects, but flexion repositioning was not measured.[7] The same study revealed greater correlation between repositioning movements in whiplash patients. This might be accounted for by greater variability in performance among a heterogenous group of subjects, which would be expected to influence correlation coefficients. However, with whiplash patients, the possibility cannot be excluded that vestibular deficits, associated with trauma, could influence the performance in the tests. Different patterns of association may be found in nontrauma neck pain patients, and evaluation of the cervical JPE test in different subcategories of neck pain patients will elucidate this further.

The lack of correlation between parameters of head repositioning and head tracking suggests that these tests may not be comparable measures of cervical proprioception. However, this study used a sample of normal subjects, limiting generalizability of the findings. In addition, a larger sample might enable detection of additional weak associations that is not revealed here.[20]

This is the first time that the cervical JPE and cervicocephalic kinesthesia tests have been compared. However, a recent study[7] showed that the performance of whiplash subjects in the JPE test weakly correlated to ocular motor function in the smooth pursuit neck torsion test also proposed as a measure of proprioception.[27] This supports the need for further studies evaluating concurrence between the different proposed tests of proprioception in various patient groups to increase understanding of exactly what underlying constructs are being measured. Sensorimotor control of head and eye movement depends on complex interactions between proprioception, other sensory cues, and motor learning, and it is likely that different tests place different challenges on these. It would seem advantageous when assessing neck proprioception to include a range of measures that challenge different aspects of head sensorimotor control. Better understanding of these mechanisms would enhance the understanding of how patients with various neck problems may be impaired in their functional ability, and the consequences of this for progression of their condition, diagnosis, and treatment.

■ Conclusion

Tests of cervical spine proprioception should use protocols optimizing stability and reliability of outcome measures. This study evaluated protocols for the cervical JPE test and the head-tracking test for cervicocephalic kinesthesia. Results demonstrated that 6 trials were needed to derive stable estimates, coinciding with higher test-retest reliability. This has important implications for experimental design and interpretation, and clinicians and researchers should consider these findings when implementing test protocols.

In this sample of normal subjects, no significant correlation was observed between performances in the 2 tests, suggesting that they may not be comparable measures of the same basic underlying construct of cervical proprioceptive function. Further studies should evaluate the levels of association in different categories of neck pain patients.

■ Key Points

- Functional outcome measures should demonstrate stability and reliability.
- Optimum protocols for the cervical JPE and cervicocephalic kinesthesia tests had not been previously evaluated.
- Six or more trials were needed to optimize stability and reliability of outcome measures in both tests.
- No correlation was shown between performances in the 2 tests.
- The cervical JPE and cervicocephalic kinesthesia tests may not be comparable measures of proprioceptive contribution to head sensorimotor control.

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