Cervicocephalic kinaesthesia: reliability of a new test approach

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ABSTRACT Background and Purpose. Relocating either the natural head posture (NHP) or predetermined points in range are clinical tests of impaired neck proprioception but memory might influence these tests. Three new tests, reasoned to be more challenging for the proprioceptive system, were developed. The objectives were to assess the reliability of all tests and whether the three new tests were more challenging for the proprioceptive system. Method. A test–retest design was used to assess the reproducibility and errors of all five tests. Twenty asymptomatic volunteers were assessed a week apart, using an electromagnetic movement sensor system, the 3-Space Fastrak. A measure of error magnitude was used to detect kinaesthetic sensibility. Comparison of the means and their corresponding dispersion were analysed descriptively. The between-day intraclass correlation coefficients (ICCs) were calculated and plots of mean differences between days 1 and 2 were conducted to estimate test reliability. Multivariate analysis of variance (MANOVA) and least significant difference (LSD) pairwise comparisons were performed to compare the test accuracy between different target positions. Results. ICCs were between 0.35 and 0.9, but plotting the data modified the interpretation in some tests. Relocating a NHP was easier when the trunk was in a neutral position than when pre-rotated (error 2.46˚ (±0.2˚) versus 5.95˚ (±0.7˚). Relocating a 30˚ rotation position (error 5.8˚ (±0.6˚) and repeatedly moving through a target (error 4.82˚ (±0.7˚) was also difficult. Conclusions. The new tests were more challenging than relocating the NHP but the reliability of tests relocating uncommon positions was questionable.

Key words: kinaesthesia, neck, proprioception, reliability

INTRODUCTION

Altered proprioceptive function associated with trauma or degenerative change may be an important factor contributing to symptoms associated with neck disorders (Revel et al., 1991; McLain, 1994). The neck mechanoreceptors are essential for sensing cervical positions and movements as well as for overall postural control with their strong connections with the visual and vestibular systems (Dutia, 1991; Gimse et
Clinically, the consequences of altered cervical mechanoreceptor sensibility may be symptoms of dizziness and light-headedness (Oostendorp et al., 1993; Karlberg et al., 1995), disordered balance (Karlberg et al., 1996) or diminished neuromuscular protection of articular tissues (Proske et al., 1988; Bosjen-Møller, 1991; O’Conner et al., 1992). The function of the proprioceptive system as a pain modulator must not be forgotten (Wall, 1989). Simple, reliable and valid tests of cervicocephalic kinaesthesia are needed to measure both altered neck proprioception and outcomes of specific rehabilitation programmes aiming to restore normal proprioception.

When measuring cervicocephalic kinaesthesia, previous studies have used simple neck movements from a starting position resembling a natural head posture (NHP) (Revel et al., 1991; Loudon et al., 1997; Rogers 1997; Heikkilä and Wenngren, 1998). The aim has been to relocate NHP after an active movement (Revel et al., 1991) or to actively relocate a position within a movement plane (Loudon et al., 1997). The reliability of the test to relocate the NHP (Revel et al., 1991) has not been established but the test to relocate a point in range has been shown to have good reliability (ICCs) (Loudon et al., 1997).

Recent research suggests that humans have a remarkable ability to relocate remembered targets by central motor programmes alone (Gandevia and Burke, 1992; Adamovich et al., 1999). The NHP might therefore be relocated without reliance on proprioceptive information. Simple movements and common tasks, which have been stored in the long-term memory, can also be performed without proprioceptive information (Rothwell et al., 1982; Nougier et al., 1996). The converse is true for non-learned complex movements (Gandevia and Burke, 1992; Nougier et al., 1996). Based on this knowledge three new tests were developed which might place more demand on the proprioceptive system.

The first were tests of complex movements where subjects drew an infinity sign (figure-of-eight on its side (∞)) with movement of the head. In the first test, subjects relocated the NHP following this complex movement. In the second, subjects repeatedly targeted the NHP as they passed through the centre of the figure-of-eight, during three successive movements. To the authors’ knowledge kinaesthesia has not been tested before during movement. A third test was adapted from the smooth pursuit neck torsion test (SPNT) (Gimse et al., 1996; Rosenhall et al., 1996). The SPNT was devised to differentiate patients with dizziness of cervical origin from patients with diseases involving the posterior intracranial fossa and Ménière’s disease (Tjell and Rosenhall, 1998). The tests of movement of a subject’s eyes as they followed a target, were compared in NHP and one in which the neck was rotated beneath the stationary head. The test detected proprioceptive deficits only when the neck was pre-positioned in rotation. In the present adaptation for a kinaesthetic test, the head was maintained in the mid-line, whereas the neck or trunk was positioned in 30° of rotation. The subject’s task was to relocate the neutral head, neck trunk position and then return to the start position (that is, a relative 30° position). It was reasoned that the changed head–trunk alignment would place more demand on the neck proprioceptive system.

The present study assessed the reproducibility and relocation errors of the three new tests as well as the two more conventional tests (Revel et al., 1991; Loudon et al., 1997). It was undertaken to give some insight as to whether the three new tests might pose a greater challenge to the pro-
prioceptive system in asymptomatic subjects in the first instance.

**METHOD**

A test–retest study design was used to assess the reliability of the measurements.

**Subjects**

Twenty asymptomatic volunteers were drawn from a pool of students and staff from The University of Queensland, Australia. Subjects with a current or past history of musculoskeletal pain in the neck and upper limbs were not considered. Ethical clearance was obtained from the University Medical Ethics Committee and all subjects provided informed consent to participate. Even though all reported to be asymptomatic at the time of testing, it was later revealed that one subject had a long history of intermittent neck pain. She was omitted from the analyses and seven males and 12 females, mean age 31.5 (±10) years (2 standard deviations (SDs)) were retained in the study.

**Instrumentation and measurements**

A 3-Space Fastrak system was used in the present study (Polhemus Navigation Science Division, Kaiser Aerospace, Vermont). The Fastrak is a non-invasive electromagnetic measuring instrument, which tracks the positions of sensors relative to a source in three dimensions. It has previously been used to assess position sense in the trunk and the lumbar spine (Maffey-Ward et al., 1996; Swinkels and Dolan, 1998). In the present study, one sensor was placed on the forehead and the other over the spinous process of C7. The electromagnetic source (transmitter) was placed in a box attached to the back of a wooden chair. A previous study has demonstrated that the 3-Space Isotrak system, which is similar equipment, is accurate to within ±0.2° (Pearcy and Hindle, 1989). The Fastrak was connected to an IBM-compatible personal computer and continually recorded the positions of the sensors relative to the source during the entire test sequence.

A software program was written to format and process the data for analysis. The software program made it possible to convert the data directly into angle files and graphs and to visualize the entire test process in real time on the screen. The rate at which individuals performed the movements was not formally controlled although all subjects were instructed to move at a comfortable slow pace. The data obtained from the Fastrak consisted of a $3 \times 3$ matrix of direction cosines for the orientation of the forehead electrode relative to the electrode placed on C7. These matrices were then analysed to give successive angular rotations (Euler angles) of the head relative to C7, about three orthogonal axes. In this way, the primary movement of axial rotation and the simultaneous coupled rotations of flexion or extension and lateral flexion were recorded, representing the accuracy with which the subjects could relocate the target positions in each task.

**Tests of cervicocephalic kinaesthesia**

The movement of axial rotation was chosen as the predominant test movement as humans use rotation most commonly in exploring the external environment (Taylor and McCloskey, 1990; Rubin et al., 1995).

**Test 1 Relocation to the NHP (Revel et al., 1991)**

The starting position was sitting with the head in NHP. Subjects were asked to per-
form full active cervical rotation to the left and right in turn and then to return and indicate when they considered they had relocated the starting position as accurately as possible. This point was recorded by activation of the electronic marker switch. Between each test movement, the subject’s head was manually adjusted back to the original starting position by the principal researcher who was guided by the real-time computer display. The examiner’s accuracy in relocating subjects’ heads was within ±0.2°, as indicated by the marker, which changed colour from red to green when the accuracy was within the set limits (Figure 1).

**Test 2 Relocation to the 30° rotation position and to NHP (Loudon et al., 1997)**

In this test, the examiner pre-positioned the subject’s head in 30° left rotation and subsequently in right rotation. The computer visual display unit (VDU) guided the researcher. A marker was placed to indicate the 30° position. Subjects were permitted to concentrate on this position of reference for a few seconds. They then turned their head to NHP and then returned to the 30° rotation position. Recordings were taken on each occasion subjects returned to the NHP and to the 30° position.

![FIGURE 1: Relocating a subject’s head to natural head posture (NHP).](image-url)
Test 3 Preset trunk rotation

Subjects sat on a chair positioned on a specially constructed platform. A familiarization session was conducted before the formal test. Subjects first concentrated on their NHP. Whilst the researcher held the subject’s head steady, the platform (and therefore the subject’s trunk) was rotated to a pre-marked 30° position of left rotation. Subjects were required to relocate their NHP with respect to the body and then return to the starting position (30° relative neck rotation). Following three trials in left trunk rotation, the test was repeated with the trunk rotated to the right.

Test 4 Figure-of-eight relocation test

Subjects were taught to perform a discreet figure-of-eight movement by moving the head. As a guide, a 10-cm diameter diagram of a figure-of-eight lying on its side (∞) was placed on a stand one metre in front of the subject. Subjects were instructed to trace the figure-of-eight with their nose to confine movement predominantly to the upper cervical spine. Each subject was permitted three practice trials of the movement with their eyes open. The examiner corrected the performance if the movement was too little or too large, that is, involving the lower cervical spine. In the formal test, subjects performed the movement three times and, after each trial, were required to relocate to the start position as accurately as possible.

Test 5 Figure-of-eight movement test

In this test, subjects repeated the figure-of-eight movement three times, without stopping, as consistently as possible. Each time a crossover was made in the figure-of-eight movement, subjects were asked to pass through their NHP as accurately as possible. They therefore crossed the starting position five times in the test sequence. There was no practice in advance of this test.

Procedure

Two researchers conducted the testing. One gave instructions to subjects and the other operated the computer and applied the marker in response to subjects’ instructions in each test. Tests 1–4, aiming at relocation of target positions of the head were conducted first, followed by Test 5 where the aim was to move repeatedly through the target position. Three trials of each test were performed to the left and then to the right. For tests 4 and 5, three repetitions of the figure-of-eight movements were performed.

Subjects were seated for all tests on a wooden chair with a backrest with hands resting in their laps. They wore a lightweight, adjustable helmet for attachment of the forehead sensor. This ensured the same placement of the forehead sensor during head or neck movements and prevented lead traction on the sensor. The sensor placed over the C7 spinous process was fastened with a double-sided tape so there was no movement of the sensor on the skin, and the lead from the sensor was secured.

The procedure was similar for all tests. For consistency, the researcher read the instructions of the particular task in advance of each test. Before each test sequence, subjects were blindfolded. The blindfold was removed after the trials to the left and right as well as between tests. Subjects sat relaxed with the head naturally positioned to the front for tests involving relocating their NHP. They concentrated on that position for a few seconds and this
position was recorded by the Fastrak as the zero starting position. This was the position of reference, both for subjects and the calculations of repositioning error. The same procedure was undertaken for the 30° baseline starting positions of tests 2 and 3, except that the researcher positioned the subject's head manually. Following the performance of each test, subjects were asked to say ‘Yes’ clearly when the starting target position was relocated. This point was marked on the computer. No verbal cues were given to subjects about their actual performance. All subjects were examined in the afternoon within the same week for both the test and the retest trials.

Data management and analyses

The criterion variable used to measure kinaesthetic sensibility was a measure of error magnitude (test accuracy) for relocation of the target position. In tests 1–4, relocation accuracy to NHP was analysed. Tests 2 and 3 also tested reproduction of the 30° rotation position. The absolute value of the error was calculated for the angular motion of axial rotation for each trial. For Test 5, the ability to repeatedly move through a target, both the angular values for the error in axial rotation and the linear distance of the forehead sensor from the crossover point were calculated from 3-D Cartesian co-ordinates. The crossover point was defined as the point at which this distance was smallest from the original starting position (NHP).

The mean error of the three trials for each test was calculated for each individual. The between-day intraclass correlation coefficients (ICCs) were calculated according to Shrout and Fleiss (1979), Model 2.1. Plots were also derived for the mean differences (2 SD) between repeated measurements on days 1 and 2 using the method of Bland and Altman (1986) as agreement between two measurements is better represented by plotting the data. A multivariate ANOVA (Pillai's Trace) was used to investigate whether there were any differences in the relocation errors between the different tests. Post hoc LSD pairwise comparisons were performed to investigate any differences demonstrated between tests in the formal analysis.

RESULTS

Relocation accuracy

For the initial analysis, data from days 1 and 2 were combined. Table 1 documents the mean relocation errors in axial rotation for all tests. These data suggest that errors were greater in relocating the 30° positions in tests 2 and 3 and NHP in Test 3 (preset trunk rotation) compared with relocating NHP in tests 1, 2 and 4. The magnitude of error in Test 5 was between that of these two groups, but closer to the higher values. The results of the ANOVA revealed there were significant differences between test positions \( F(6,0,13) = 8.4; p = 0.001 \). The post hoc analyses (LSD pairwise comparisons) revealed that of the 21 possible combinations, there were statistically significant differences between 14 pairs of tests. The tests that did not demonstrate significant differences were the following:

- Test 1 versus Test 4
- Test 3 (NHP) versus Test 2 (30°)
- Test 3 (NHP) versus Test 3 (30°)
- Test 3 (NHP) versus Test 5
- Test 2 (30°) versus Test 3 (30°)
- Test 2 (30°) versus Test 5
- Test 3 (30°) versus Test 5

which confirmed preliminary observations.
Reliability

Table 2 presents the relocation errors averaged over all trials for each test on days 1 and 2 and the corresponding between-day ICCs. The results indicated that there were some differences between tests in between day reproducibility but the ICCs for all tests lay from 0.35 to 0.90. Any observed differences between tests to the left and right were not statistically significant (post hoc paired Student’s t-tests).

Three tests were chosen to demonstrate the plots of the mean differences and 2 SDs of the differences between days 1 and 2. These were Test 1, relocating the NHP from the left (Figure 2), Test 3, for relocation of the 30˚ position from the left (Figure 4) and Test 5, the movement test (Figure 4).

They were chosen as they demonstrated fair to excellent agreement according to their ICC values (0.44, 0.61 and 0.90, respectively). In interpreting the plots, each dot represents an individual score. The actual differences between days 1 and 2 are on the y axes and mean values for Day 1 plus Day 2 are on the x axes. The plots demonstrate that the variance between days was much greater in Test 3 with an ICC score of 0.61 (Figure 3) than in Test 1 with
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FIGURE 2: Plot of the agreement between days in relocating NHP from left rotation in Test 1. Mean difference is –0.8° and 2 SD (±3.0°).

FIGURE 3: Plot of the agreement between days in relocating the left 30° position in Test 3. Mean difference is 0.37° and 2 SD (±12.0°).

an ICC score of 0.44 (Figure 2). Nevertheless, the plot and the ICC (0.90) for Test 5 both demonstrated good agreement between days (Figure 4). The plots between the trials performed on days 1 and 2 showed the same pattern as plotting the averaged of three trials between days, confirming the appropriateness of using averaged values to plot the difference between days.

DISCUSSION

The present results demonstrate that the kinaesthetic tests assessed in this study may be divided into two classes with respect to difficulty. Best accuracy was demonstrated in relocating NHP when the trunk was in neutral (tests 1, 2 and 4) (see Table 1). Furthermore, the magnitude of the relocation
error for NHP in these tests was similar to that reported for asymptomatic subjects in two other kinaesthetic studies relocating the neutral position of the lumbar spine where the same equipment was used (Maffey-Ward et al., 1996; Swinkels and Dolan, 1998). Subjects demonstrated greater relocation errors in the tests in which the trunk was preset in rotation, whether they were requested to relocate to NHP or a 30˚ rotation position (Test 3). Relocating the 30˚ neck rotation position (Test 2) and moving accurately through a target (Test 5) proved as difficult and there were no statistically significant differences between these tests. These tests also demonstrated more variability (see Table 1).

The smaller relocation error in tests requiring return to a familiar NHP (tests 1, 2 and 4) as compared to those involving a non-familiar posture (Test 3) or unfamiliar task (Test 5) reflects previous research (Bizzi et al., 1992; Gandevia and Burke, 1992; Nougier et al., 1996; Adamovich et al., 1999) and may support the basis for developing these new tests. However, the accuracy in relocating NHP after complex movement (Test 4) was unexpected. The familiar target of the NHP may have been the overriding influence. Experimental brain research indicates that ascending afferent signals can be selectively gated at all levels of the central nervous system (CNS) according to the relevance of the incoming information (Collins et al., 1998; Loeb et al., 1999). It could also be reasoned that moving the neck in a complex pattern might input a massive stimulation to the neck mechanoreceptors (Prochazka and Gorassini, 1998). Recent research has also revealed attenuation of ‘muscular sense’ during active movements, which is most evident during large, rapid movements (Collins et al., 1998). This may indicate that Test 4 did not challenge the proprioceptive system in the way it was postulated to do so in this study.

The ‘between-day’ reliability (ICCs) of all tests was between 0.35 and 0.90 (see Table 2). However an overriding factor was revealed in the plots of the differences between days for tests 1, 3 and 5 (see figures 2–4). These showed that the standard deviation of the difference was much greater in

![FIGURE 4: Plot of the agreement between days in moving through the target in Test 5. Mean difference is 0.09˚ and 2 SD (±3.7˚).](image-url)
Test 3 with a higher ICC than in Test 1 with a lower ICC. Greater fluctuation in the scores on Day 2 compared with Day 1 in Test 3 indicates that this target position may be too unreliable to monitor changes in cervicocephalic kinaesthesia. These results confirm that reliability of repeated measurements cannot be evaluated by correlation coefficients alone (Keating and Matyas, 1998). The ICCs do not indicate the magnitude of score fluctuations in degrees. This information is highly relevant if the tests advocated here are to be used to monitor changes in cervicocephalic kinaesthesia in patients with cervical musculoskeletal disorders. By also calculating the mean difference and the standard deviation of the difference between repeated measurements in accordance with Bland and Altman (1986), it is possible to know whether an observed change represents real change in cervicocephalic kinaesthesia or is a fluctuation typically observed in the test. The results of the present study support this method. The results of the plot and ICC for Test 5 are, however, an example where both statistical methods demonstrate good agreement.

The usefulness of a test is dependent on its ability to detect both people with the impairment and without the impairment. The target positions in Test 3 (a new test) and the 30˚ target position in Test 2 (a previously introduced test) demonstrated greater errors and variability than some other targets in this study. Therefore these tests seem to be unreliable. Nevertheless, Test 2 has detected a difference between asymptomatic subjects and whiplash patients (Loudon et al., 1997). The error and variability in Test 3 reflects the problem encountered when designing a test reasoned to rely more on proprioceptive function. The function of easier tests used to detect impaired position sense may already be stored in the long-term memory. Thus the dilemma, which requires further study, is the choice between tests with greater variability but with some evident sensitivity and tests with more accuracy but which may rely more on memory than genuine kinaesthetic sense.

When reviewing the methodology of the present study, the 3-Space Fastrak device was chosen for its accuracy (Pearcy and Hindle, 1989). Previous studies have used a light beam (laser light) fastened to the top of the head by a helmet (Revel et al., 1991) and a simple cervical range-of-motion device (CROM) (Loudon et al., 1997). Direct comparisons of results are therefore not possible. The use of a lightweight helmet to attach the forehead sensor may have given subjects some exteroceptive cues due to the circumferential pressure on the skin (McNair et al., 1996; Birmingham et al., 1998). Any influence of the lightweight helmet cannot be differentiated in the present study. The amount of practice was the same for all subjects but differed for each test according to how difficult it was to understand its performance. The ordering of tests was not randomized, which may have resulted in some learning effects across tests.

CONCLUSION

The kinaesthetic tests examined in the present study may be divided into two classes with respect to difficulty. Relocating the NHP was significantly more accurate than relocating uncommon postures and moving through a target. The discrepancies in the ICCs and plots of data, question the use of ICCs as the only measure of reliability. A future dilemma appears to be a compromise in choice between tests which may rely on memory and tests that challenge the proprioceptive system.
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REFERENCES


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