Reliability and validity of the sensorimotor control tests in patients with neck pain and its associated disorders. A systematic review and meta-analysis

Niklas Särkilahti, Joona Lavapuro

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ABSTRACT

Purpose: The objectives of this systematic review were to synthesize the current evidence regarding neck sensorimotor testing in patients with neck pain, the ability to make a difference between different neck pain patient groups and healthy controls by testing, and to recognize factors that might affect test results.

Methods: We performed the data search using PubMed, Embase, PsycINFO, CINAHL, and Scopus databases based on three groups of keywords: neck pain, sensorimotor tests, and reliability and validity of the clinical tests. We used a two-step screening process to identify studies. Furthermore, we screened the reference lists for additional studies. We included all neck sensorimotor tests in the review but analyzed only those for which at least three studies reported the same variable and parameter results. Hedges g was used to present the difference between different neck pain groups and between different neck pain groups and those without symptoms. We assessed the quality of the studies using the QUADAS tool.

Results: The final review included 29 studies, of which 20 were related to the joint position error (JPE) test, four to the smooth pursuit neck torsion (SPNT) test and five to the balance test. The studied neck pain groups were traumatic (WAD), non-specific neck pain (NSNP), and neck pain with dizziness. According to our meta-analysis, sensorimotor control was poorer in all tests in patients with neck pain compared to healthy controls (effect size 0.17-3.54). Furthermore, the JPE in the WAD group was higher than the NSNP group (effect size 0.24). The size of the difference between the groups seemed to be influenced by the intensity of the pain and the presence of dizziness.

Conclusion: To evaluate sensorimotor control as a phenomenon, we should be able to determine which variables can affect the test results. According to our review, pain intensity and dizziness appear to affect the results of sensorimotor tests. However, there still needs to be more information on the effects of various factors on sensorimotor control. Therefore, the reference standard is still missing.

INTRODUCTION

Sensorimotor control is defined as the central nervous system´s control of movement, balance, posture, and joint stability [Röijezon et al. 2015; Franklin et al. 2011]. Systematic reviews have shown altered sensorimotor control, such as decreased accuracy of cervical repositioning and increased postural sway, in individuals with neck pain compared with healthy individuals [Ruhe et al. 2011; de Vries et al. 2015; Stanton et al. 2016; de Zoette et al. 2017; Mazaheri et al. 2021] and therefore, cervical sensorimotor control tests and exercises are commonly used in clinical practice. However, opposite results have also been reported. De Zoette et al. [2017, 2019], for example, did not find a difference in seven cervical sensorimotor control tests between the neck pain group and those without symptoms, nor a relationship between sensorimotor control and pain.

The reason for the inconsistent results has remained unclear. According to the literature, dizziness and the location of the neck pain seem to influence the results of sensorimotor tests [Tjell et al. 1998; Treleaven et al. 2003; Treleaven et al. 2011; Mazaheri et al. 2021]. Furthermore, the neck pain group results often seem to vary significantly more than those without symptoms [Stanton et al. 2016; de Zoette et al. 2017; Mazaheri et al. 2021]. These may indicate that different neck pain symptom profiles may affect sensorimotor control.

The sensitivity and specificity of the used tests are crucial for correct patient classification. Therefore, we should be able to define more precisely the indications for using sensorimotor tests in patients with neck pain. Effective interventions can only be determined when the target patient group is appropriately identified.

This systematic review aimed to synthesize the current evidence regarding sensorimotor testing in patients with neck pain, assess the differences between different neck pain groups and healthy controls, and recognize factors that might affect test results.

METHODS

This review was registered prospectively on the International Prospective Register of Systematic Reviews (PROSPERO) database (registration number: CRD42020207504). Reporting was done in line with Preferred Reporting Items for Systematic and Meta-Analyses (PRISMA) (Moher et al. 2009).

Data sources and search strategy

We performed the data search using PubMed, Embase, PsycINFO, CINAHL, and Scopus databases published from inception to the date of search, October 17th, 2020. We updated the search on May 9th, 2023. With support from the university librarian, we developed the strategy, including Medical Subject Headings and free-text terms and adapted it to the search language of each database. Our search strategy used three groups of keywords: neck pain, sensorimotor tests, and reliability and validity of the clinical tests. The complete search strategy is shown in detail in Appendix 1. We also manually screened the reference lists of the included studies for additional studies.

Study selection

We used a two-step screening process to identify studies. Initially, the two evaluators (NS and MH) independently reviewed the titles and abstracts of the studies and graded the studies as ’potentially relevant’ or ’insignificant’. In the second phase, the evaluators independently performed a full-text review of the studies identified as ´potentially relevant´ and graded them as ´relevant´ or ´insignificant´. In both phases, the evaluators met to discuss their study selections and to resolve disagreements. A fourth evaluator (JT) made the decision if no consensus was found. The evaluators of the updated search were NS and JL.

An article was included if it met the following criteria: 1) a full-text original article; 2) published in English in a scientific peer-reviewed journal; 3) adult (≥18 years old) patients with neck pain and/or healthy individuals; 4) the reliability and/or validity of the sensorimotor test is assessed. The exclusion criteria were: 1) recommendations, comments, dissertations, reports, conference proceedings, treatment recommendations, books or book articles, and lecture materials; 2) literature reviews; 3) a concurrent condition that could affect the nervous system (e.g., multiple sclerosis, Parkinson's disease) or vestibular system (e.g., Meniere's disease, benign paroxysmal positional vertigo) present.

We calculated inter-rater reliability between evaluators´ gradings (´relevant´ or ´insignificant´) using percentages of agreement and Cohen Kappa with a 95% confidence interval (CI) at both screening stages. Kappa values above 0.81 have been proposed as almost perfect; 0.61-0.8 as substantial; 0.41-0.6 as moderate; 0.21-0.4 as fair; and below 0.2 as poor (Sim and Wright 2005). In addition, we evaluated inter-rater disagreement with McNemar’s test. We used a significant level of 0.05 (two-tailed) for inter-evaluator disagreement. EL performed all statistical analyses with SAS software, Version 9.4 of the SAS System for Windows (SAS Institute Inc., Cary, NC, USA).

Quality assessment

Two reviewers (NS and JL) independently applied the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) to each study to evaluate the methodological quality (QUADAS-2, 2023). We choose QUADAS-2 because it is recommended for systematic reviews to assess the risk of bias and applicability of diagnostic accuracy studies (Whiting et al. 2011). QUADAS-2 involves a 3-point scale rating concerning the applicability and risk of low, high, or unclear bias. We resolved mismatches by discussion. We included all selected articles in the study regardless of the risk of bias.

Data extraction

Two reviewers extracted data from the original (NS and MH) studies and the updated (NS and JL) search. We extracted the same information from each study: sample size, sex, age, height, weight, duration of symptoms, symptom and functional capacity assessments (Visual analogue scale, Neck Disability Index, Tampa Scale of Kinesiophobia, etc.), description of the test and used instrument, and the results. After the data partition, it was organised according to the symptom profiles and tests by the first reviewer and checked by the second (MH) and third (JL) reviewers.

Data synthesis and analysis

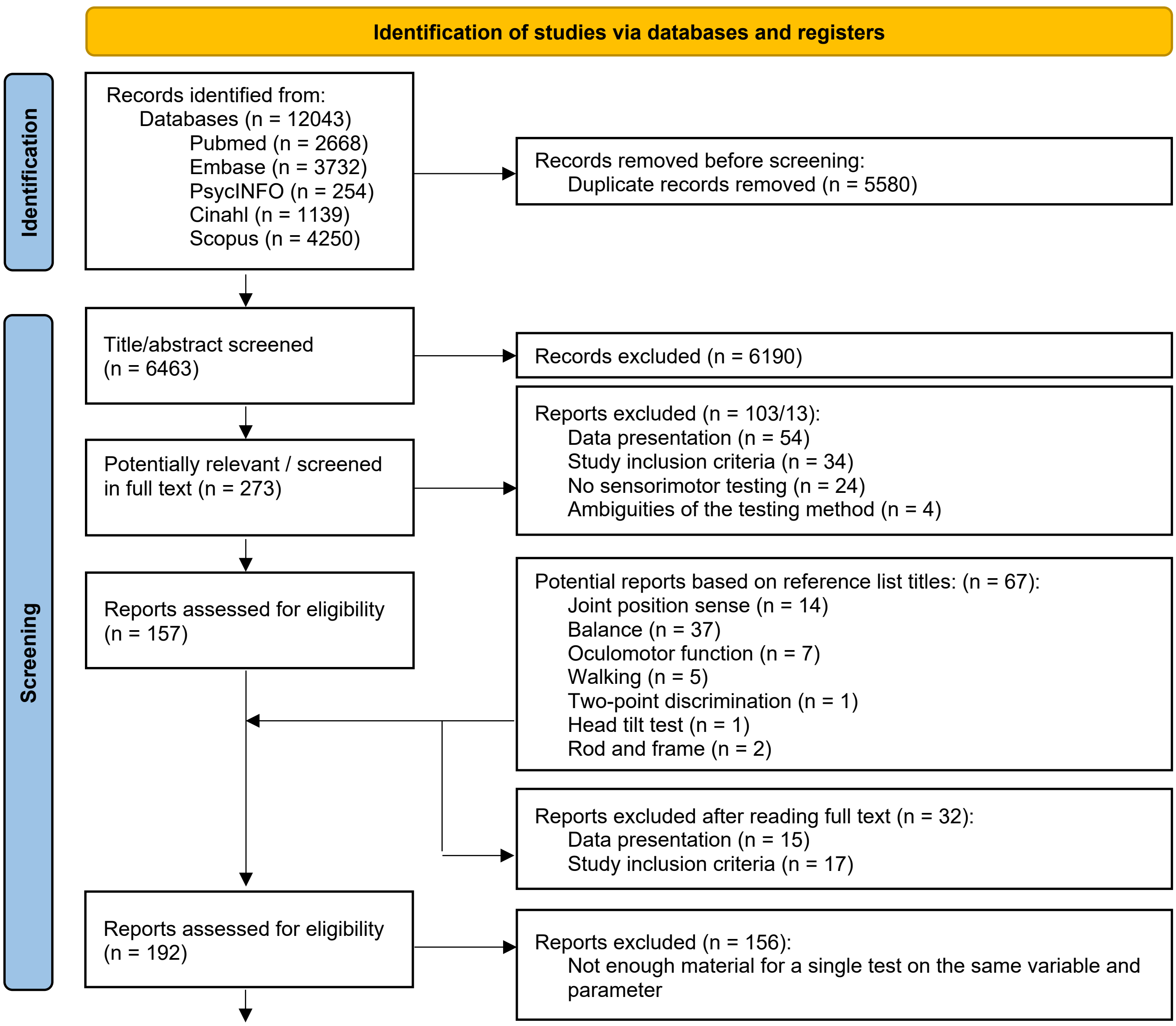
All the data from the studies were transferred to an Excel spreadsheet and divided according to each type of neck pain (e.g. non-specific neck pain, radiating neck pain, traumatic neck pain, cervicogenic dizziness). If the study only presented the results of one group or included different neck pain groups, but the results were not segregated, the study was excluded.

The results were then pooled for meta-analysis. Data for all variables and parameters of each test were extracted in the form of mean scores and standard deviation. Where standard error (SE) was only reported, the standard deviation (SD) was calculated ($SD = SE \times \sqrt{n}$). Results presented as medians or in figures were excluded. Data were analysed when at least three studies reported the results of the same variable and parameter. Although in meta-analyses, the number of studies (at least five studies) is emphasised instead of sample sizes, as in the random effects modelling of meta-analyses (Guolo and Varin 2017; Jackson and Turner 2016; Seide et al. 2019), the rule of three studies was chosen because we estimate that the data will otherwise remain small. Hedges g was used to present the difference between different neck pain groups and between different neck pain groups and those without symptoms, depending on the available data. The difference between groups was interpreted as small if the effect size (ES) was 0.2, as medium if the ES was 0.5, and as large if the ES was 0.8 or more (Cohen 1988).

RESULTS

Study selection

The literature search retrieved 12043 studies, 5580 of which were duplicates. The screening process is described in detail in Figure 1. The final review included 36 studies (Revel 1991; Heikkilä et al. 1996; Tell et al. 1998; Kristjansson et al. 2002; Michaelson et al. 2003; Sterling et al. 2003; Treleaven et al. 2003; Prushansky et al. 2004; Sterling et al. 2004; Treleaven et al. 2005; Grip et al. 2007; Woodhouse et al. 2008; Hill et al. 2009; Roren et al. 2009; van den Oord et al. 2010; Dispenza et al. 2011; Jorgensen et al. 2011; Uthaikhup et al. 2012; Juul-Kristensen et al. 2013; Elsig et al. 2014; Lange 2014; Dugailly et al. 2015; Cheever et al. 2017; De Pauw et al. 2018; Portelli et al. 2018; Goncalves et al. 2019; Ghamkhar et al. 2020; Lopez-de-Uralde-Villanueva et al. 2020; Micarelli et al. 2020; Alalawi et al. 2022a; Alalawi et al. 2022b; Alizadeh et al. 2022; Cid et al. 2022; Moustafa 2022; Reddy et al. 2022).



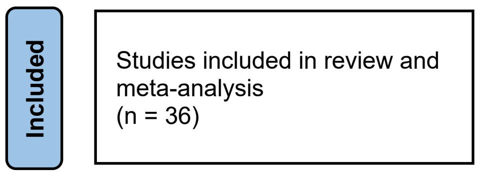


Figure 1. Prisma flow chart demonstrating the screening process.

In the first phase, Cohen's kappa (95% CI) for inter-rater reliability was 0.57 (0.51-0.62), and inter-rater agreement was 96.9% between the evaluators. In the second phase, Cohen's kappa was 0.39 (95% CI 0.28-0.50), and inter-rater agreement was 71.1%. In both phases, there was a significant difference ($p<0.05$) in the inter-evaluator disagreement.

Characteristics of included studies

Of the studies included in the review, 26 (Revel 1991; Heikkilä et al. 1998; Kristjansson et al. 2003; Sterling et al 2003; Treleaven et al. 2003; Sterling et al. 2004; Grip et al. 2007; Woodhouse et al. 2008; Hill et al. 2009; Roren et al. 2009; van den Oord et al. 2010; Uthaikhup et al. 2012; Elsig et al. 2014; Dugailly et al. 2015; Cheever et al. 2017; De Pauw et al. 2018; Portelli et al. 2018; Goncalves et al 2019; Lopez-de-Uralde-Villanueva et al. 2020; Micarelli et al. 2020; Alalawi et al. 2022a; Alalawi et al. 2022b; Cid et al. 2022; Ghamkhar et al. 2020; Moustafa 2022; Reddy et al. 2022) were related to joint position sense. The accuracy of joint position sense was assessed by repositioning error (JPE), defined as the distance between the target's position and the point indicated by the target. All studies evaluated the head repositioning to neutral after movements in different directions. The result was reported as an absolute error either in one test direction (e.g. rotation to the left) or in one movement plane (e.g. total result of left and right rotations). The Fastrak motion tracker and laser were the most common instruments for assessing JPE.

Four included studies (Tell et al. 1998; Prushansky et al. 2004; Treleaven et al. 2005; Dispenza et al. 2011) assessed oculomotor function with the Smooth Pursuit Neck Torsion test (SPNT). All studies used electro-oculography to record eye movement while following a moving target in neutral and torsional neck positions. The results were reported as a mean gain (the ratio between the eye movements and of the target) in each test position and as a difference between the gain in natural and the average values in the torsional position (SPNT difference).

Six included studies (Michaelson et al. 2003; Jorgensen et al. 2011; Juul-Kristensen et al. 2013; Lange 2014; De Pauw et al. 2018; Alizadeh et al. 2022) assessed balance using a static force platform. The platform recorded the postural sway. The results were reported as confidence ellipse areas (CEA). CEA was defined as the area of the 95% bivariate ellipse, entailing approximately 95% of the points of the centre of the pressure path. The tests were done both with eyes closed and open.

A summary of the included studies, the demographic data of the subjects, the test implementations and the results can be found in Table 1.

Citation	Subjects	Duration of symptoms	Description of test	Instrument	Summary of results, Mean (SD)
Joint position sense					
Lopez-de-Uralde-Villanueva et al 2020	Total n=183; NSNP n=68 (m19/f49), mean age 39.91 (SD 14.36); HC n=48; (m18/f30); mean age 26.6 (SD 14.14)	Chronic (>3 months)	Sitting on the chair which was placed 90 cm from a target; Head repositioning to neutral after motion within submaximal range; Movement directions: Flex, ext and rot; 3 repetitions.	A laser device	NSNP: Rot 4.54° (2.59); Flex 4.10° (2.34); Ext 5.21° (3.78) - HC: Rot 3.89° (1.49); Flex 3.97° (1.50); Ext 4.24° (2.37)
Grip et al 2007	Total n=99; WAD n=22 (m5/f17), mean age 49 (SD 15); NSNP n=21; (m7/f14), mean age 49 (SD 16); C n=24; (m8/f16), mean age 50 (SD 18)	Chronic (>3 months)	Sitting on the chair which was placed 100 cm from target; Head repositioning to neutral from target (flex and ext 25°, rot 30°); 5 repetitions	Proreflex system	NSNP: Rot 4.54° (2.59); Flex 4.10° (2.34); Ext 5.21° (3.78) - NSNPN: Rot 5.8° (3.4); Flex 5.01° (2.64); 5.73° (3.72) - HC: Rot 3.89° (1.49); Flex 3.97° (1.50); Ext 4.24° (2.37)
Cheever et al 2017	Total n=40; NSNP n=22 (m9/f13), mean age 25.5 (SD 9.75); HC n=18 (m9/f9), mean age 23 (SD 5.91)	NR	Sitting on the chair which was placed 90 cm from a target; Head repositioning to neutral after motion within maximum range; Movement directions: Flex, ext and rot; 8 repetitions.	A laser device	WAD: Rot R 3.70° (1.9); Rot L 4.00° (2.10) - Flex 3.40° (1.60); Ext 3.5° (1.80) - NSNP: Rot R 3.70° (1.60); Rot L 3.60° (3.00); Flex 2.80° (1.20); Ext 2.90° (1.30) - HC: Rot R 3.1° (1.3); Rot L 3.5° (1.3); Flex 2.90° (0.90); Ext 2.70° (1.00)
Elsig et al 2014	Total n=60; NSNP n=30 (m5/f25), mean age 36.9 (SD 13.62); HC n=30 (m5; f25), mean age 37.2 (SD 13.5)	Chronic (>6 months)	Position and movement range NR; Movement directions: Flex, ext and rot; 8 repetitions.	A laser device	NSNP: Rot R 3.27° (1.72); Rot L 3.1° (1.15); Flex 3.43° (1.75); Ext 3.19° (1.31) - HC: Rot R 2.78° (0.87); Rot L 2.58° (0.83); Flex 1.75° (0.98); Ext 2.65° (0.95)
Uthaikhup et al 2012	Total n=40; NSNP n=20 (m8/f12), mean age 73.2 (SD 6.2); HC n=20 (m6; f14), mean age 69.55 (SD 4.2)	Chronic (>3 months)	Position and movement range NR; Movement directions: Ext and rot; 3 repetitions.	Fastrack	NSNP: Rot R 5.5° (3.1); Rot L 5.1° (4); Ext 5.2° (3.4) - HC: Rot R 4.2° (2.2); Rot L 2.8° (1.8); Ext 3.6° (2.4)

Kristjansson et al 2003	Total n=63; WAD n=22 (m11/f11), mean age 33.4 (SD 10.6); NSNP n=20 (m11/f9), mean age 30.0 (SD 9.1); HC n=21 (m10/f11), mean age 26.9 (SD 6.4)	Chronic (3–48 months)	Sitting on the chair; Head repositioning to neutral after motion within comfortable limits; Movement directions: Rot; 3 repetitions.	Fastrack	NSNP: Rot 3.33° (1.42) - WAD: Rot 4.14° (1.58) - HC: Rot 2.48° (1.12)
Woodhouse et al 2008	Total n=173; WAD n=56 (m22/f34), mean age 38.19 (SD 10.8); NSNP n=57 (m19/f38), mean age 43.7 (SD 12.6); HC n=57 (m29/f28), mean age 38.2 (SD 10.9)	Chronic (6–10 months)	Sitting on the chair which was placed 150 cm from a target; Head repositioning to neutral after motion within comfortable limits; Movement directions: Rot; 2 repetitions.	Fastrack	NSNP: Rot 3.17° (1.1) - WAD: Rot 3.35° (1.6) - HC: Rot 2.86° (1.2)
Goncalves et al 2019	Total n= 66; NSNP n=33 (m7/f26), mean age 43.6 (SD 13.3); HC n=33 (m7/f26), mean age 43.5 (SD 14.1)	Chronic (>3 months)	Sitting on the chair which was placed 90 cm from a target; Head repositioning to neutral after motion within maximum range; Movement directions: Rot; 6 repetitions.	A laser device	NSNP: Rot R 5.12° (2.67); Rot L 5.01° (3.25) - HC: Rot R 3.79° (1.71); Rot L 3.87° (2.1)
Micarelli et al 2020	Total n=191; NPD n=93 (m42/f51), mean age 43.6 (SD 13.3); HC n=98 (m48/f50), mean age 43.5 (SD 14.1)	Chronic (>3 months)	Sitting on the chair which was placed 90 cm from a target; Head movement range NR; Movement directions: Flex, ext and rot; 3 repetitions	A laser device	NPD: Rot R 5.32° (1.26); Rot L 5.05 (1.04); Flex 4.96° (1.19); Ext 4.97° (1.23) - HC: Rot R 2.43° (0.66); Rot L 2.48° (0.61); Flex 2.59° (0.6); Ext 2.63° (0.62)
van den Oord et al 2010	Total n=117; NSNP n=83 (m83/f0), mean age NR; HC n=34 (m34/f0), age NR	NR	Sitting on the chair; Head repositioning to neutral after motion within submaximal range; Movement directions: Flex-ext and rot; 10 repetitions.	Zebris	NSNP Rot 1.9° (0.6); Flex-ext 2.8° (1) - HC: Rot 1.8° (0.6); Flex-ext 3.1° (1.2)
Sterling et al 2004	Total n=100; WAD n=80 (m24/f56), mean age 33.5 (SD 14.7); HC n=20 (m9; f11), mean age 39.5 (SD 14.6)	Acute (≤ 1 month)	Position and movement range NR; Movement directions: Ext and rot; 3 repetitions.	Fastrack	WADMP: Rot R 2.6° (0.3); Rot L 2.4° (0.2); Ext 3.6° (0.4) - WADSP: Rot R 4.5° (0.7); Rot L 3.3° (0.5); Ext 5.4° (0.9) - HC Rot R 2.3° (0.5); Rot L 2.3 (0.3); Ext 2.9° (0.6)

Portelli et al 2018	Total n=44; NSNP n=22 (m9/f13), mean age 21.0 (SD 3.5); HC n=22 (m7/f15), mean age 20.1 (SD 1.2)	Chronic (>3 months)	Sitting on the chair which was placed 90 cm from a target; Head repositioning to neutral after motion within 50% of maximum range; Movement directions: Flex, ext and rot; 3 repetitions.	A laser device	NSNP Rot R 4.27° (1.49); Rot L 4.48° (1.84); Flex 3.91° (1.44); Ext 3.98 (1.85) - HC Rot R 3.95° (1.34); Rot L 3.62° (1.57); Flex 2.95° (1.17); Ext 3.35 (1.46)
Dugailly et al 2015	Total n=71; NSNP n=35 (m11/f24), mean age 42 (SD 8); HC n=36 (m14/f22), mean age 42 (SD 5)	Chronic (>6 months)	Sitting on the chair which was placed 180 cm from a target; Head repositioning to neutral after motion within maximum range; Movement directions: Flex, ext and rot; 6 repetitions.	A laser device	NSNP: Rot R 5.3° (2.5); Rot L 5.5° (2.7); Flex 5.1° (2.6); Ext 7.3 (3.4) - HC: Rot R 3° (1.2); Rot L 3° (1.4); Flex 3.1° (1.7); Ext 3.5 (1.3)
Treleaven et al 2003	Total n=146; WADD n=76 (m22/f54), mean age 39.11 (SE1.8); WADND n=26 (m7/f19), mean age 40.23 (SE1.9); HC n=44 (m15/f29), mean age 34.1 (SE1.8)	Chronic (>3 months)	Sitting on the chair; Head repositioning to neutral after motion within comfortable limits; Movement directions: Extension and rotation. 3 repetitions.	Fastrack	WADD: Rot R 4.5 (0.3); Rot L 3.9° (0.3); Ext 3.5° (0.3) - WADND Rot R 2.9° (0.4); Rot L 2.8° (0.4); Ext 3.5° (0.4) - HC 2.5° (0.2); Rot L 2° (0.2); Ext 2.4° (0.3)
Hill et al 2008	Total n=150; WADD n=50 (m/f NR), mean age 35.5 (SD 8.1); WADND n=50 (m/f NR), mean age 35 (SD 1.9); HC n=50 (m/f NR), mean age 29.5 (SD 8.3)	Chronic (>3 months)	Sitting on the chair; Head repositioning to neutral after motion within comfortable limits; Movement directions: Ext and rot. 3 repetitions.	Fastrack	WADD: Rot R 4.55°; Rot L 4.01°; Ext 3.61° - WADND Rot R 2.93°; Rot L 3.07°; Ext 2.84° - HC 3.16°; Rot L 2.47°; Ext 3.01°
De Pauw et al 2018	Total n=103; WAD n=35 (m0/f35), mean age 47 (SD 1.11); NSNP n=38 (m0/f38), mean age 38 (SD 1.41); HC n=30 (m0/f30), mean age 30.45 (SD 1.15)	Chronic (>3 months)	Sitting on the chair which was placed 90 cm from a target; Head movement with maximum range of motion; Movement directions: Flexio-extension and rotation; 10 repetitions.	A laser device	WAD Rot 4.3° (2.16); Flex-Ext 3.97° (2.05) - NSNP 3.81° (1.47); 3.5° (1.2) - C Rot 3.46° (1.44); Flex-Ext 3.04° (0.99)

Heikkilä et al 1998	Total n=66; WAD n=27 (m14/f13), mean age 33.8 (NR); C n=39 (m15/f24), age 35 (NR)	Chronic (6 months - 10 years)	Sitting on the chair which was placed 90 cm from a target; Head repositioning to neutral after motion within maximum range; Movement directions: Flex, ext and rot; 10 repetitions.	A laser device	WAD: Rot R 4.32° (2.86); Rot L 3.99° (3); Flex 5.12° (3.6); Ext 5.21° (3.46) - HC Rot R 2.78° (2); Rot L 2.69° (1.78); Flex 2.54° (2.13); Ext 2.84° (1.84)
Revel 1991	Total n=60; NSNP n=30 (m10/f20), mean age 45 (SD NR); HC n=30 (m10/f20), mean age 44 (SD NR)	Chronic	Sitting on the chair which was placed 90 cm from a target; Head repositioning to neutral after motion within maximum range; Movement directions: Flex, ext and rot; 10 repetitions.	A laser device	NSNP: Rot R 6.1° (2.23); Rot L 6.11° (2.1); Flex 5..48° (0.23); Ext 5.47° (2.29) - HC Rot R 3.5° (0.76); Rot L 3.5° (1.14); Flex 3.31° (1.14); Ext 3.43° (0.82)
Roren et al 2008	Total n=82; NSNP n=41 (m11/f30), mean age 54.7 (SD 14.2); HC n=41 (m18/f23), mean age 30.5 (SD 11.4)	NR	Sitting on the chair which was placed 90 cm from a target; Head repositioning to neutral after motion within maximum range; Movement directions: Rot; 10 repetitions.	A laser device	NSNP: 6.3° (12.4) - HC: 3.6° (0.8)
Sterling et al 2003	Total n=86; WADMP n=22 (m8/f14), mean age 34 (SD 12.6); WADSP n=19 (m3/f16), mean age 41 (SD13.6); HC n=20 (m8/f12), mean age 40.1 (SD 13.6)	Acute (1–3 months)	Sitting on the chair; Head repositioning to neutral after motion within comfortable limits; Movement directions: Ext and rot. 3 repetitions.	Fastrack	WADSP: Rot R 2.7° (0.2); Rot L 2.7° (0.2); Ext 3.4° (0.3) - WADSP: Rot R 4.8° (0.3); Rot L 3.2° (0.3); Ext 4.1° (0.3) - HC: Rot R 2.7° (0.3); Rot L 2.6° (0.3); Ext 2.8° (0.3)
Oculomotor function					
Balance					

Table 1. Summary of the included studies. CM = centimeter; Ext = Extension; f = Female; Flex= Flexion; HC = Healthy controls; n = Study population; m = Male; NPD = Neck pain with dizziness; NR = Not reported; NSNP = Non-specific neck pain; NSNPN = Non-specific neck pain with neuropathic features; Rot = Rotation; Rot R = Rotation to right; Rot L = Rotation to left; SD = Standard deviation; WAD = Whiplash associated disorder; WADD = Whiplash associated disorder with dizziness; WADMP = Whiplash associated disorder with mild pain; WADND = Whiplash associated disorder with no dizziness; WADSP = Whiplash associated disorder with severe pain;

Joint position error

Description of the participants

The types of neck pain examined in the studies were non-specific neck pain (NSNP), traumatic neck pain (TNP), and neck pain with dizziness (NPD). However, in the TNP group, two studies (Treleaven et al. 2003; Hill et al. 2009) divided subjects into dizziness and non-dizziness subgroups, and two studies (Sterling et al. 2003; Sterling et al. 2004) divided the subjects according to the pain severity. Therefore, four different analyses were performed in which the data from these four studies were pooled with other data from TNP studies as follows: TNP with dizziness and mild pain (TNPDM); 2) TNP with dizziness and severe pain (TNPDS); 3) TNP without dizziness and mild pain (TNPNDM); and 4) TNP without dizziness and severe pain (TNPNDS). The NPD group consisted of individuals with traumatic (Treleaven et al. 2003; Hill et al. 2009) and non-specific (Micarelli et al. 2020) neck pain.

The sample size in the NSNP group was 568 (range 8-68), in the TNP group 533 (range 18-80) individuals, in the NPD 219 (range 50-93), and in the healthy controls (HC), 908 (range 14-98). Most of the subjects were women (65%). Two studies (Hill et al. 2009; Reddy et al. 2022) did not report numbers for men and women. There was a significant statistical difference in the relative proportions of the gender distribution between the groups (Fisher's Exact Test $p<0.01$).

The mean age was 39.27 (SD 12.73) in the NSNP group, 39.10 (SD 5.46) in the WAD group, 39.30 (SD 3.90) in the NPD group and 36.32 (SD 10.80) in HC. One study (van den Oord et al. 2010) did not report the average age of the subjects, and in one study (Heikkilä et al. 1996), the standard deviation value was unclear. Therefore, we excluded these results from the age analysis. Meta-analysis showed that the subjects in the neck pain groups were older than those in the HC groups. Similarly, the TNP group compared to the NSNP group. A summary of the demographic factors between different groups is presented in Table 2. For other demographic factors, such as pain level or functional capacity, we could not make an intergroup comparison due to heterogeneous data.

Group	**Number of studies**	**n male/female (range)**	**Difference of relative proportions of the gender distribution**	**Average age (range)**	**Age difference, effect size**
TNP	5	48/117 (0–22/11–35)	p<0.01	43.12 (33.4–49)	1.38
NSNP		47/119 (0–19/9–38)		41.57 (30–49)	
HC	11	113/214 (0–29/11–33)		37.27 (26.9–50)	
TNPDM		120/268 (0–24/11–56)	p<0.01	39.17 (33.4–49)	0.72
TNPDS		115/270 (0–24/11–56)	p<0.01	39.77 (33.4–49)	0.77
TNPNDM		105/233 (0–24/11–56)	p<0.01	39.23 (33.4–49)	0.74
TNPNDS		100/235 (0–24/11–56)	p<0.01	39.83 (33.4–49)	0.78
HC	18	250/332 (0–61/0–30)	p<0.01	35.85 (20.1–69.6)	0.55
NSNP		179/373 (0–19/0–49)		39.27 (21–73.2)	
HC	3	63/79 (15–48/29–50)	p<0.01	36.53 (29.5–46)	0.31
NPD		64/105 (22–42/51–54)		39.31 (35.5–43.3)	

Table 2. A summary of the demographic factors between different groups. HC = Healthy controls; NPD = Neck pain with dizziness; NSNP = Non-specific neck pain; TNP = Traumatic neck pain; TNPDM = TNP with dizziness and mild pain; TNPDS = TNP with dizziness and severe pain; TNPNDM = TNP without dizziness and mild pain; TNPNDS = TNP without dizziness and severe pain.

Differences between groups

Meta-analysis showed a larger error in head repositioning in rotation in individuals with TNP than those with NSNP. However, the difference between the groups was small (ES 0.24). Repositioning error was also larger in all neck pain groups compared to HCs. The extent of the difference (ES 0.38-1.24) between TNP groups and HC depended on the movement direction tested and the TNP subcategories analysed. The difference was from medium to large (ES 0.56-1.14) between NSNP and HC and large (1.05-1.49) between NPD and HC in all directions of movement. The detailed results of the meta-analysis of the JPE test between different groups in each direction are shown in Table 3. The forest plots demonstrating meta-analysis of the absolute error when repositioning the head to neutral from rotation, flexion and extension are presented in Appendix 2.

Group comparison	Rotation right, ES	Rotation left, ES	Rotation, ES	Flexion, ES	Extension, ES	Flexion-extension, ES
TNP vs. NSNP			0.24			
TNPDM vs. HC	0.81	0.94			0.43	
TNPDS vs. HC	1.24	1.06			0.6	
TNPNDM vs. HC	0.79	0.85			0.38	
TNPNDS vs. HC	1.10	0.97			0.6	
TNP vs. HC			0.6			
NSNP vs. HC	1.01	1.14	0.71	0.91	0.65	0.56
NPD vs. HC	1.42	1.49			1.05	

Table 3. The differences in joint position error test between different groups. ES = Effect size; HC = Healthy controls; NSNP = Non-specific neck pain; NPD = Neck pain with dizziness; TNP = Traumatic neck pain; TNPDM = TNP with dizziness and mild pain; TNPDS = TNP with dizziness and severe pain; TNPNDM = TNP without dizziness and mild pain; TNPNDS = TNP without dizziness and severe pain.

Oculomotor function

Description of the participants

Two (Tjell et al. 1998; Treleaven et al. 2005) of the four studies divided patients with WAD into dizziness and non-dizziness subcategories. Therefore, two different analyses were performed in which the data from these two studies were pooled with other data from TNP studies as follows: 1) TNP with dizziness (TNPD) and 2) TNP without dizziness (TNPND).

The sample size in the TNP group was 238 (range 25-50) and 126 (range 23-50) in the HC group. Most of the subjects were women (62%). There was no statistical difference in gender ratios between TNPD and HC or TNPND and HC, p=0.55 and p=0.53, respectively (Fisher´s Exact test). The mean age was 37.83 (SD 2.21) in the TNPD group, 36.45 (SD 2.76) in the TNPND group and 35.37 (SD 7.98) in HC. Because the studies used different methods of reporting demographic data, we could not make an intergroup comparison.

Differences between groups

Meta-analysis showed that the neutral gain was lower, and the SPNT difference was greater in individuals with TNP than HC. The difference was large between TNP and HC. The detailed results of the meta-analysis of the SPNT tests between different groups are shown in Table 4. The forest plots demonstrating meta-analysis of the neutral gain and the difference between the gain in neutral and the average values in the torsional position are presented in Appendix 2.

Group comparison	Number of studies	n male/female (range)	Average age (range)	Neutral gain, ES	SPNT difference, ES
HC	4	54/72 (7-20/11/30)	35.38 (29.9-47)		
TNPD		64/99 (10-23/14-38)	37.83 (35.5-40.3)	2.02	3.54
TNPND		53/85 (8-23/14/38)	36.45 (34-40.3)	1.76	2.28

Table 4. The differences in Smooth pursuit neck torsion test between individuals with traumatic neck pain and healthy controls. ES = Effect size; HC = Healthy controls; TNPD = Traumatic neck pain with dizziness; TNPND = Traumatic neck pain without dizziness.

Balance

Description of the participants

The sample size in the NSNP group was 183 (range 30-85), in the TNP group 54 (range 9-35) and in the HC 220 (range 10-109). Almost all subjects were women (92%). One study [Lange et al. 2014] did not report numbers for women and men. There was no statistical difference in gender ratios between NSNP and HC or TNP and HC, p=1.0 (Fisher´s Exact test). The mean age was 39.89 (SD 4.48) in the NSNP group, 42.9 (SD 4.75) in the TNP group, and 37,14 (SD 5.86) in HC. Meta-analysis showed that the subjects in the TNP group were older than those in the HC group. One study [Lange et al. 2014] reported age as the median; therefore, we could not make an intergroup comparison between the NSNP group and HC. A summary of the demographic factors between different groups is presented in Table 5.

Group	Number of studies	n male/female (range)	Difference of relative proportions of the gender distribution	Average age (range)	Age difference, effect size
HC	3	3/53 (0-3/10-30)	p<0.01	35.78 (30.45-41)	4.72
TNP		3/51 (0–3/6-35)		42.9 (37.7-47)	
HC	3	0/139 (0–0/30-109)	p<0.01	37.27 (30.45-45)	
NSNPEC		0/123 (0-0/38–85)		41.5 (38-45)	
HC	3	12/127 (0-12/18-109)	p<0.01	39.16 (33.37-45)	
NSNPEO		13/102 (0-13/17-85)		40.84 (36.67-45)	

Table 5. A summary of the demographic factors between different groups. HC = Healthy controls; NSNPEC = Non-specific neck pain with eyes closed; NSNPEO = Non-specific neck pain with eyes open; TNP = Traumatic neck pain.

Differences between groups

Meta-analysis showed that the postural sway was larger in individuals with neck pain than HC when the test was done with eyes closed. The difference was small (ES 0.37) between NSNP with eyes closed and HC and large (ES 1.17) between TNP and HC. However, when the test was done with eyes open, there were no differences between NSNP and HC. The forest plots demonstrating meta-analysis of the CEA are presented in Appendix 2.

Methodological quality

The methodological quality of the included studies according to QUADAS-2 is summarized in Table 5. The main shortcomings were a lack of… TÄYDENTYY

DISCUSSION

Our study aimed to clarify sensorimotor control in different types of neck pain and identify possible factors that can affect sensorimotor control test results. We were able to perform a meta-analysis of three commonly used sensorimotor tests: the JPE, SPNT and balance tests. Our review showed that joint-position sense, oculomotor function and postural sway were poorer than healthy controls in individuals with neck pain. Furthermore, the JPE in individuals with TNP was higher compared to NSNP.

Although there were differences between the groups, to evaluate sensorimotor control as a phenomenon, we should also be able to determine which variables can affect the test and what the cutoffs for a positive test are. For example, according to our review, the mean JPE after left or right rotation ranged from 0.35° to 4.2° in healthy controls, from 2.37° to 6.1° in individuals with NSNP, and from 2.6° to 4.6° in individuals with TNP. However, Revel et al. (1991) reported that less than 4.5° error indicates normal cervical proprioception. Furthermore, two recent studies showed that the minimal detectable change (MDC95%) in the JPE test is estimated to vary between 2.4° and 5° in healthy controls and between 2.7° and 2.9° in individuals with neck pain (Conclaves et al. 2019; Lopez-de-Uralde-Villanueva et al. 2022). This suggests that some of the results of neck pain groups included in our meta-analysis can be classified as normal. Therefore, the results between groups may not be clinically significant. We could not assess the clinical significance of the SPNT and balance test results due to the lack of comparable normal values.

In a meta-analysis by Mazzaher et al. (2021), dizziness appeared to affect joint position sense and balance in individuals with neck pain. The results of the subjects who experienced dizziness were reported separately in the five studies included in our review. Three of these studies were related to the JPE test (Treleaven et al. 2003; Hill et al. 2009; Micarelli et al. 2020), and two to the SPNT test (Tjell et al. 1998; Treleaven et al. 2005). Our meta-analysis revealed a very large group difference between individuals with neck pain and dizziness and HC in the JPE test. Furthermore, the difference between the TNP and HC groups seemed to increase in the JPE and SPNT tests when individuals with dizziness were included in the analysis compared to those without dizziness. In the JPE test, pain intensity also seemed to affect the difference between the TNP group and HC. It should be noted, however, that we could not perform a separate comparative analysis between the different neck pain groups, those with and without dizziness or those with mild and severe pain, due to the rule of the three studies we used.

The quality of the meta-analysis is only as good as the data reported in the studies. Therefore, we tried to find as much comparable data as possible on sensorimotor tests in patients with neck pain. However, this became a challenge. Although our review revealed many different tests, there was a large variation in test implementations, variables, parameters, and analysis methods. For example, the sway amplitude of the posturography was reported in the total envelope area or the 90% or 95% confidence ellipse area. We excluded the studies if we could not collect data from at least three studies that used the same analysis method, parameter, and variable in a single test. Therefore, our review included only three tests, and the variables to be investigated remained small, for example, in the balance test.

We, however, pooled the results between the studies despite the tests being carried out in slightly different ways. In the JPE test, for example, studies used various equipment, numbers of repetitions and head rotation range when returning the head to the neutral position. Furthermore, in the SPNT test, different velocities of a sinusoidal stimulus, frequencies and visual angles were used. In posturography, the test implementations were mainly comparable, but one study used a wide standing position and a long test time. Since the implementation of the tests seems to affect the reliability of the test (Ruhe et al. 2010; English et al. 2022; Rosker et al. 2022), our meta-analysis may include tests with different levels of reliability. Furthermore, a large variation in the implementation of the tests raises the suspicion that our analysis may include studies that used non-validated tests instead of validated tests. This weakens the quality of our meta-analysis.

Several studies have reported that, for example, in healthy individuals, age and sex can affect sensorimotor control, especially oculomotor control and balance (Era et al. 2005; Kerber et al. 2006; Demaille-Wlodyka et al. 2007). Therefore, the diversity of the studied groups can also affect our analyses. According to our meta-analysis, in the JPE and balance tests, neck pain groups were older than HC. However, this analysis may be biased due to the discrepant results in one study (De Pauw et al. 2018). Although De Pauw et al. (2018) reported age variation as a standard deviation, the wide range and large difference between the median and mean raises doubts about the reported indicators.
Furthermore, there was a statistically significant difference between gender ratios in the study groups in the JPE test. Due to the different measures used, we could not perform a more detailed analysis of other factors, such as pain or disability. However, it was interesting to note that studies comparing differences between different types of neck pain in the JPE test reported significantly more pain and disability in the TNP group than in the NSNP group (Kristjansson et al. 2003; Woodhouse et al. 2008; De Pauw et al. 2018). Therefore, the small difference observed in our meta-analysis between the NTP and NSNP groups in the JPE test may be due to differences in pain intensity or disability rather than the trauma itself.

The sensorimotor tests included in our review are currently widely used for neck pain. The results of our review suggest that the background of the sensorimotor impairment is not necessarily neck pain or trauma alone but rather a combination of different factors. This is supported, for example, by the Treleaven et al. (2011) study, which showed that in traumatic neck pain but not in non-traumatic neck pain, the location of the pain seems to affect sensorimotor control. Although our results should be treated cautiously, they suggest that in future studies, patients with neck pain should be divided into more specific subgroups based on the symptom profile than before. Furthermore, we can argue that the reference standards of the sensorimotor tests are still missing, and the available data is very heterogeneous. Therefore, we need more data in the future about the factors affecting sensorimotor control and the results of standardised tests. Only after this can we know which tests are reliable and usable for neck pain and which are not.