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REVIEW PAPER

The Effectiveness of Cervical Sensorimotor Control Training for the Management of Chronic Neck Pain Disorders: A Systematic Review and Meta-Analysis

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Abstract

This systematic review and meta-analysis aimed to evaluate the effectiveness of cervical sensorimotor control training for the management of chronic neck pain (NP) disorders compared to no treatment, or other conservative or non-conservative treatments. The review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (PROSPERO registration number: CRD42022381714). A comprehensive database search was performed (until November 2023) for randomized controlled trials (RCTs) and clinical trials evaluating the effects of cervical sensorimotor control training on several subjective and objective outcomes in adults with chronic NP (traumatic or non-traumatic origin). Data on study and patient characteristics, outcome measures, and effects on primary and secondary outcomes were extracted. Seven RCTs (409 participants) were included, of which 6 qualified for meta-analysis. Low-certainty evidence suggests that cervical sensorimotor control training is more effective for reducing pain (standardized mean difference (SMD): 0.48; 95% confidence interval (CI): 0.07 to 0.89) and improving cervicocephalic kinesthesia at short term than no treatment, and for reducing kinesiophobia at intermediate term compared to other treatment modalities. No significant between-group differences were found for other outcomes and follow-ups (very low-to-moderate-certainty evidence). Considering the significant improvements in cervicocephalic kinesthesia, cervical sensorimotor control training could be an important element in the rehabilitation of patients with chronic NP disorders. However, the current evidence in the literature is scarce to draw conclusions regarding its effectiveness as a stand-alone rehabilitation program.

Keywords: *chronic neck pain, exercise, meta-analysis, neck kinesthesia, proprioception, sensorimotor control*

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Introduction

Neck pain (NP) is one of the most commonly reported musculoskeletal disorders (Kazeminasab et al., 2022), affecting more than 30% of people annually (Cohen, 2015). It is an important public health concern in the general population (Safiri et al., 2020) that often results in significant disability and economic costs (Hurwitz et al., 2018; Kazeminasab et al., 2022). Patients with NP suffer from pain and discomfort, while also report being limited in their daily activities due to pain-related disability (Nolet et al., 2015). Such functional limitations can affect patients' quality of life, which is often compromised in this population (Lin et al., 2010; Nolet et al., 2015; Pedisic et al., 2013). In addition, patients with chronic NP may suffer from fear of movement (kinesiophobia) (Asiri et al., 2021; Demirbüken et al., 2016; Uluğ et al., 2016), the higher severity of which is associated with greater pain and disability as well as lower quality of life (Luque-Suarez et al., 2019).

Furthermore, previous research shows that NP is associated with reduced cervical range of motion (ROM) (Rudolfsson et al., 2012) as well as alterations in cervical motor control which have been observed in patients with NP through impaired activation of the deep cervical flexor muscles demonstrated during the craniocervical flexion test (CCFT) (Chiu et al., 2005; Jull et al., 2008) and altered cervical sensorimotor function (de Vries et al., 2015; Kristjansson & Treleaven, 2009; Stanton et al., 2016). More specifically, sensorimotor deficits commonly seen in patients with NP can arise from abnormal cervical afferent input (Kristjansson & Treleaven, 2009) affecting patients' ability to sense the position and movement of body parts and, consequently, how they respond to external and internal changes in the environment throughout their daily activities (Proske & Gandevia, 2012). In addition, the results of a recent study suggest that NP as such can also significantly affect cervical sensorimotor control function, as an increased error in cervical joint repositioning was observed in healthy subjects after experimentally induced NP (Wang et al., 2022). Accordingly, altered cervicocephalic kinesthetic awareness (de Vries et al., 2015; Stanton et al., 2016) and postural balance (Ruhe et al., 2011) are commonly identified in patients with NP. Moreover, it has been suggested that altered sensorimotor control due to cervical proprioceptive deficits could contribute to the recurrence and chronicity of NP (Kristjansson & Treleaven, 2009; Qu et al., 2022; Röijezon et al., 2015), while there is growing evidence that adaptations in neuromuscular function (e.g., changes in muscle properties and activity, mobility, sensorimotor control) can occur not only in patients with chronic NP, but also in individuals with recurrent NP during a period in remission (Alalawi et al., 2022; Devecchi et al., 2021). These findings suggest that restoration of neuromuscular function is along with pain relief important in the management of patients with NP disorders and that neuromuscular characteristics should be monitored during clinical assessment using objective outcome measures to properly understand the effectiveness of rehabilitation approaches (Jull, 2016). In this regard, addressing sensorimotor control deficits has been proposed as one of the most important aspects of treating patients with NP (Kristjansson & Treleaven, 2009; Peng et al., 2021; Treleaven, 2008).

To date, the effects of various rehabilitation approaches on chronic NP have been investigated and evaluated. Nevertheless, research shows that patient outcomes remain suboptimal, underscoring the need to develop more effective approaches for treating chronic NP (Bier et al., 2018; Blanpied et al., 2017; Castellini et al., 2022; Sterling et al., 2019). Different types of cervical sensorimotor control exercises that aim to enhance cervical kinesthetic functions (i.e., position sense, movement sense) have shown promising results when used in combination or as stand-alone rehabilitation program for chronic NP, in terms of improving specific outcomes, including pain, neck disability, quality of life, kinesiophobia, neck mobility and motor control, as well as sensorimotor function (Cetin et al., 2022; Espí-López et al., 2021; Gallego Izquierdo et al., 2016; Humphreys & Irgens, 2002; Jull et al., 2007; Nusser et al., 2021; Pérez-Cabezas et al., 2020; Reddy et al., 2021; Revel et al., 1994; Rezaei et al., 2018; Saadat et al., 2019; Sarig Bahat et al., 2015, 2018; Sremakaew et al., 2023; Tejera et al., 2020). To the best of our knowledge, no prior reviews have examined the effectiveness of these training modalities in patients with chronic NP. Previous systematic reviews and meta-analyses have mainly focused on specific training modalities aimed at improving only one aspect of cervical sensorimotor control (Ahern et al., 2020; Grassini, 2022; Gross et al., 2015; McCaskey et al., 2014; Petersen et al., 2013), while others have investigated the effectiveness of motor control exercises (Rasmussen-Barr et al., 2023), which, in contrast to cervical sensorimotor control exercises, are primarily aimed at improving control of craniocervical flexion movement and activation of the deep cervical flexor muscles (de Zoete et al., 2021; Jull et al., 2009). This gap in the literature highlights the necessity of conducting a systematic review and meta-analysis to consolidate evidence on the effects of cervical sensorimotor control training to provide new insights for the treatment of chronic NP.

The aim of this systematic review and meta-analysis was to investigate the effectiveness of cervical sensorimotor control training on the above-described signs and symptoms related to chronic NP disorders. Studies with interventions combining cervical sensorimotor control training with another type of rehabilitation program were excluded from the review in order to investigate causality by isolating the effect of a specific rehabilitation approach.

Methods

The review was conducted according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Hutton et al., 2015; Moher et al., 2009) and was registered at the International prospective register of systematic reviews (PROSPERO registration number: CRD42022381714).

Data sources and searches

The electronic databases PubMed, PEDro, ScienceDirect and Web of Science were searched for literature. Gray literature of published interventions and systematic reviews was searched through Google Scholar and DART-Europe E-theses Portal. Reference lists of relevant reviews and their included articles were searched as well as PROSPERO databases to identify any important ongoing and/or unpublished systematic reviews. Unpublished studies were not sought. The databases were systematically searched from inception to November 2023 using the following search string: (neck OR cervical) AND (propriocept* OR kinest* OR kinaest* OR kinemat* OR coordination OR "motor control" OR sensorimotor OR "position sense" OR "movement sense" OR "movement control") AND (training* OR exercise* OR rehabilitation* OR intervention* OR program* OR regime*). As different databases require different search strategies, the search strings for the

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individual databases were adapted. The following filters were used for individual databases: (a) Clinical trial, Randomized controlled trial (PubMed); (b) Clinical trial (PEDro); (c) Research articles (ScienceDirect); (d) Article (Web of Science).

Study selection

Two review authors (I.L. and Z.M.R.) independently screened titles and abstracts. Duplicate records were removed using Microsoft Excel (Microsoft Corporations, Redmond, Washington, USA). The same two review authors evaluated the eligibility of the retrieved full-text articles. Discrepancies that arose during eligibility assessment were resolved through discussion and by consultation with a third author (V.S.) when necessary. Randomized controlled trials (RCTs) and clinical trials were included if they met the following criteria: (1) study population consisted of adults (mean age: 18+ years) with chronic NP (> 3 months duration, traumatic or non-traumatic origin); (2) involving an intervention with cervical sensorimotor control training/exercises that are based on position sense, movement sense and/or movement control during or after active head and neck movements and are aimed to improve cervical sensorimotor control; (3) cervical sensorimotor control training was compared to (a) no treatment or (b) any other conservative or non-conservative treatments. Studies were excluded if cervical sensorimotor control training did not involve active head and neck movements. Studies focusing on other modalities: cervical muscle strengthening and endurance exercises, proprioceptive neuromuscular facilitation, neuromuscular joint facilitation, vestibular rehabilitation, mental imagery exercises, laterality training, and postural balance training were excluded from this review. Interventions where cervical sensorimotor control training was combined with any other type of rehabilitation program were excluded.

Outcome measures

The primary outcomes of interest were objective measures of sensorimotor control function (i.e., cervicocephalic kinesthetic awareness and postural balance) and pain intensity measured by a pain scale (i.e., visual analog scale (VAS) or numerical rating scale (NRS)). The secondary outcomes of the review were subjective functional limitations assessed by neck disability-specific scale (i.e., Neck Disability Index (NDI)), objective measures of cervical ROM and CCFT and subjectively measured quality of life and kinesiophobia.

Data extraction and quality assessment

Two review authors (I.L. and Z.M.R.) extracted the data independently, while the third author (V.S.) checked the accuracy of the entered data. Data on study and patient characteristics, outcome measures and effects on primary and secondary outcomes were extracted. When studies reported more than two intervention groups that could be included in the review, data were extracted from all study arms. When necessary, authors of the included studies were contacted to obtain additional data.

For the included studies, risk of bias was assessed independently by two review authors (I.L. and Z.M.R.) using the PEDro scale (Herbert et al., 1998). The PEDro scale has been shown to be a valid (de Morton, 2009; Macedo et al., 2010) and reliable (Maher et al., 2003) measure for assessing the methodological quality of clinical trials. Trials are considered to be of good to excellent quality if they score at least 6 points (Cashin & McAuley, 2020), which is a widely used cut-off point in the literature (Armijo-Olivo et al., 2015).

The certainty of evidence was assessed according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach (Guyatt et al., 2011) and was classified as high, moderate, low, or very low. Certainty of evidence was downgraded according to the: risk of bias, inconsistency, imprecision, indirectness, and publication bias (Furlan et al., 2015).

Data synthesis and analysis

Only studies that provided sufficient data to calculate the standardized mean difference (SMD: Hedges' g) were included in the meta-analysis. The SMD was calculated as the difference between changes from baseline in the intervention and comparator groups based on the reported means, standard deviations (SDs), and sample sizes of each group. If the SD was not available, it was estimated using the standard error (SE), confidence interval (CI), or p-value according to the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2022). In addition, if studies reported the sample size, median and interquartile range, these were used to estimate the mean and SD by using a formula-based method developed by Wan et al. (Wan et al., 2014). In studies with multiple relevant intervention groups, the 'shared' group was split into two or more groups with smaller sample sizes to allow inclusion in the meta-analysis and to examine heterogeneity across intervention arms (Higgins et al., 2022).

A random-effects model was used to pool the results of individual trials. The heterogeneity variance $\tau 2$ was calculated using the restricted maximum likelihood method (Viechtbauer, 2005) and Knapp-Hartung adjustments were used to calculate the CI around the pooled effect (Knapp & Hartung, 2003). Hedges' g values of ≥ 0.2, ≥ 0.5, and > 0.8 were interpreted as small, medium, and large effects, respectively (Ellis, 2010). The between study heterogeneity was assessed using the I2 statistic, where values of 0%-40% might not be important, 30%-60% may represent moderate heterogeneity, 50%-90% may represent substantial heterogeneity, and 75%-100% may represent considerable heterogeneity (Higgins et al., 2022). A subgroup analysis was performed based on the comparator intervention to separately consider the effects of the interventions when compared with no treatment or other conservative or non-conservative treatments. All statistical analyses were performed in R statistical software (version 4.3.0) (R Core Team, 2023) using the "meta" package, and p-values of less than 0.05 were considered statistically significant.

Protocol changes after the initial PROSPERO registration

After the initial PROSPERO registration, but before any analyses were performed, the following changes were made to the protocol and were submitted to our record: slight changes in terminology regarding training modalities; using PEDro scale to assess risk of bias; adding the criterion not to exclude interventions involving ocular exercises; using Hedges' g to calculate effect size and using the data synthesis strategy described in the above paragraph.

Results

Flow of studies through the review

The study selection process is shown in Figure 1. A total of 3860 records were identified through a comprehensive database search strategy, while 2 were found in other sources (i.e.,

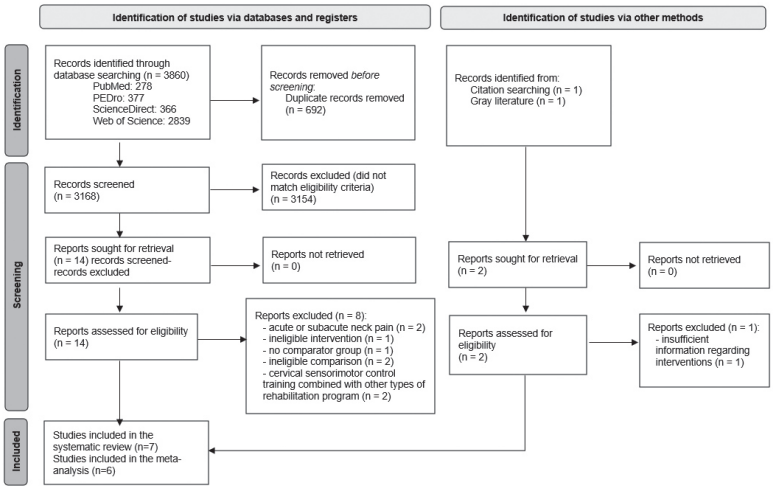

Figure 1. Prisma flowchart illustrating the study selection process

reference and gray literature searches). After removing duplicates and screening articles by title and abstract, 16 papers were retrieved for full-text screening. Altogether, 7 studies (7 papers with 9 intervention comparisons, involving 409 participants) met the inclusion criteria and were included in the systematic review (Gallego Izquierdo et al., 2016; Humphreys & Irgens, 2002; Jull et al., 2007; Revel et al., 1994; Rudolfsson et al., 2014; Sarig Bahat et al., 2018; Tejera et al., 2020). Among them, 6 studies (6 papers with 7 intervention comparisons) that provided sufficient data were included in the meta-analysis (Gallego Izquierdo et al., 2016; Humphreys & Irgens, 2002; Jull et al., 2007; Revel et al., 1994; Sarig Bahat et al., 2018; Tejera et al., 2020). All studies included in the systematic review were RCTs, and two of them were 3-arm studies (Rudolfsson et al., 2014; Sarig Bahat et al., 2018). Two studies appeared to meet the inclusion criteria but were excluded from the review because of ineligible intervention comparisons considering our inclusion criteria (Rezaei et al., 2018; Sarig Bahat et al., 2015).

Characteristics of included trials

A comprehensive overview of all trials (n = 7) that met the predefined criteria is provided in Table 1. The included trials encompassed 9 intervention comparisons that included 8 interventions with cervical sensorimotor control training. A total of 409 participants were included in the trials. Two trials included only women (Jull et al., 2007; Rudolfsson et al., 2014), while in others the proportion of women ranged from 50% to 85% (Gallego Izquierdo et al., 2016; Humphreys & Irgens, 2002; Revel et al., 1994; Sarig Bahat et al., 2018; Tejera et al., 2020). Mean duration of the interventions with cervical sensorimotor control training was 6.1 weeks (4 to 11 weeks). Three interventions included cervical proprioceptive training, consisting of head relocation practice, gaze stability, eye-follow and eye-head coordination exercises (Gallego Izquierdo et al., 2016; Jull et al., 2007; Revel et al., 1994), two interventions included kinematic or neck-specific training using virtual reality (Sarig Bahat et al., 2018; Tejera et al., 2020) and three interventions included eye-head-neck-upper limb coordination exercises (Humphreys & Irgens, 2002), neck coordination exercise with a custom-made training device (Rudolfsson et al., 2014) and kinematic training with a laser pointer (Sarig Bahat et al., 2018), respectively. In four intervention comparisons, the comparator group received no treatment (Humphreys & Irgens, 2002; Revel et al., 1994; Sarig Bahat et al., 2018), while in five intervention comparisons the comparator group received other conservative or non-conservative treatments, including craniocervical flexion training (Gallego Izquierdo et al., 2016; Jull et al., 2007), neck-specific exercises (performing neck movements while maintaining craniocervical flexion) (Tejera et al., 2020), strength training for the neck and shoulders (Rudolfsson et al., 2014), or massage (Rudolfsson et al., 2014).

Regarding the primary outcomes defined in the review, 4 trials investigated the short-term effects on cervicocephalic kinesthetic awareness (cervical position sense or movement sense) (Humphreys & Irgens, 2002; Jull et al., 2007; Revel et al., 1994; Sarig Bahat et al., 2018), 1 on postural balance (Rudolfsson et al., 2014) and 6 on pain intensity (Gallego Izquierdo et al., 2016; Humphreys & Irgens, 2002; Jull et al., 2007; Revel et al., 1994; Sarig Bahat et al., 2018; Tejera et al., 2020), while 1 trial reported the results on the intermediate-term effects on pain intensity (Tejera et al., 2020). Long-term effects on postural balance and pain intensity were only investigated in 1 trial (Rudolfsson et al., 2014). Furthermore, the results on the secondary outcomes defined in the review were reported in 5 trials at short-term follow-up (Gallego Izquierdo et al., 2016; Jull et al., 2007; Revel et al., 1994; Sarig Bahat et al., 2018; Tejera et al., 2020), whereas only one trial included relevant intermediate-term follow-up (Tejera et al., 2020) and another trial included long-term follow-up (Rudolfsson et al., 2014). In the included trials, short-term follow-up was conducted at the end (Gallego Izquierdo et al., 2016; Humphreys & Irgens, 2002; Jull et al., 2007; Rudolfsson et al., 2014; Sarig Bahat et al., 2018; Tejera et al., 2020), 2 weeks (Revel et al., 1994) or 1 month (Tejera et al., 2020) after the intervention, while intermediate- and long-term follow-up was conducted 3 (Tejera et al., 2020) and 6 months (Rudolfsson et al., 2014) after the intervention, respectively.

A quantitative synthesis of the results was performed when adequate data were available for a particular outcome from the included studies. In this regard, only the results on pain intensity and subjective functional limitations at short-term follow-up (considering the earliest follow-up point) were synthesized, while the results on other outcomes could not be summarized quantitatively due to insufficient data and considerable differences in outcome reporting and assessment methods.

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Table 1. Characteristics of included trials (intervention comparisons)

Author and year (study design)	PEDro score	Sample size (I/C)	Age* (I/C) and sex of participants	Intervention duration (weeks)	Modality	Comparator intervention	Intervention dose (minutes/ week)	Outcome measures
Gallego Izquierdo et al., 2016 (RCT)	8	28 (14/14)	I: 29.93(7.34) C: 28.43(6.16) Sex: males (35.7%) and females (64.3%)	8	Cervical proprioceptive training	Craniocervical flexion training	140	CCFT, NDI, PPT, VAS
Humphreys & Irgens, 2002 (RCT)	5	28 (14/14)	22.6 (19-30)† Sex: males (50%) and females (50%)	4	Eye-head-neck-upper limb coordination exercises	No treatment	NR (2 sessions/day)	HRA, VAS
Jull et al., 2007 (RCT)	6	58 (28/30)	I: 39.0(11.6) C: 42.7(10.8) Sex: females	6	Cervical proprioceptive training	Craniocervical flexion training	70-140	JPE, NDI, NRS
Revel et al., 1994 (RCT)	4	60 (30/30)	48(14) (25-80)† I: 47‡ (25-74)† C: 46.5‡ (25-80)† Sex: males (15%) and females (85%)	8	Cervical proprioceptive training	No treatment	60-80	Drug intake (NSAID, AD), HRA, ROM, self-assessed functional improvement, VAS
Rudolfsson et al., 2014 (RCT)	6	70 (35/35)	I: 50.7(8.6) C: 51.6(9.0) Sex: females	11	Neck coordination exercise with a custom-made training device	Strength training for neck and shoulders	60	Postural sway, precision of goal directed arm movements
Rudolfsson et al., 2014 (RCT)	6	66 (35/31)	I: 50.7(8.6) C: 51.2(9.0) Sex: females	11	Neck coordination exercise with a custom-made training device	Massage	60	Fast axial cervical rotations, NRS, postural sway, precision of goal directed arm movements, ROM
Sarig Bahat et al., 2018 (RCT)	7	60 (30/30)	I: 48‡ (35.5, 59)§ C: 48‡ (35, 59)§ Sex: males (26.7%) and females (73.3%)	4	Kinematic training using a laser pointer	No treatment	80	Cervical motion kinematics, EQ-5D, GPE, NDI, ROM, TSK, VAS
Sarig Bahat et al., 2018 (RCT)	7	60 (30/30)	I: 48‡ (38.5, 57.5)§ C: 48‡ (35, 59)§ Sex: males (30.0%) and females (70.0%)	4	Kinematic training using virtual reality	No treatment	80	Cervical motion kinematics, EQ-5D, GPE, NDI, ROM, TSK, VAS
Tejera et al., 2020 (RCT)	7	44 (22/22)	29.7(10.81) I: 32.72(11.63) C: 26.68(9.21) Sex: males (47.7%) and females (52.3%)	4	Virtual reality-based neck-specific training	Neck-specific exercises	NR (2 sessions/ week)	CPM, FABQ, NDI, PASS-20, PCS, PPT, ROM, TS, TSK, VAS

Note. AD: analgesic drugs; C: comparator group; CCFT: Craniocervical flexion test; CPM: Conditioned Pain Modulation; EQ-5D: EuroQoL 5-Dimension Questionnaire; FABQ: The fear-avoidance beliefs questionnaire; GPE: Global perceived effect; HRA: head repositioning accuracy; I: intervention group; JPE: joint position error; NDI: Neck Disability Index (subjective functional limitations related to neck pain disorders); NR: not reported; NRS: numerical rating scale; NSAID: nonsteroidal anti-inflammatory drugs; PASS-20: Pain Anxiety Symptoms Scale; PCS: Pain Catastrophizing Scale; PPT: pressure pain thresholds; RCT: randomized controlled trial; ROM: Active Cervical Range of Motion; TS: Temporal Summation; TSK: Tampa Scale of Kinesiophobia; VAS: visual analog scale (pain intensity). *Values are presented as mean(SD) unless otherwise indicated. † Age range (min-max). ‡ Median age. § Interquartile range of age (Q1, Q1).

Table 2. PEDro scores of included studies

Study	Eligibility criteria	Random allocation	Concealed allocation	Baseline comparability	Blind subjects	Blind therapist	Blind assessors	Adequate follow-up	Intention-to-treat analysis	Between-group comparisons	Point estimates and variability	Total score (0 to 10)
Gallego Izquierdo et al. (2016)	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Humphreys & Irgens (2002)	Y	Y	N	Y	N	N	N	Y	N	Y	Y	5
Jull et al. (2007)	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Revel et al. (1994)	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Rudolfsson et al. (2014)	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Sarig Bahat et al. (2018)	Y	Y	Y	Y	N	N	Y	N	Y	Y	Y	7
Tejera et al. (2020)	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	7

Note. N: no; PEDro: Physiotherapy Evidence Database; Y: yes.

Table 3. Summary of certainty of evidence using the GRADE approach

Outcome	Number of participants and studies	Risk of Bias*	Inconsistency†	Imprecision‡	Indirectness§	Publication Bias¶	Certainty of evidence - GRADE
Comparison: Cervical sensorimotor control training vs. no treatment							
Short-term follow-up							
Cervicocephalic kinesthetic awareness	164 participants 3 studies (4 intervention comparisons)	Serious limitations, downgraded by one level.	No serious inconsistency.	Serious limitations, downgraded by one level.	No serious indirectness.	No serious publication bias.	++00 LOW
Pain intensity	164 participants 3 studies (4 intervention comparisons)	Serious limitations, downgraded by one level.	No serious inconsistency.	Serious limitations, downgraded by one level.	No serious indirectness.	No serious publication bias.	++00 LOW
Subjective functional limitations	76 participants 1 study (2 intervention comparisons)	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	No serious indirectness.	No serious publication bias.	+++0 MODERATE
Cervical range of motion	136 participants 2 studies (3 intervention comparisons)	Serious limitations, downgraded by one level.	No serious inconsistency.	Serious limitations, downgraded by one level.	No serious indirectness.	No serious publication bias.	++00 LOW
Quality of life	76 participants 1 study (2 intervention comparisons)	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	No serious indirectness.	No serious publication bias.	+++0 MODERATE
Kinesiophobia	76 participants 1 study (2 intervention comparisons)	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	No serious indirectness.	No serious publication bias.	+++0 MODERATE
Comparison: Cervical sensorimotor control training vs. other conservative or non-conservative treatments							
Short-term follow-up							
Cervicocephalic kinesthetic awareness	58 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Postural balance	86 participants 1 study (2 intervention comparisons)	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Pain intensity	130 participants 3 studies	No serious risk of bias.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	+000 VERY LOW
Subjective functional limitations	130 participants 3 studies	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Cervical range of motion	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Craniocervical flexion test	28 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Kinesiophobia	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
1-month follow-up							
Pain intensity	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW

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Table 3. Summary of certainty of evidence using the GRADE approach

Outcome	Number of participants and studies	Risk of Bias*	Inconsistency†	Imprecision‡	Indirectness§	Publication Bias¶	Certainty of evidence - GRADE
Subjective functional limitations	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Cervical range of motion	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Kinesiophobia	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Intermediate-term follow-up							
Pain intensity	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Subjective functional limitations	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Cervical range of motion	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Kinesiophobia	44 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Long-term follow-up							
Postural balance	84 participants 1 study (2 intervention comparisons)	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Pain intensity	57 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW
Cervical range of motion	57 participants 1 study	No serious risk of bias.	No serious inconsistency.	Serious limitations, downgraded by one level.	Serious limitations, downgraded by one level.	No serious publication bias.	++00 LOW

Note. GRADE: Grading of Recommendations Assessment, Development and Evaluation. ++++ (high): We have a lot of confidence that the true effect is similar to the estimated effect. +++0 (moderate): We believe that the true effect is probably close to the estimated effect. ++00 (low): We believe that the true effect might be markedly different from the estimated effect. +000 (very low): We believe that the true effect is probably markedly different from the estimated effect. *Serious limitations were identified if more than 25% of studies were classified as being of less than good quality with a PEDro score < 6. † Serious limitations were identified in case of statistically significant heterogeneity test, I2 ≥ 50%, or if the direction of the study results was different in the majority (≥75%) of studies. ‡ Serious limitations were identified if sample size was smaller than 400, in case of wide confidence intervals (CIs) when data were presented as standardized mean difference, or if comparisons included only a single study. § Serious limitations were identified if the population, interventions and outcomes in the studies were not representative of those defined in the inclusion criteria of the review. ¶ Serious limitations were identified if the presented study results differed from the original protocol or study objectives.

Risk of bias and certainty of evidence

The results of risk of bias assessment using the PEDro scale are presented in Table 2. PEDro scores ranged from 4 to 8 and the mean PEDro score was 6.1 (SD 1.4). None of the studies met the blind subjects and therapist criteria and most did not meet the concealed allocation and intention-to-treat analysis criteria (Humphreys & Irgens, 2002; Jull et al., 2007; Revel et al., 1994; Rudolfsson et al., 2014).

The summary of certainty of evidence using the GRADE approach is presented in Table 3 and shows that the certainty of evidence (GRADE) for individual outcomes ranged from very low to moderate.

Effect of cervical sensorimotor control training versus no treatment

The results of three trials involving four interventions (n = 164; low certainty of evidence due to high risk of bias and imprecision) showed significant effectiveness of cervical sensorimotor control training for improving cervicocephalic

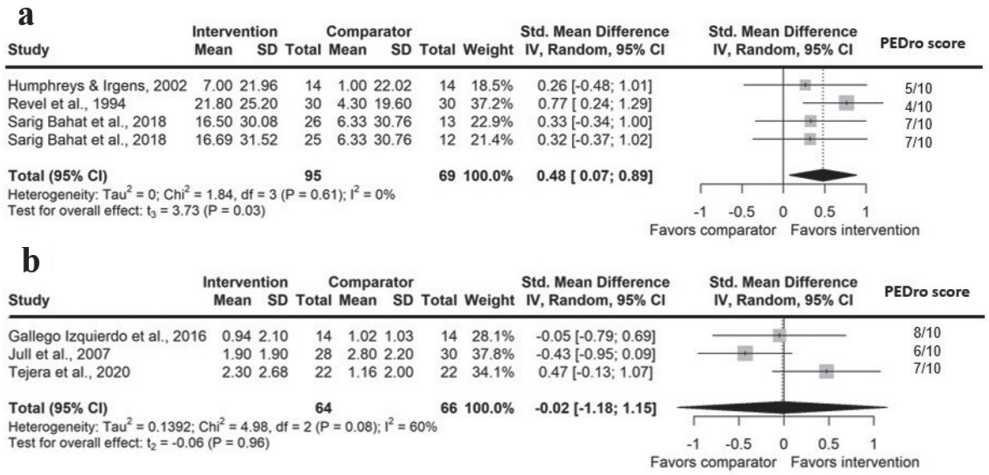

Figure 2. Forest plots for the effect of cervical sensorimotor control training versus (a) no treatment (3 trials, n = 164) (Humphreys & Irgens, 2002; Revel et al., 1994; Sarig Bahat et al., 2018) or (b) other conservative or non-conservative treatments (3 trials, n = 130) (Gallego Izquierdo et al., 2016; Jull et al., 2007; Tejera et al., 2020) on pain intensity at short-term follow-up

kinesthetic awareness at short-term follow-up compared with no treatment (Humphreys & Irgens, 2002; Revel et al., 1994; Sarig Bahat et al., 2018), which was associated with greater improvement in head repositioning accuracy, measured with a laser pointer ($p<0.05$) (Humphreys & Irgens, 2002; Revel et al., 1994), and various cervical motion kinematics measured with a customized neck virtual reality system ($p<0.05$) (Sarig Bahat et al., 2018). In addition, the above-mentioned three trials with four interventions also compared the short-term effects of cervical sensorimotor control training and no treatment on pain intensity (Humphreys & Irgens, 2002; Revel et al., 1994; Sarig Bahat et al., 2018). The pooled SMD was 0.48 (95% CI: 0.07 to 0.89; p = 0.03; n = 164; I2 = 0%; low certainty of evidence due to high risk of bias and imprecision) (Figure 2a), indicating a medium effect in favor of cervical sensorimotor control training on reducing pain intensity at short-term follow-up compared to no treatment.

With respect to the secondary outcomes, based on pooled results from a single 3-arm trial involving 76 subjects, there is moderate certainty of evidence (due to imprecision) for no additional benefit of cervical sensorimotor control training compared with no treatment in reducing subjective functional limitations at short-term follow-up (SMD = 0.32; 95% CI: -0.90 to 1.53; p = 0.19; I2 = 0%) (Figure 3a) (Sarig Bahat et al., 2018). Furthermore, the short-term effects of cervical sensorimotor control training on improving cervical ROM were compared with no treatment in two trials (n = 136; low certainty of evidence due to high risk of bias and imprecision) (Revel et al., 1994; Sarig Bahat et al., 2018). In the first trial, the intervention group demonstrated greater improvement in cervical ROM (measured with a linear measure) from right to left rotation (p = 0.007), but not from flexion to extension (Revel et al., 1994), while in the second trial (3-arm trial), no differences were found between groups in cervical ROM improvement (measured with a customized neck virtual reality system) (Sarig Bahat et al., 2018). According to the results of the aforementioned 3-arm trial, there is moderate certainty of evidence (n = 76; limitations in imprecision) that there is no difference in the short-term effects of cervical sensorimotor control training on quality of life (assessed by EuroQoL 5-Dimension Questionnaire) and kinesiophobia (assessed by Tampa Scale of Kinesiophobia (TSK)) compared to no treatment (Sarig Bahat et al., 2018).

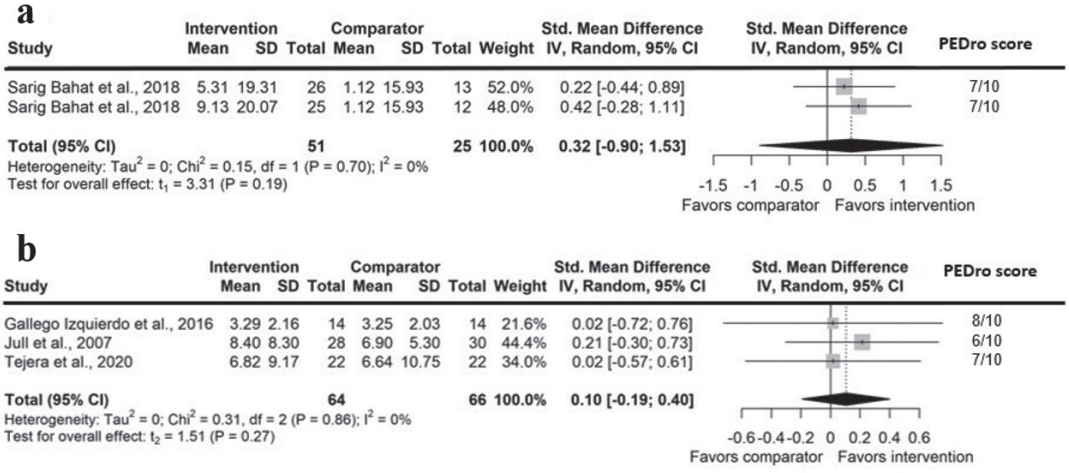

Figure 3. Forest plots for the effect of cervical sensorimotor control training versus (a) no treatment (1 3-arm trial, n = 76) (Sarig Bahat et al., 2018) or (b) other conservative or non-conservative treatments (3 trials, n = 130) (Gallego Izquierdo et al., 2016; Jull et al., 2007; Tejera et al., 2020) on subjective functional limitations at short-term follow-up

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Effect of cervical sensorimotor control training versus other conservative or non-conservative treatments

Regarding the primary outcomes, a single trial (n = 58; low certainty of evidence due to imprecision and indirectness) comparing the short-term effects of cervical sensorimotor control training and craniocervical flexion training on cervicocephalic kinesthetic awareness (by measuring cervical joint position error (JPE) with a 3-Space Fastrak device) reported greater improvement in the former group, which was related to greater reduction in JPE from right rotation ($p<0.05$), but there were no differences in reduction in JPE from left rotation and extension between the two groups (Jull et al., 2007). Furthermore, a 3-arm trial reported no differences in the short- and long-term effects of cervical sensorimotor control training on improving postural balance (measured with a force platform) compared with strength training for the neck and shoulders or massage (short-term follow-up: n = 86, long-term follow-up: n = 84; low certainty of evidence due to imprecision and indirectness) (Rudolfsson et al., 2014). Three trials involving 130 subjects examined the short-term effects of cervical sensorimotor control training on pain intensity in comparison with other conservative or non-conservative treatments (Gallego Izquierdo et al., 2016; Jull et al., 2007; Tejera et al., 2020). At short-term follow-up, cervical sensorimotor control training was no better than other conservative or non-conservative treatments in reducing pain (SMD = -0.02; 95% CI: -1.18 to 1.15; p = 0.96; I2 = 60%; very low certainty of evidence due to inconsistency, imprecision and indirectness) (Figure 2b). Furthermore, no between-group differences were reported in reduction of pain intensity at 1-month and intermediate-term follow-up (1 trial; n = 44; low certainty due to imprecision and indirectness) (Tejera et al., 2020), as well as in reduction of pain intensity at long-term follow-up (1 trial; n = 57; low certainty due to imprecision and indirectness) (Rudolfsson et al., 2014).

The short-term effects of cervical sensorimotor control training on subjective functional limitations compared with other conservative or non-conservative treatments were examined in three trials involving 130 subjects (Gallego Izquierdo et al., 2016; Jull et al., 2007; Tejera et al., 2020). As shown in Figure 3b, the overall effect was non-significant, indicating that cervical sensorimotor control training was no better than other conservative or non-conservative treatments in reducing subjective functional limitations in the short term (SMD = 0.10; 95% CI: -0.19 to 0.40; p = 0.27; I2 = 0%; low certainty of evidence due to imprecision and indirectness). Furthermore, a single trial (n = 44; low certainty due to imprecision and indirectness) reported significant between-group differences ($p<0.05$) in reduction of kinesiophobia (assessed by TSK) at intermediate-term follow-up in favor of cervical sensorimotor control training when compared with neck-specific exercises (Tejera et al., 2020). However, the aforementioned trial also found no differences between groups in the effects on subjective functional limitations at 1-month and intermediate-term follow-up, on cervical ROM (measured with the cervical range of motion (CROM) device) at short-term, 1-month and intermediate-term follow-up, and on kinesiophobia at short-term and 1-month follow-up (Tejera et al., 2020). In addition, cervical sensorimotor control training was found to be no better than craniocervical flexion training in improving performance in CCFT at short-term follow-up, based on low certainty of evidence (1 trial; n = 28; limitations in imprecision and indirectness) (Gallego Izquierdo et al., 2016), nor in improving cervical ROM at long-term follow-up when compared with massage, as reported in a 3-arm trial (n = 57; low certainty of evidence due to imprecision and indirectness) (Rudolfsson et al., 2014).

Discussion

This systematic review and meta-analysis aimed to investigate the effectiveness of cervical sensorimotor control training for the management of chronic NP disorders by evaluating its effects on various subjective and objective outcome measures. The review found low-certainty evidence that cervical sensorimotor control training was superior to no treatment for improving cervicocephalic kinesthetic awareness and reducing pain intensity at short-term follow-up. However, the only study that showed a significant effect on pain and significantly influenced the pooled effect showed high risk of bias (Revel et al., 1994), which may lead to an overestimation of the actual intervention effect. Furthermore, according to low-to-moderate certainty of evidence, there were no between-group differences at short-term follow-up in improving subjective functional limitations, ROM, quality of life and kinesiophobia. When cervical sensorimotor control training was compared to other conservative or non-conservative treatments, no differences were found between groups in improving pain and ROM at any follow-up (very low-to-low certainty of evidence), subjective functional limitations at short-term, 1-month and intermediate-term follow-up (low-certainty evidence), performance on the CCFT at short-term follow-up (low-certainty evidence), postural balance at short- and long-term follow-up (low-certainty evidence), and kinesiophobia at short-term and 1-month follow-up (low-certainty evidence). There is low-certainty evidence that cervical sensorimotor control training was better than other conservative or non-conservative treatments for reducing kinesiophobia at intermediate-term follow-up, as well as cervicocephalic kinesthetic awareness at short-term follow-up, however this was demonstrated only for one out of three head-to-neutral movement directions.

While the presented results are based on a smaller number of studies, our review fills an important gap in the literature by providing a comprehensive overview of the available evidence concerning the effectiveness of cervical sensorimotor control training for chronic NP disorders by examining the effects on several objective and subjective outcomes. In contrast, previous systematic reviews and meta-analyses have predominantly focused on specific training modalities aimed at improving only one aspect of cervical sensorimotor control (i.e., eye-head coordination exercises, head relocation practice and/or gaze stability or eye-follow exercises (Gross et al., 2015; McCaskey et al., 2014; Petersen et al., 2013), and neck-specific training using virtual reality (Ahern et al., 2020; Grassini, 2022)). As a consequence, the focus of these reviews was limited and included a narrower range of interventions. The findings of the present review question the effectiveness of cervical sensorimotor control training as a standalone rehabilitation program for chronic NP disorders, particularly when compared with other conservative or non-conservative treatments. However, such training might demonstrate greater effects as part of a multimodal treatment, as many recent studies have shown positive results from interventions combining cervical sensorimotor control training with other types of rehabilitation approaches (Cetin et al., 2022; Espí-López et al., 2021; Nusser et al., 2021; Pérez-Cabezas et al., 2020; Reddy et al., 2021; Saadat et al., 2019; Sremakaew et al., 2023).

Cervical sensorimotor control exercises are thought to improve position and movement sense of the cervical spine and

improve neural connections between the neck, eyes and vestibular system (Bolton, 1998; Gallego Izquierdo et al., 2016; Jull et al., 2007; Qu et al., 2022; Sarig Bahat et al., 2015). The reduction in perceived neck pain when training precise head and neck movements with these exercises could be due to improved fine control of head and neck movements in response to surrounding stimuli (Gallego Izquierdo et al., 2016; Nusser et al., 2021; Qu et al., 2022; Sarig Bahat et al., 2015, 2018), which may lead to better pain control (Revel et al., 1994). This notion has been supported by a recent article in which experimentally induced neck pain in healthy subjects resulted in increased cervical JPE when moving from flexion to the neutral position (Wang et al., 2022). These results demonstrate that the presence of pain is associated with altered cervicocephalic kinesthetic awareness, implying that an improvement in the latter could conversely have an influence on neck pain. In addition to the improved ability to move the head further and more precisely (Sarig Bahat et al., 2015, 2018), specific exercises for sensorimotor control of the cervical spine (i.e., cervical proprioceptive training) have also shown effects on other aspects of neuromuscular function, specifically the coordination between the deep and superficial cervical flexors, as measured by performing CCFT (Gallego Izquierdo et al., 2016), which could lead to a reduction in neck pain due to more efficient muscle recruitment patterns and support of the cervical segments (Jull et al., 2007; Mayoux-Benhamou et al., 1994). Moreover, eye-head coordination exercises could have an effect on the activation of the suboccipital muscles (Bexander & Hodges, 2023), which, like the deep cervical flexors, have a high density of muscle spindles (Boyd-Clark et al., 2002; Liu et al., 2003), further indicating the effect of such training on neuromuscular coordination of the deep cervical muscles.

Although the results of this review showed that cervical sensorimotor control training was not superior in terms of its effects on most outcomes, significant improvements in cervicocephalic kinesthetic awareness were demonstrated. Moreover, the same three studies with four intervention comparisons that reported significant effects of cervical sensorimotor control training for improving cervicocephalic kinesthetic awareness in the short term compared with no treatment also demonstrated a significant overall effect on pain reduction at short-term follow-up in favor of cervical sensorimotor training in the meta-analysis (Humphreys & Irgens, 2002; Revel et al., 1994; Sarig Bahat et al., 2018). In view of the above, exercises aimed at enhancing cervical sensorimotor control could be considered an important element in the rehabilitation of patients with chronic NP disorders. Nevertheless, as findings of this review are based on a small number of studies, it is not possible to draw conclusions about the effectiveness of cervical sensorimotor control training for the management of chronic NP disorders based on the currently available evidence. Therefore, further studies of high quality are needed in this research area, that would focus not only on the assessment of subjective but also on objective outcome measures (e.g., neck mobility and motor control), which are equally important for clinical evaluation.

Limitations

The findings of our review are based on very low-to-moderate certainty of evidence and should be considered with caution. Given the small number of included studies and the associated small sample sizes, imprecision was the most common reason for downgrading the certainty of evidence. Indirectness was also a common limitation due to nonrepresentative populations in certain studies that included only one sex (i.e., women) (Jull et al., 2007; Rudolfsson et al., 2014) or included only participants with chronic non-specific NP thereby excluding chronic NP of traumatic origin (Gallego Izquierdo et al., 2016; Rudolfsson et al., 2014; Tejera et al., 2020). In addition, 2 of the 7 included studies presented with high risk of bias, which further limited the evidence regarding the effects on specific outcomes (Humphreys & Irgens, 2002; Revel et al., 1994). Furthermore, the pooled results were presented with wide 95% CIs, which is related to the small number of studies and, in one case, to substantial heterogeneity between studies. The latter may be due to variability in the outcome measures, as 1 study used NRS (Jull et al., 2007), while the other 2 studies used VAS to measure pain intensity (Gallego Izquierdo et al., 2016; Tejera et al., 2020). Lastly, due to the lack of available data, variability in the outcome measurements and lack of longer-term follow-ups we were unable to synthesize the evidence regarding the effects on the objective and certain subjective outcomes, which, in addition to pain and subjective functional limitations, are also important health-related outcomes in clinical practice.

Conclusions

There is low-certainty evidence that cervical sensorimotor control training is more effective for improving cervicocephalic kinesthetic awareness and reducing pain in the short term compared to no treatment, and for reducing kinesiophobia in the intermediate term compared to other conservative or non-conservative treatments. However, based on the available evidence, no conclusions can be drawn about the effectiveness of cervical sensorimotor control training for the management of chronic NP disorders as a stand-alone rehabilitation program. Although the aim of our systematic review and meta-analysis was to investigate solely the effectiveness of cervical sensorimotor control training to investigate the causality by isolating the effect of a specific rehabilitation approach, clinical practice guidelines support multimodal treatment approaches. Therefore, more concise evidence should be gathered in the future to investigate the effectiveness of combined treatment approaches including also cervical sensorimotor control exercises.

Conflict of interest

The authors declare no conflict of interest.

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Data availability

Data (i.e., material used for the review, including detailed database search process, data extraction, data used for analyses, code and documentation of statistical analysis, etc.) are available from the corresponding author upon reasonable request.

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