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Original article

Sensorimotor tests, such as movement control and laterality judgment accuracy, in persons with recurrent neck pain and controls. A case-control study

Simone Elsig [a, b, *], Hannu Luomajoki [c], Martin Sattelmayer [a], Jan Taeymans [b], Amir Tal-Akabi [b], Roger Hilfiker [d, a]

[a] University of Applied Sciences and Arts Western Switzerland Valais (HES-SO Valais-Wallis), School of Health Sciences, Physiotherapy, Leukerbad, Switzerland

[b] Bern University of Applied Sciences, Health, Bern, Switzerland

[c] Zurich University of Applied Sciences, School of Health Professions, Winterthur, Switzerland

[d] University of Applied Sciences and Arts Western Switzerland Valais, School of Health Sciences, Health & Social Work, Sion, Switzerland

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ABSTRACT

Assessing sensorimotor abilities, such as movement control, becomes increasingly important for the management of patients with neck pain because of the potential contribution to the development of chronic neck pain. Our aim was to evaluate whether sensorimotor tests could discriminate between persons with neck pain and persons without neck pain and to assess correlations among the assessments. A matched case-control study with 30 persons with recurrent neck pain and 30 controls was conducted. We tested two-point discrimination (TPD), joint position error (JPE), muscle activation with the craniocervical flexion test (CCFT), laterality judgment accuracy and movement control (MC). We administered the Fear Avoidance Beliefs Questionnaire (FABQ), the Neck Disability Index (NDI) and the painDetect questionnaire. According to the areas under the curve (AUC), tests for the JPE (0.69), CCFT (0.73), MC (0.83) and laterality judgment accuracy (0.68) were able to discriminate between persons with and without neck pain. Among the five tests, laterality judgment accuracy exhibited moderate to large correlations with the JPE and MC, and moderate correlations were observed between the TPD and CCFT (*r* between −0.4 and −0.5). We recommend the assessment of various aspects of sensorimotor ability and of central representation of the body schema, even in patients with mild neck pain. For clinical practice, we recommend the craniocervical flexion test, testing of laterality judgment accuracy and three movement control tests (cervico-thoracic extension, protraction–retraction of the head and quadruped cervical rotation).

1. Introduction

Sensorimotor abilities are often reduced in patients with chronic neck pain, and kinesthetic sense is disturbed in patients with traumatic or idiopathic neck pain (Revel et al., 1991; Kristjansson et al., 2003; Treleaven et al., 2003). Patients with neck pain had impaired activation patterns of the neck muscles, e.g., higher activation of the superficial neck flexors and lower activation of the deep neck flexors, compared with people without neck pain (Jull et al., 2004; Falla et al., 2004a, 2004b, 2004c). This disturbance of neuro-motor control will not automatically return to normal function when the patients are pain free (Sterling et al., 2001; Jull et al., 2002). Deficits in neuro-motor control (Falla et al., 2004b) and impairments in head and neck position sense (Armstrong et al., 2008) could play a role in the development of recurrent or chronic neck pain.

Neck pain has a lifetime prevalence between 14.2% and 71% (mean 48.5%) (Fejer et al., 2006) with a higher prevalence among women (Hoy et al., 2010). Because of the increasing sedentary lifestyle, the prevalence of neck pain might increase (Falla, 2004). Approximately 50%–85% of the patients with neck pain do not completely recover (Carroll et al., 2009), and they develop persistent or recurrent neck pain (Cote et al., 2004).

Recently, various studies proposed subgrouping patients with back pain for research and treatment (Childs et al., 2004; O'Sullivan,

* Corresponding author. University of Applied Sciences and Arts Western Switzerland Valais (HES-SO Valais-Wallis), School of Health Sciences, Physiotherapy, Leukerbad, Switzerland.

E-mail address: simone.elsig@gmail.com (S. Elsig).

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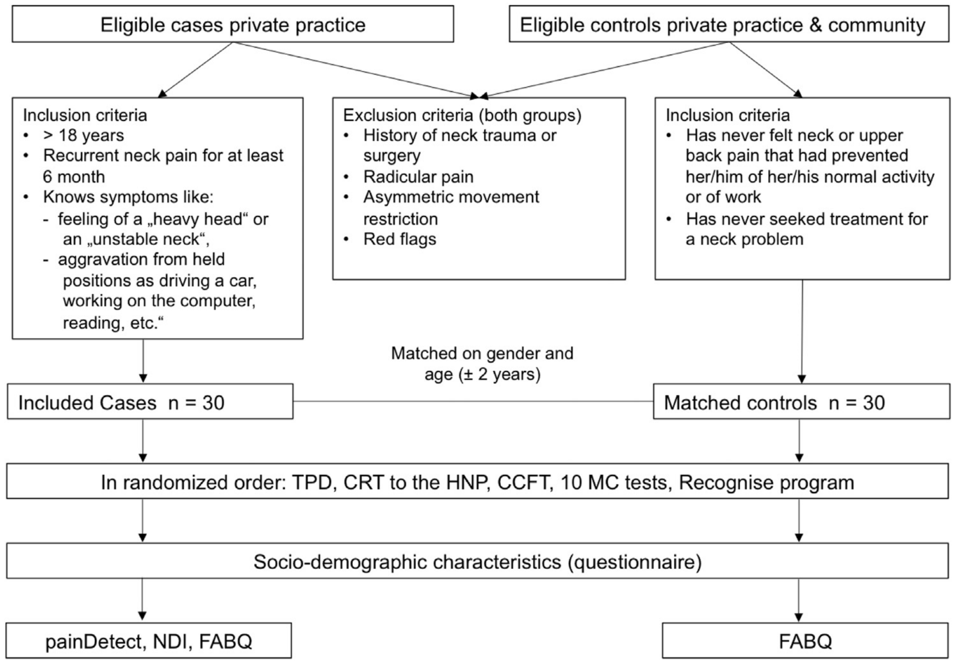

Fig. 1. Flow-chart. TPD: two-point discrimination; CRT to the NHP: cervicocephalic relocation test to the neutral head position; CCFT: craniocervical flexion test; MC: movement control; NDI: Neck Disability Index; FABQ: Fear Avoidance Beliefs Questionnaire.

2005; Waddell, 2005; Luomajoki et al., 2007). Patients with disturbed movement control form one subgroup (O'Sullivan, 2005). For low back pain, evidence shows that matched interventions for subgroups are more efficient than non-matched interventions (Vibe Fersum et al., 2013). Although the movement control concept applies to all body parts (O'Sullivan, 2005), few studies have investigated movement control impairments in patients with neck pain.

We defined the term "movement control" in the present study as the ability to perform active movements while maintaining a harmonic alignment of the segments (i.e., no shift) with an appropriate muscle response. Other terms used in the literature are motor control deficit (Woodhouse and Vasseljen, 2008), control impairment (O'Sullivan, 2005), movement impairment syndrome and relative flexibility (Sahrmann, 2011).

Sensorimotor abilities, including movement control, are recommended intervention targets and should be assessed. Unfortunately, there is no consensus about the best tests for the evaluation of these abilities in patients with neck pain (Pinsault et al., 2008a).

In a matched case-control study of 30 persons with recurrent neck pain and 30 persons without neck pain, we set out to test the following hypotheses: a) different tests for sensorimotor abilities, such as movement control tests, two-point discrimination, the cervicocephalic relocation test to the neutral head position, the craniocervical flexion test and a test for laterality judgment, could discriminate between persons with recurrent neck pain and persons without neck pain; and b) these tests are correlated among one another and with pain duration, pain intensity, disability, fear avoidance beliefs and tests for neuropathic or central sensitization.

2. Methods

2.1. Design

A matched case-control study was performed.

2.2. Sample size

To obtain a significance level of 5% and a power of 80%, a fair to good area under the curve (AUC) needs 29 cases (MedCalc, 2014). To allow for one drop out, we included 30 cases.

2.3. Participants

Thirty adults (≥18 years) with recurrent episodes of non-traumatic neck pain for more than six months and 30 age- and gender-matched controls without neck pain were included (see Fig. 1). The persons with neck pain had to complain of such symptoms as feeling instability of the neck, the feeling of a heavy head or aggravation of the symptoms by sustained postures, such as driving, working on a computer, and reading. The exclusion criteria were neurological signs, vertigo, nausea, visual disturbances, traumatic neck pain and neck surgery. The controls never felt neck or upper back pain that had prevented them from their normal activity or pain that was responsible for incapacity for work, and the controls never had medical attention or treatment for a neck problem.

A physiotherapist who was not involved in the measurements or in the data analysis recruited 51 persons, and the first author of this study recruited nine persons. The recruitment and the tests were performed from November 2012 until March 2013 in a private physiotherapy practice in Switzerland. The first author of this study, who was blinded to the group allocation of the persons (except of nine persons), conducted all the tests. All the participants gave written informed consent, and the study was approved by the local ethics committee.

2.4. Measurements

We selected five tests for different aspects of the sensorimotor system:

2.4.1. Tactile stimuli: two-point discrimination test (TPD)

The person was lying prone with the face in the nose slot of the bed. The TPD (Moberg, 1990) was assessed with a caliper ruler, not visible to the person, in the horizontal direction at the C2 level and then at the C7 level. The TPD is the smallest distance that can be perceived as two points. The TPD was determined for both measuring points as the average of a descending run (from 50 mm descending in 5 mm increments) and an ascending run (from 0 mm ascending in 5 mm increments) (Luomajoki and Moseley, 2011). To avoid guessing, we placed out of sequence "catch trials".

2.4.2. Proprioception: Joint Position Error (JPE)

The JPE of the cervical spine was assessed with the cervicocephalic relocation test to the neutral head position. For the description of the test, please see (Revel et al., 1991). We used the mean of eight trials for each direction, rotation to the left, rotation to the right, extension and flexion, to obtain a reliable test result (Pinsault et al., 2008a). After each trial, the examiner moved the head of the person back to the starting position by avoiding giving feedback about the relocation performance. The vertical and horizontal deviations from the starting point were measured. The global error, which is the direct distance between the end point after the relocation task and the starting point, was calculated trigonometrically. We calculated the root mean squares for the errors in the vertical, horizontal and global directions and converted these values into degrees. The mean global error represents the mean of the global errors of the four directions. For the calculation, please see (Rix and Bagust, 2001).

2.4.3. Muscle activation: Craniocervical Flexion Test (CCFT)

The person was lying in the supine crook position with the neck in a neutral position, and the line from the forehead to the chin was horizontal. A folded towel was placed under the head if necessary. A pressure sensor (Stabilizer from Chattanooga Stabilizer Group Inc., Hixson, TN, USA) was placed under the sub-occipital region and inflated to a pressure of 20 mmHg. The examiner asked the person to perform a gentle nodding motion of craniocervical flexion to reach the first stage at 22 mmHg and to hold the position for 10 s. The person then relaxed and continued the test in the same way for the next four levels (24, 26, 28 and 30 mmHg). Compensatory movements (documented in Jull et al. (2008)) were corrected once, and the test was stopped at the second compensatory movement. We recorded the activation score, which is the maximum pressure achieved and held constant for 10 s with minimal activity in the superficial muscles and without any compensatory movements (Hudswell et al., 2005).

2.4.4. Motor output: Tests for Movement Control (MC)

We selected eight tests with good results in a reliability study (Patroncini and Hannig, 2012), and added two tests proposed by McDonnell (rocking back in quadruped position and quadruped cervical rotation) (Sahrmann, 2011). The verbal instruction was standardized (see online Appendix A). If the performance was not correct after one correction of the examiner, this movement was rated as incorrect. Every single movement control test was recorded in a dichotomized variable (correct/not correct), and the total score represents the number of tests that were not correctly performed.

2.4.5. Cortical representation of the body schema: laterality judgment accuracy

We used the NOI Recognise online program (www.noigroup.com) (Moseley, 2004) for the neck to assess the laterality judgment accuracy. The person was looking at pictures shown on a laptop and had to decide whether the picture was showing the right or left side of the body or whether the person in the picture was moving to the right or to the left. Twenty pictures were displayed in a random order at five second intervals. We calculated the mean percentage of correctly identified pictures over both sides.

We used the Neck Disability Index (NDI) (Vernon, 2008) to describe the participants with neck pain. Because central sensitization (Stone et al., 2013) and fear avoidance beliefs (Boersma and Linton, 2006) are important aspects of neck pain, we added two questionnaires: the painDetect questionnaire (Freynhagen et al., 2006) and the Fear Avoidance Beliefs Questionnaire (FABQ) (Staerkle et al., 2004).

2.5. Procedure

All the persons performed these five sensorimotor tests in a randomized order and completed a questionnaire on socio-demographic characteristics. The persons with neck pain had to complete all the questionnaires, and the persons without neck pain completed the FABQ with instructions to fill it out as if they had pain. The entire procedure lasted between 40 and 60 min per person (see Fig. 1).

2.6. Data management and statistical analysis

The distribution of the data was verified visually and with the Shapiro Wilk test. The mean differences between persons with neck pain and persons without neck pain were calculated with a linear regression model with robust standard errors, taking into account the clustering of matched persons. We used Hedges' g effect sizes (Rosnow et al., 2000). Effect sizes of 0.2 are considered small, 0.5 are considered medium and 0.8 are considered large (Cohen, 1992). The odds ratios were computed with conditional logistic regression (Breslow and Day, 1980). We calculated the areas under the curve (AUC) for all the variables and for a combination of the most promising movement control tests for the discrimination between persons with and without neck pain. AUC values $\geq$0.9 indicate excellent discrimination, $\geq$0.8 indicate good discrimination, $\geq$0.7 indicate fair discrimination and $<$0.7 indicate poor discrimination (Chow, 2003). An AUC value of 0.5 represents no discrimination (Hanley and McNeil, 1982). Pearson correlations for the five sensorimotor tests and the questionnaires in the group of persons with neck pain were calculated. Values of 0.1 indicate small correlation, 0.3 indicate medium correlation and 0.5 indicate large correlation (Cohen, 1992). The calculations were performed with Stata version 12 (College Station, Texas).

3. Results

We included 30 persons with neck pain (25 women) with a mean age of 36.9 years and 30 age- and gender-matched controls (mean age 37.2 years).

Of the patients with neck pain, twenty-four (80%) had Neck Disability Index values below 15 points, which represents a mild disability (Vernon, 2008), five persons (17%) had values between 15 and 24 (moderate disability) and one person (3%) scored over 24 (severe disability) (see Table 1).

Of the applied tests, the mean global joint position error (AUC 0.69, 95% CI 0.56–0.82), the craniocervical flexion test (AUC 0.73, 95% CI 0.6–0.85), the movement control tests (total score) (AUC 0.83, 95% CI 0.73–0.93), the laterality judgment accuracy (AUC 0.68, 95% CI 0.54–0.82) and the FABQ-Work (AUC 0.67, 95% CI 0.53–0.81) could discriminate between persons with and without pain. For detailed results, see Table 2 and online Appendix B.

Three of the movement control tests, the extension of the cervico-thoracic junction, the protraction–retraction of the head

Table 1
Characteristics of the participants.

Variables	Persons without neck pain			Persons with neck pain			Difference
	N	Mean (SD)	Min to max	*N*	Mean (SD)	Min to max	Mean diff. (95% CI) or % diff. (95% CI)
Age (years)	30	37.2 (13.5)	19–63	30	36.9 (13.62)	18–61	−0.3 (−0.79 to 0.19)
Women	30	25 (83%)		30	25 (83%)		0 (0%)
Pain duration (months)				30	76.7 (78.04)	6–360	
Present Pain (NRS 0–10)				30	3.13 (2.01)	0–8	
Worst Pain (NRS 0–10)				30	6.7 (2.05)	0–10	
Average Pain (NRS 0–10)				30	4.43 (2.24)	0–9	
Neck Disability Index (0–50)				30	10.7 (5.12)	4–26	
PainDetect Score (0–38)				30	10.8 (5.93)	2–25	

NRS: Numeric Rating Scale.

Table 2
Test results stratified by persons with and without pain and between group differences.

Variables	Persons without neck pain			Persons with neck pain			Difference	Effect size	AUC (95% CI)
	N	Mean (SD)	Min to max	*N*	Mean (SD)	Min to max	Mean diff. (95% CI) or % diff. (95% CI)		
Two-point discrimination C2 (mm)	30	28.3 (6.28)	20–45	30	29.75 (5.89)	20–42.5	1.45 (−1.93 to 4.83)	0.24	0.571 (0.424–0.718)
Two-point discrimination C7 (mm)	30	29.75 (6.99)	15–42.5	30	32.5 (8.07)	20–47.5	2.75 (−0.89 to 6.39)	0.36	0.592 (0.447–0.737)
Mean Global Joint Position Error (°)	30	2.67 (0.55)	1.76–3.71	30	3.25 (0.96)	1.98–6.43	**0.58 (0.2–0.96)**	0.74	**0.691 (0.558–0.824)**
Craniocervical Flexion Test	30	28.07 (2.85)	20–30	30	25.87 (2.73)	20–30	**−2.2 (−3.6 to −0.8)**	−0.79	**0.726 (0.598–0.854)**
MC sitting rocking forward	30	23 (77%)		30	17 (57%)		−20% (−36.7 to 10.7%)		0.6 (0.481–0.719)
MC sitting rocking back	30	22 (73%)		30	18 (60%)		−13% (−43.3 to 3.3%)		0.567 (0.447–0.687)
MC ext. cervico-thoracic junction	30	29 (97%)		30	20 (67%)		−30% (−47.9 to 12.1%)		**0.65 (0.558–0.742)**
MC lifting the right arm	30	30 (100%)		30	28 (93%)		−7% (−16.1 to 2.1%)		0.533 (0.488–0.579)
MC lifting the left arm	30	30 (100%)		30	27 (90%)		−10% (−20.7 to 0.7%)		0.55 (0.495–0.605)
MC bilateral arm. lifting (3 kg)	30	30 (100%)		30	28 (93%)		−7% (−16.1 to 2.1%)		0.533 (0.488–0.579)
MC head pro- and retraction	30	27 (90%)		30	19 (63%)		−27% (−47.3 to 6.7%)		**0.633 (0.53–0.737)**
MC supine lower neck flexion	30	26 (87%)		30	23 (77%)		−10% (−29.3 to 9.3%)		0.55 (0.451–0.649)
MC quadruped rocking back	30	28 (93%)		30	26 (87%)		−7% (−21.1 to 9.1%)		0.533 (0.457–0.61)
MC quadruped cervical rotation	30	23 (77%)		30	9 (30%)		−47% (−69.3 to 24.7%)		**0.733 (0.62–0.847)**
MC Score (0–10)	30	1.07 (0.91)	0–3	30	2.83 (1.56)	0–6	**1.77 (0.99–2.54)**	1.39	**0.832 (0.73–0.933)**
Laterality judgment accuracy (%)	28	76.61 (13.2)	40–100	28	65.71 (17.31)	20–90	**−10.89 (−18.22 to −3.57)**	−0.71	**0.68 (0.54–0.82)**
FABQ-Work (0–42)	29	8.72 (6.88)	0–22	29	13.72 (7.78)	0–32	**5 (0.46 to 9.54)**	0.68	**0.669 (0.528–0.81)**
FABQ-Physical Activity (0–24)	29	8.86 (5.95)	0–24	29	11.28 (5.66)	0–21	2.41 (−1.35 to 6.18)	0.42	0.626 (0.48–0.772)

AUC: area under the curve; MC: Movement Control Tests, dichotomized as correct/not correct, number of persons who correctly performed the movement; MC Score: number of incorrect performed movements; FABQ: Fear Avoidance Beliefs Questionnaire. Two persons had missing data in the test for laterality judgment accuracy because of technical problems while one person had missing data each for the work-related and the physical activity-related score of the Fear Avoidance Beliefs Questionnaire.
Values in bold indicate statistical significance for the differences or values above 0.5 for the AUCs.

and the quadruped cervical rotation, had AUC values significantly above 0.5 (Table 2), and the AUC for the sum of these three tests was not significantly different from the sum of all ten movement control tests (see Fig. 2).

The odds of having neck pain were significantly higher in persons with higher mean global joint position error. A lower activation score in the craniocervical flexion test, a higher score in the movement control tests (all ten tests or three tests) and lower laterality judgment accuracy showed significantly higher odds of having recurrent neck pain (Table 3).

All the correlations among the tests are presented online in Appendix B. The joint position error and the total score of the movement control tests showed moderate to large correlations with the laterality judgment accuracy ($r = -.50$ and $r = -.47$). The Neck Disability Index was moderately associated with the joint position error ($r = .44$), laterality judgment accuracy ($r = -.40$) and Fear Avoidance Beliefs Questionnaire (work related: $r = .58$ and activity related: $r = .44$). A moderate correlation was found between the two-point discrimination test and the craniocervical flexion test ($r = -.41$). No significant correlations were found between the five sensorimotor tests and pain intensity, but pain duration was significantly associated with laterality judgment accuracy ($r = -.46$). The activity related Fear Avoidance Beliefs Questionnaire demonstrated a moderate correlation with the two-point discrimination test ($r = .42$), and none of the five tests was correlated with the painDetect questionnaire.

4. Discussion

The main findings of our matched case-control study (neck pain versus no neck pain) were: a) the test for joint position error, the craniocervical flexion test, the laterality judgment accuracy and three tests for movement control were able to discriminate between cases and controls, and the two-point discrimination test could not discriminate between cases and controls; b) joint position error and movement control correlated with the laterality judgment accuracy. The Neck Disability Index was correlated with joint position error, laterality judgment accuracy and Fear Avoidance Beliefs.

One limitation could be that all the tests were performed by the same person. The examiner was theoretically not aware if a person was a case or a control, but because the study was performed in a small private practice, she was aware of the status of nine participants. The small sample size does not allow for large multivariable analyses.

Strengths of our study are that we investigated different tests for different aspects of the broad concept of proprioception (e.g., tactile stimuli, perception of joint positions, muscle activation, and cortical representation of the body schema) and that we compared different assessments of the sensorimotor ability with tests for movement control.

We found no published data for two-point discrimination in the cervical region in persons with neck pain. In patients with low back

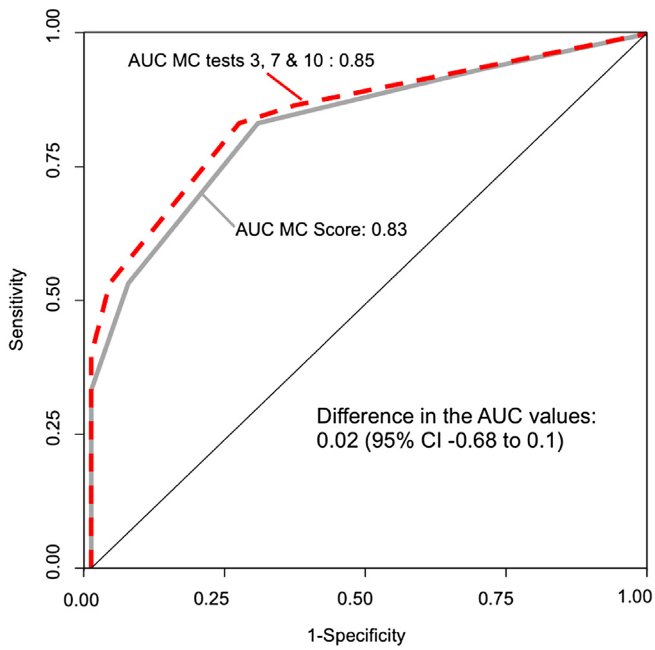

Fig. 2. ROC Curve Movement Control Tests. Receiver Operating Characteristic Curve (ROC Curve) for the summary score of all ten movement control tests (gray line) and the combination of three movement control tests, i.e. extension cervico-thoracic junction, protraction–retraction of the head, and quadruped cervical rotation (red dashed line). The difference in the area under the curve (AUC) is 0.02 (95% CI −0.68 to 0.1) in favor of the combination of the three tests. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

pain, Luomajoki and Moseley (2011) described a correlation (Pearson's r) of 0.49 between the two-point discrimination and lumbopelvic movement control tests. We found a lower correlation of 0.31 (95% CI −0.06 to 0.60) between the two-point discrimination and movement control tests for the cervical spine, but given the wide confidence interval, the two results are still compatible. The two-point discrimination test was the only sensorimotor test in our study that could not significantly discriminate between persons with and without neck pain (AUC C7: 0.59; 95% CI 0.45–0.74).

There is consistent evidence that joint position error could discriminate between persons without pain and patients with whiplash-associated pain or patients with a high level of disability. For patients with non-traumatic neck pain and patients with milder disability, the data are less clear (Rix and Bagust, 2001; Treleaven et al., 2003). In accordance with other authors (Revel et al., 1991; Kristjansson et al., 2003; Pinsault et al., 2008b; Roren et al., 2009), we found that the test for joint position error could differentiate between persons with and without neck pain. In our study, the mean global error of the patients was clearly below the threshold value of 4.5° determined by Revel et al. (1991). Those participants were likely more disabled than the patients in our study because the authors did not exclude persons with traumatic neck pain.

In contrast to our study, Teng et al. (2007) found that mild chronic neck pain had no influence on cervicocephalic kinesthetic sense, but that study excluded participants with scores over 15 points in the NDI. The correlation between the joint position error and the NDI score that was found by us and in other studies could explain the different results (Armstrong et al., 2008).

The total score of the ten movement control tests showed an excellent discriminative ability (AUC: 0.83; 95% CI 0.73–0.93), which is in accordance with other studies (Woodhouse and Vasseljen, 2008; Kristjansson and Oddsdottir, 2010). Three of the single movement control tests had the same discriminative ability as the total score of all ten movement control tests. These three tests should be used in current clinical practices.

We based our selection procedure mainly on the good preliminary results of the Patroncini and Hannig (2012) reliability study. In physiotherapy practice, further movement control tests are used. We cannot exclude that other tests would be appropriate for the assessment of movement control, and there is a clear need to systematically evaluate the psychometric properties of these tests.

Our results for the craniocervical flexion test are in accordance with several studies showing that persons with neck pain perform worse in this test compared with persons without neck pain (Jull et al., 1999; Falla, 2004; Falla et al., 2004c; Tai Wing Chiu et al., 2005).

A recent study investigated the laterality judgment accuracy for the neck using the Recognise program and collected normative data of pain-free participants (Wallwork et al., 2013). They found higher percentages of accuracy than found in our study. This could be explained by the different test protocol with a test trial before the test and the inclusion of forty, instead of twenty, pictures shown to the participants. A current study in subjects with whiplash associated disorders and asymptomatic subjects found no difference between the two groups (Pedler et al., 2013), but in our study, the laterality task could discriminate between persons with and without neck pain. We cannot explain these conflicting results. Our results are consistent with other studies concluding that chronic pain is associated with the disruption of the cortical representation of the body schema (Moseley and Flor, 2012). In a recent study, two-point discrimination was related to laterality judgment accuracy in persons with back pain and in pain-free controls but not in persons with knee osteoarthritis (Stanton et al., 2013). We did not find a correlation between these two tests. In our study, the laterality

Table 3
Association between test results and neck pain.

Variables	Unadjusted odds ratio (95% CI)	*P*-value unadjusted	Adjusted odds ratio (95% CI)	*P*-value adjusted
Age (per year)	0.69 (0.39–1.25)	0.22	0.69 (0.39–1.25)	0.215
Two-point discrimination at C2 (mm)	1.04 (0.950–1.13)	0.383	1.04 (0.96–1.14)	0.332
Two-point discrimination at C7 (mm)	1.06 (0.98–1.15)	0.146	1.06 (0.98–1.15)	0.137
Mean Global Joint Position Error (°)	**4.44 (1.23–15.96)**	**0.023**	**4.35 (1.18 to 16.11)**	**0.028**
Craniocervical Flexion Test	**0.74 (0.59–0.94)**	**0.014**	**0.75 (0.59 to 0.96)**	**0.022**
MC Score (3 tests)	**11.54 (1.71–77.8)**	**0.012**	**11.35 (1.67 to 76.94)**	**0.013**
MC Score (0–10)	**2.32 (1.27–4.24)**	**0.007**	**2.26 (1.25 to 4.11)**	**0.008**
Laterality judgment accuracy (%)	**0.94 (0.88–0.99)**	**0.023**	**0.94 (0.89 to 0.99)**	**0.03**
FABQ-Work Score	1.07 (1–1.15)	0.05	1.07 (1–1.15)	0.061
FABQ-Physical Activity Score	1.05 (0.97–1.14)	0.208	1.05 (0.97–1.14)	0.228

Adjusted for gender and age.
MC: Movement Control Tests, dichotomized as correct/not correct, number of persons who correctly performed the movement.
MC Score: number of incorrect performed movements.
Values in bold indicate statistical significance for the differences or values above 0.5 for the AUCs.

judgment accuracy showed a large correlation with joint position error and movement control. We cannot exclude that a third, non-measured variable, is responsible for this association. This association indicates that even in this group of patients with rather mild disability, the management should contain treatment approaches that include aspects of cortical representation of the body schema and central pain processing. The relatively low association between movement control and joint position error was unexpected but is in accordance with previous results (Swait et al., 2007). We hypothesize that the tests for movement control are more complex than the rather uni-dimensional cervicocephalic relocation test to the neutral head position.

5. Conclusions

We recommend the assessment of different aspects of sensorimotor ability, even in patients with mild neck pain, to detect movement control impairment and to avoid recurrent neck pain. To date, the most promising tests for clinical practice are the craniocervical flexion test, the testing of laterality judgment accuracy and three of the investigated tests for movement control (the extension of the cervico-thoracic junction, the protraction–retraction of the head and the quadruped cervical rotation).

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary material

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.math.2014.05.014.

References

Armstrong B, McNair P, Taylor D. Head and neck position sense. Sports Med 2008;38:101–17.

Boersma K, Linton SJ. Expectancy, fear and pain in the prediction of chronic pain and disability: a prospective analysis. Eur J pain 2006;10:551–7.

Breslow NE, Day NE. Statistical methods in cancer research. The analysis of case-control studies, Vol. 1; 1980. Distributed for IARC by WHO, Geneva, Switzerland.

Carroll LJ, Hogg-Johnson S, van der Velde G, Haldeman S, Holm LW, Carragee EJ, et al. Course and prognostic factors for neck pain in the general population: results of the Bone and Joint Decade 2000–2010 Task Force on Neck Pain and Its Associated Disorders. J Manip Physiol Ther 2009;32:S87–96.

Childs MJD, Fritz JM, Piva SR, Whitman JM. Proposal of a classification system for patients with neck pain. J Orthop Sports Phys Ther 2004;34:686–700.

Chow S-C. Encyclopedia of biopharmaceutical statistics. New York: Marcel Dekker; 2003.

Cohen JA. Power primer. Psychol Bull 1992;112:155–9.

Cote P, Cassidy JD, Carroll LJ, Kristman V. The annual incidence and course of neck pain in the general population: a population-based cohort study. Pain 2004;112:267–73.

Falla D. Unravelling the complexity of muscle impairment in chronic neck pain. Man Ther 2004;9:125–33.

Falla D, Bilenkij G, Jull G. Patients with chronic neck pain demonstrate altered patterns of muscle activation during performance of a functional upper limb task. Spine 2004a;29:1436–40.

Falla D, Jull G, Edwards S, Koh K, Rainoldi A. Neuromuscular efficiency of the sternocleidomastoid and anterior scalene muscles in patients with chronic neck pain. Disabil Rehabil 2004b;26:712–7.

Falla D, Jull GA, Hodges PW. Patients with neck pain demonstrate reduced electromyographic activity of the deep cervical flexor muscles during performance of the craniocervical flexion test. Spine 2004c;29:2108–14.

Fejer R, Kyvik KO, Hartvigsen J. The prevalence of neck pain in the world population: a systematic critical review of the literature. Eur Spine J: official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society 2006;15: 834–48.

Freynhagen R, Baron R, Gockel U, Tolle TR. painDETECT: a new screening questionnaire to identify neuropathic components in patients with back pain. Curr Med Res Opin 2006;22:1911–20.

Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology 1982;143:29–36.

Hoy DG, Protani M, De R, Buchbinder R. The epidemiology of neck pain. Best Pract Res Clin Rheumatol 2010;24:783–92.

Hudswell S, von Mengersen M, Lucas N. The cranio-cervical flexion test using pressure biofeedback: a useful measure of cervical dysfunction in the clinical setting? Int J Osteopath Med 2005;8:98–105.

Jull G, Barrett C, Magee R, Ho P. Further clinical clarification of the muscle dysfunction in cervical headache. Cephalalgia 1999;19:179–85.

Jull G, Kristjansson E, Dall'Alba P. Impairment in the cervical flexors: a comparison of whiplash and insidious onset neck pain patients. Man Ther 2004;9:89–94.

Jull G, Trott P, Potter H, Zito G, Niere K, Shirley D, et al. A randomized controlled trial of exercise and manipulative therapy for cervicogenic headache. Spine 2002;27: 1835–43.

Jull GA, O'Leary SP, Falla DL. Clinical assessment of the deep cervical flexor muscles: the craniocervical flexion test. J Manip Physiol Ther 2008;31:525–33.

Kristjansson E, Dall'Alba P, Jull G. A study of five cervicocephalic relocation tests in three different subject groups. Clin Rehabil 2003;17:768–74.

Kristjansson E, Oddsdottir GL. "The Fly": a new clinical assessment and treatment method for deficits of movement control in the cervical spine. Spine 2010;35: E1298–305.

Luomajoki H, Kool J, de Bruin ED, Airaksinen O. Reliability of movement control tests in the lumbar spine. BMC Musculoskelet Disord 2007;8:90.

Luomajoki H, Moseley GL. Tactile acuity and lumbopelvic motor control in patients with back pain and healthy controls. Br J Sports Med 2011;45:437–40.

MedCalc. Statistical Software. 13.1.0 ed.; 2014. Ostend, Belgium.

Moberg E. Two-point discrimination test. Scand J Rehab Med 1990;22:127–34.

Moseley GL. Why do people with complex regional pain syndrome take longer to recognize their affected hand? Neurology 2004;62:2182–6.

Moseley GL, Flor H. Targeting cortical representations in the treatment of chronic pain: a review. Neurorehabil Neural Repair 2012;26:646–52.

O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. Man Ther 2005;10:242–55.

Patroncini M, Hannig S. Inter-Tester Reliabilität aktiver Tests zur Bewegungskontrolle der Halswirbelsäule [Master of Advanced Studies]. Winterthur: Zurich University of Applied Sciences; 2012.

Pedler A, Motlagh H, Sterling M. Laterality judgments are not impaired in patients with chronic whiplash associated disorders. Man Ther 2013;18:72–6.

Pinsault N, Fleury A, Virone G, Bouvier B, Vaillant J, Vuillerme N. Test–retest reliability of cervicocephalic relocation test to neutral head position. Physiother Theory Pract 2008a;24:380–91.

Pinsault N, Vuillerme N, Pavan P. Cervicocephalic relocation test to the neutral head position: assessment in bilateral labyrinthine-defective and chronic, nontraumatic neck pain patients. Arch Phys Med Rehabil 2008b;89:2375–8.

Revel M, Andre-Deshays C, Minguet M. Cervicocephalic kinesthetic sensibility in patients with cervical pain. Arch Phys Med Rehabil 1991;72:288–91.

Rix GD, Bagust J. Cervicocephalic kinesthetic sensibility in patients with chronic, nontraumatic cervical spine pain. Arch Phys Med Rehabil 2001;82:911–9.

Roren A, Mayoux-Benhamou MA, Fayad F, Poiraudeau S, Lantz D, Revel M. Comparison of visual and ultrasound based techniques to measure head repositioning in healthy and neck-pain subjects. Man Ther 2009;14:270–7.

Rosnow RL, Rosenthal R, Rubin DB. Contrasts and correlations in effect-size estimation. Psychol Sci 2000;11:446–53.

Sahrmann SA. Movement system impairment syndromes of the extremities, Cervical and Thoracic Spines. St. Louis, Missouri: Elsevier Mosby; 2011.

Staerkle R, Mannion AF, Elfering A, Junge A, Semmer NK, Jacobshagen N, et al. Longitudinal validation of the fear-avoidance beliefs questionnaire (FABQ) in a Swiss-German sample of low back pain patients. Eur Spine J: official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society 2004;13:332–40.

Stanton TR, Lin CW, Bray H, Smeets RJ, Taylor D, Law RY, et al. Tactile acuity is disrupted in osteoarthritis but is unrelated to disruptions in motor imagery performance. Rheumatology 2013;52(8):1509–19.

Sterling M, Jull G, Wright A. The effect of musculoskeletal pain on motor activity and control. J Pain 2001;2:135–45.

Stone AM, Vicenzino B, Lim EC, Sterling M. Measures of central hyperexcitability in chronic whiplash associated disorder-a systematic review and meta-analysis. Man Ther 2013;18:111–7.

Swait G, Rushton AB, Miall C, Newell D. Evaluation of cervical proprioceptive function. Spine 2007;32:E692–701.

Tai Wing Chiu T, Yuk Hung Law E, Hiu Fai Chiu T. Performance of the craniocervical flexion test in subjects with and without chronic neck pain. J Orthop Sports Phys Ther 2005;35:567–71.

Teng CC, Chai H, Lai DM, Wang SF. Cervicocephalic kinesthetic sensibility in young and middle-aged adults with or without a history of mild neck pain. Man Ther 2007;12:22–8.

Treleaven J, Jull G, Sterling M. Dizziness and unsteadiness following whiplash injury: characteristic features and relationship with cervical joint position error.

J Rehabil Med: official journal of the UEMS European Board of Physical and Rehabilitation Medicine 2003;35:36–43.
Vernon H. The Neck Disability Index: state-of-the-art, 1991–2008. J Manip Physiol Ther 2008;31:491–502.
Vibe Fersum K, O'Sullivan P, Skouen JS, Smith A, Kvale A. Efficacy of classification-based cognitive functional therapy in patients with non-specific chronic low back pain: a randomized controlled trial. Eur J pain 2013;17:916–28.
Waddell G. Subgroups within "nonspecific" low back pain. J Rheumatol 2005;32.
Wallwork SB, Butler DS, Fulton I, Stewart H, Darmawan I, Moseley GL. Left/right neck rotation judgments are affected by age, gender, handedness and image rotation. Man Ther 2013;18:225–30.
Woodhouse A, Vasseljen O. Altered motor control patterns in whiplash and chronic neck pain. BMC Musculoskelet Disord 2008;9:90.