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EXERCISE THERAPY INCLUDING THE CERVICAL EXTENSOR MUSCLES IN INDIVIDUALS WITH NECK PAIN: A SYSTEMATIC REVIEW

David Colman[1] , Christophe Demoulin[1,2], Marc Vanderthommen[1], Olivier Saive[1], Nancy Durieux[3], Barbara Cagnie[4], Jean-François Kaux[1,2], and Stéphanie Grosdent[1,2]

[1]*Department of Sport and Rehabilitation Sciences, University of Liège, Liège, Belgium*
[2]*Physical and Rehabilitation Medicine, University Hospital of Liège, University of Liège, Liège, Belgium*
[3]*Research Unit for a Life-Course Perspective on Health & Education—RUCHE, Faculty of Psychology, Speech and Language Therapy and Educational Sciences, University of Liège, Liège, Belgium*
[4]*Department of Rehabilitation Sciences, University of Gent, Gent, Belgium*

Keywords: Neck pain, rehabilitation interventions, exercise therapy, cervical extensor muscles

Abstract

Objective: To review the use (dosage parameters and combination with other therapeutic interventions) of cervical extensor muscle exercises and their effect on pain, disability (primary outcomes), range of motion, endurance and strength (secondary outcomes) in people with neck pain.

Data sources: An extensive literature search was conducted through MEDLINE (Ovid), Scopus (Elsevier) and Physiotherapy Evidence Database (PEDro) up to May 2023. The reference lists of all included studies and relevant reviews were screened for additional studies.

Review methods: Randomised controlled trials reporting the use of cervical extensor muscle exercises (alone or combined) applied to adults with idiopathic or traumatic neck pain were included. Study selection, data extraction and critical appraisal (PEDro assessment scale) were performed by two blinded reviewers. Data extraction included dosage parameters, other modalities combined with these exercises and outcomes.

Results: Thirty-five randomised controlled trails (eight of which were complementary analyses) with 2409 participants fulfilled the inclusion criteria. Twenty-six were of moderate to high quality. In most studies, cervical extensor muscle exercises were combined with various other therapeutic modalities and applied at different dosages. Only two studies (one high and one low quality) specifically assessed their effectiveness. The high-quality study showed significant improvements in neck pain and disability, pressure point threshold and neck mobility after both low load and high load training for 6 weeks.

Conclusion: The results suggest cervical extensor muscle exercises may reduce neck pain and disability; however firm conclusions cannot be drawn because of the few studies that addressed this question and the heterogeneity of the dosage parameters.

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Introduction

Neck pain is one of the most common musculoskeletal conditions worldwide. It is associated with a high socio-economic burden in terms of diagnosis, management and work disability.[1–3] In 2015, low back pain and neck pain were ranked as the fourth leading causes of disability-adjusted life years globally, just after ischaemic heart disease, cerebrovascular disease and lower respiratory tract infection.[4] The high recurrence rate of neck pain[2,5] could result from motor and proprioceptive[6] impairments that are induced by the pain episode and are not automatically restored.[7]

Altered activity of the cervical flexor muscles is well known to be associated with neck-related disability.[8] Recently, several studies found that the cervical extensor muscles could also be impaired in people with neck pain. The changes reported include delayed onset[9,10] and offset time,[11] higher levels of antagonist muscle activity,[12] altered directional specificity of muscle activity,[13] reduced spatial redistribution of muscle activity[14] and changes in inter-muscular recruitment.[13] Although changes in muscle activity depend on the individual,[15] the activity of the deepest cervical extensor muscles (semispinalis cervicis and multifidus) is commonly reduced, whereas more superficial extensor muscles, such as the splenius capitis, tend to become overactive.[16,17] These muscle activity changes are sometimes associated with a decrease in strength[18,19] or endurance[20] of the cervical extensor muscles and can result in morphological changes, such as alterations in cross-sectional area[21] and fatty infiltration,[22–25] especially in individuals with chronic whiplash-associated disorders.

Exercise therapy has been considered as a useful tool for neck pain rehabilitation for many years now,[26–29] and it is indicated as a crucial component of the treatment of subacute and chronic neck pain in clinical practice guidelines.[30] Guidelines currently recommend an individualised and progressive programme of cervico-thoracic exercises targeting the different neck muscles, as well as the scapula-thoracic and shoulder muscles.[31] Following some reports that low load exercises that specifically target cervical extensor muscle impairments effectively reduce these impairments,[32,33] specific exercises for the deep cervical extensor muscles[34,35] and global exercises for the cervical extensor muscles have been developed and progressively integrated into neck pain rehabilitation programmes. Nevertheless, a recent Delphi study concluded that guidance on optimal exercise or dosage variables is lacking.[36] To our knowledge, the content and effectiveness of rehabilitation programmes that include cervical extensor muscle exercises have not been systematically reviewed.

The aim of this study was to review the use (dosage parameters and their combination with other therapeutic interventions) of cervical extensor muscle exercises and their effect on pain and disability (primary outcomes), and range of motion, endurance and strength (secondary outcomes) in people with neck pain.

Methods

This review was conducted according to a registered protocol (PROSPERO: CRD42020153242) that was updated in August 2022 and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines.[37]

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Studies were included if (a) the groups of interest were composed of adults (i.e. at least 18 years old) with non-specific neck pain or whiplash-associated disorders, (b) the experimental group performed at least one active cervical extensor muscle exercise for at least 60 s, (c) at least one of the following outcomes was measured: pain intensity, disability, cervical range of motion, endurance and/or strength of the neck extensor muscles, (d) the study was a randomised controlled trial and (e) the article was written in English or French.

An extensive literature search was conducted through MEDLINE (Ovid), Scopus (Elsevier) and Physiotherapy Evidence Database (PEDro) up to 23 May 2023. The search strategies used for MEDLINE and Scopus were developed in collaboration with an expert in systematic reviews, using a combination of MeSH terms and free terms, which are listed in Appendix 1. The PEDro database was searched by combining the keyword 'neck extensor' with the following filters: 'head or neck' and 'clinical trial'. In addition, the reference lists of all included studies and of all relevant reviews were screened for additional studies.

Following the search, all identified citations were collated and uploaded into Microsoft Excel and duplicates were removed. Then, titles and abstracts were screened by two independent reviewers (DC and SG) who determined if they fulfilled the inclusion criteria for the review. The full texts of potentially eligible studies were retrieved and screened by the same two reviewers. Full text studies that did not meet the inclusion criteria were excluded (Appendix 2). Any disagreements that arose between the reviewers were resolved through discussion or with a third reviewer (CD).

Data extraction was performed by DC and SG. The data extracted included specific details about the participants, intervention descriptions, follow-up duration and outcomes of significance to the review objective. Any disagreements that arose between the reviewers were resolved through discussion or with the same third reviewer. If required, the authors of the articles included were contacted to request missing or additional data.

Selected articles were critically appraised by two independent reviewers (DC and SG) for methodological quality using the PEDro scale (http://www.pedro.fhs.usyd.edu.au). Any disagreement or ambiguous issues were resolved through discussion between DC and SG or with a third reviewer (CD).

The PEDro scale is a multi-item scale that consists of 11 items that address various aspects of the study methodology. A PEDro score from 0 to 10 is obtained by summing the item scores (item 1 is not scored); therefore higher scores indicate greater methodological quality. The scale is valid and sufficiently reliable for the assessment of methodological quality of randomised controlled trials.[38,39] Trials were considered high quality if they scored 6 or higher on the PEDro scale.[40]

Data and the results of the selected studies were collected and analysed according to the review aim. We reported details of cervical extensor muscle exercise dosage parameters (such as duration, intensity, progression, specificity and level of supervision) and the association of other modalities (e.g. manual therapy and cognitive approaches). Regarding exercise intensity, we considered 'low load' exercises as those that aimed to increase control, activity and coordination of specific (mostly deep) muscles and to reduce the imbalance between deep and superficial muscles using submaximal (<50% maximal voluntary contraction) and painless contractions. We considered 'high load' as any exercises

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that recruited most of the synergist muscles (deep and superficial) with the aim to increase strength and/or endurance and that involved submaximal to maximal contractions (>50% maximal voluntary contraction). Cervical extensor muscle exercises were considered as being 'progressive' when methods (i.e. duration, resistance or repetitions) were used to increase the load of the exercises during the rehabilitation programme.

For clarity, we classified the studies into five arbitrary categories, according to whether the cervical extensor muscle exercises were the only therapeutic intervention, if they were combined with other neck or shoulder girdle muscle exercises or if they were supplemented or not with any passive interventions. The primary outcomes investigated in this review were neck disability and neck pain intensity at different time points; other outcomes such as muscle activity, cervical range of motion, cervical extensor muscle endurance, strength or activity were also sought and reported. For each outcome, we reported the baseline, short- and long-term follow-up values for each intervention group. We also reported within-group and between-group differences at each time point. Where appropriate, the results are presented in tables.

Results

Figure 1 represents the study flow diagram. The electronic database search yielded 3419 citations (1102 from MEDLINE, 2301 from Scopus and 16 from PEDro), and 28 were found through other resources, leading to a total of 3447 references. After removing duplicate records (*n* = 906), and screening titles and abstracts, 89 articles remained. Of these, 35 fulfilled the inclusion criteria, including 27 randomised controlled trials and eight reports about follow-up or complementary analyses of these 27 randomised controlled trials. The list of the 54 excluded studies and reasons for exclusion can be found in Appendix 2.

Figure 1. PRISMA flow diagram showing the study selection process.

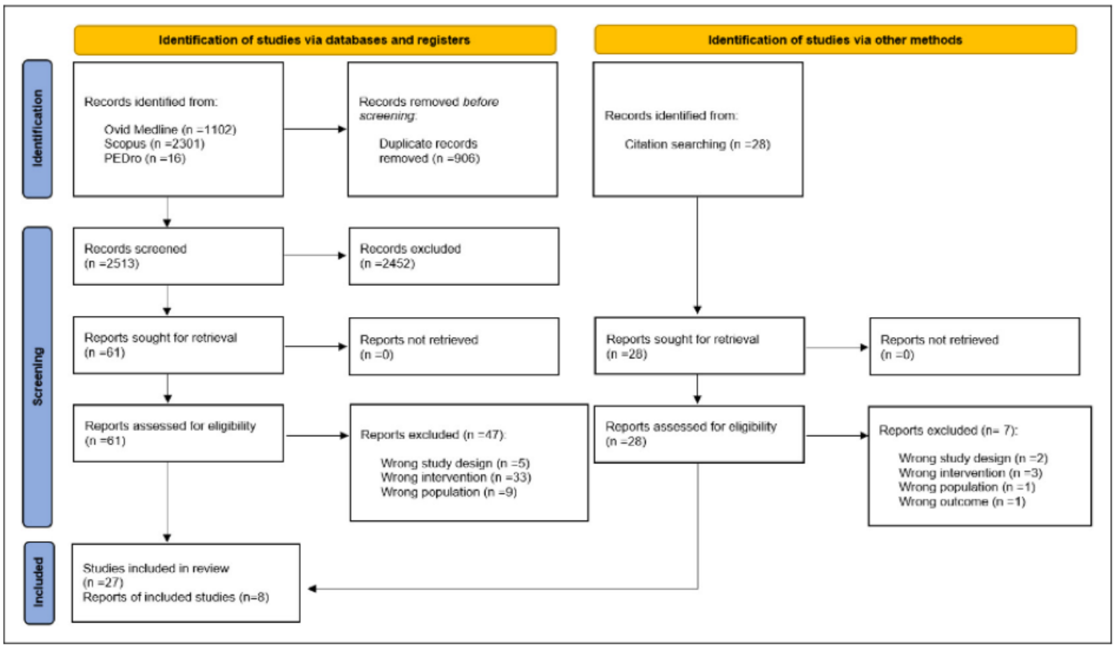

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Table 1. Modalities of cervical extensor muscle exercises.

Study (author, year)	PEDro score (/10)	CEM exercise characteristics (intensity/progression)	Rx duration (weeks)	Number of supervised sessions (*n*)	Session duration (min)	TRT (hour)	Home exercises (frequency/ duration)
Cervical extensor muscle exercises only (CEM—O)							
Suvarnnato et al., 2019	5	LL	6	12	10	2	3×/day 6 weeks
Gimenez-Costa et al., 2022	8	LL	6	6	20–25	2–2.5	2×/day 6 weeks
		HL	6	6	20–25	2–2.5	
Cervical extensor muscle exercises combined with other neck exercises (CEM—N)							
Borisut et al., 2013	5	Progressive LL → HL	12 (LL: 4; HL: 8)	0	0	0	1×/day 12 weeks
Hingarajia et al., 2012	6	Unclear description but progressive	4	8	30	4	2×/day 4 weeks
Li et al., 2017	6	LL → HL	6 (LL: 4; HL: 2)	6	NR	NR	N
		HL	6				
Bernal-Utrera et al., 2020 and 2022 [Group 1]	7	LL	3	3	20–30	1–1.5	1×/day 3 weeks
Chung and Jeong, 2018	7	Progressive HL	8	24	30	12	N
Khan et al., 2014	7	LL	12	3	NR	NR	2×/day 5 day /weeks 12 weeks
		HL	12	3	NR	NR	
Falla et al., 2013	8	LL → HL	8 (LL: 6; HL: 2)	8	30	4	2×/day 8 weeks
Landén Ludvigsson et al., 2015 and 2016[2], 2018[3], 2020[4] and Peterson et al., 2015 [Group 1]	8,7 [2–4]	LL → HL	12 (LL: 3, HL: 9)	24	NR	NR	2–3×/day (3 weeks) then 1×/week (9 weeks)
Rodriguez-Sanz et al., 2021 [Group 1]	8	LL → HL	4 (LL : 2; HL: 2)	4	20	1.3	2–5×/day 4 weeks

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Table 1. (Continued)

Study (author, year)	PEDro score (/10)	CEM exercise characteristics (intensity/progression)	Rx duration (weeks)	Number of supervised sessions (*n*)	Session duration (min)	TRT (hour)	Home exercises (frequency/ duration)
Cervical extensor muscle exercises combined with other neck and shoulder exercises (CEM—A)							
Mehri et al., 2020	5	LL → HL	8 (LL: 4; HL: 4)	24	30–60	12–24	N
Ask et al., 2009	7	LL Progressive HL	6	6 to 10	30	3–5	1×/day 6 weeks
Cervical extensor muscle exercises combined with other neck muscle exercises and passive interventions (CEM—N/P)							
Bobos et al., 2016	5	Progressive HL	7	14	30–40	7–9	2×/week 7 weeks
Chiu et al., 2005 and 2005[2]	7,6[2]	Progressive LL	6	12	NR	NR	N
Rodriguez-Sanz et al., 2021 [Group 2]	8	LL → HL	4	4	20	1.3	2–5×/day 4 weeks
Cervical extensor muscle exercises combined with other active and passive interventions (CEM—A/P)							
Cetin et al., 2022	5	LL → HL	6	18	40	12	N
Jordan et al., 1998	5	LL	6	12	60	12	Unclear
Kim and Kwag, 2016	5	Unclear description	4	12	NR	NR	N
Ris et al., 2016	6	Unclear description	16	12	30–90	10	2×/day 16 weeks
Willaert et al., 2020	6	LL → functional HL Progressive HL	12	18	30–60	9.5	N
Jull et al., 2007	7	LL	10	10 to 15	30	5–7.5	2×/day 10 weeks
Lytras et al., 2023	7	LL → HL	10	40	60	40	N
Ylinen et al., 2003, 2006[2] and 2007[3]	7,5 [2,3]	HL	2	10	45–60	7.5–10	3×/week 52 weeks
Landén Ludvigsson et al., 2015 and 2016[2], 2018[3], 2020[4] and Peterson et al., 2015 [Group 2]	8,7 [2–4]	LL → HL	12	24	NR	NR	2–3×/day (3 weeks) and then 1×/ week (9 weeks)
Lytras et al., 2020	8	LL → HL	10	40	60	40	N
Michaleff et al., 2014	8	LL → HL	12	20	60	20	

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Table 1. (Continued)

Study (author, year)	PEDro score (/10)	CEM exercise characteristics (intensity/progression)	Rx duration (weeks)	Number of supervised sessions (*n*)	Session duration (min)	TRT (hour)	Home exercises (frequency/ duration)
			(LL: 4; HL: 8)				5×/week 12 weeks
Sremakaew et al., 2022	8	LL → HL	6	12	30–60	6–12	1×/ day 6 weeks
Sterling et al., 2015	9	LL	6	10	60–90	10–15	N

Note: TRT does not include rehabilitation hours undertaken as part of additional home exercise programme. If PEDro scores for follow-up studies differed from the reference study, the follow-up study's score is shown in italic and is referenced by a superscript number.
CEM: cervical extensor muscles; Rx: treatment; min: minute; TRT: total supervised rehabilitation time per person; LL: low load cervical extensor muscle exercise; HL: high load cervical extensor muscle exercise; N: any home exercises reported; LL → HL: low load cervical extensor muscle exercises progressed towards high load cervical extensor muscle exercises; NR: not reported.

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Table 2. Effectiveness on primary outcomes.

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
Cervical extensor muscle exercises only (CEM—O)			
Suvarnnato et al., 2019 (5/10)	54 adults with CNP 'CEM—O' group (*n* = 18): LL exercises for SCe 'Other' group (*n* = 18): LL exercises for CFM (twice per week under supervision, twice/day self-exercise at home) Control group (*n* = 18): Usual care including general exercise, stretching, upper limb strengthening, MT, electrotherapy (10 to 12 sessions, 20 to 30 min) Intervention period: 6 weeks	1. Disability [NDI (%)] 2. Pain intensity [NPRS (0–10)] Outcome assessments: 4 assessments (baseline, 6 weeks, 10 weeks, 18 weeks)	1. SFU: CEM – O (mD −16.7) = Other (mD −12.3) > Control (mD −2.9) LFU: CEM—O (mD – 17.0) > Other (mD −10.7) > Control (mD −1.4) 2. SFU: CEM—O (mD −2.5) = Other (mD −1.8) > Control (mD −0.6) LFU: CEM—O (mD −2.0) = Other (mD −1.3) = Control (mD −0.7)
Giménez-Costa et al., 2022 (8/10)	46 women with CNP 'CEM—O1' group (*n* = 23): LL exercises for CEM and SCe 'CEM—O2' group (*n* = 23): HL exercises for CEM Intervention period: 6 weeks	1. Disability [NDI (0–50)] 2. Pain intensity [VAS (0–100)] Outcome assessments: 2 assessments (baseline, 6 weeks + NDI at 6 months)	1. SFU: CEM—O1 (mD −6.1*) = CEM – O2 (mD −4.7*) LFU: CEM—O1 (mD −4.7*) = CEM – O2 (mD −4.5*) 2. SFU: CEM—O1 (mD −20.9 mm*) = CEM – O2 (mD – 18.0 mm*)
Cervical extensor muscle exercises combined with other neck exercises (CEM—N)			
Borisut et al., 2013 (5/10)	100 women with chronic work-related neck pain 'CEM—N1' group (*n* = 25): LL progressed towards HL exercises for CEM and CFM 'CEM—N2' group (*n* = 25): LL progressed towards HL exercises for CEM and CFM, deep CFM exercises (twice per week under supervision, once/day at home) 'Other' group (*n* = 25): Deep CFM exercises (twice per week under supervision, once/day at home) Control group No intervention	1. Disability [NDI (0–50)] 2. Pain intensity [VAS (0–100)] Outcome assessments: 2 assessments (baseline, 12 weeks)	1. SFU: CEM—N1 (mD – 13.5*) = CEM-N2 (mD – 13.5*) = Other (mD – 15.6*) > Control (mD 2.3) CEM—N2 (mD −13.5*) = Other (mD −15.6*) > Control (mD 2.3) 2. SFU: CEM—N1 (mD – 16.3 mm*) < CEM – N2 (mD −44.6 mm*) = Other (mD – 13.0 mm*) > Control (mD 2.3 mm) CEM—N2 (mD −44.6 mm*) > Other

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
	Intervention period: 12 weeks		(mD −13.0 mm*) > Control (mD 2.3 mm)
Hingarajia et al., 2012 (6/10)	50 women with CNP 'CEM—N' group (*n* = 25): Tailored and progressive exercises for CEM, CFM, LFM (unclear description of intensity) 'Other' group (*n* = 25): Progressive LL exercises for deep CFM Intervention period: 4 weeks	1. Disability [NDI (0–50)] 2. Pain intensity [VAS (0–10)] Outcome assessments: 2 assessments (baseline, 4 weeks)	1. SFU: CEM—N (mD −3.5*) = Other (mD −5.2*) 2. SFU: CEM—N (mD −2.3 cm*) = Other (mD −2.7 cm*)
Li et al., 2017 (6/10)	102 women with chronic work-related neck pain 'CEM—N1' group (*n* = 36): LL progressed towards HL exercises for CEM, CFM, LFM, booklet (ergonomic) 'CEM—N2' group (*n* = 32): HL exercises for CEM, CFM, LFM, booklet (ergonomic). Control group (*n* = 34): Information's on ergonomic, stress management, relaxation, meditation, diet, booklet (ergonomic) Intervention period: 6 weeks	1. Disability [NDI (%)] 2. Pain intensity [VAS (0–10] Outcome assessments: 4 assessments (baseline, 2 weeks, 4 weeks, 6 weeks, 3 months)	1. SFU: CEM—I (mD −12.5*) = CEM – N2 (mD −12.1*) > Control (mD −0.3) CEM—N2 (mD −12.1*) > Control (mD −0.3) LFU: CEM—N1 (mD −13.3*) = CEM – N2 (mD −13.1*) > Control (mD −1.2) CEM—N2 (mD −13.1*) > Control (mD −1.2) 2. SFU: CEM—N1 (mD −2.9*) > CEM – N2 (mD −2.4*) > Control (mD −0.3) CEM—N2 (mD −2.4*) > Control (mD −0.3) LFU: CEM—N1 (mD −3.3*) > CEM – N2 (mD −2.9*) > Control (mD −0.1) CEM—N2 (mD −2.9*) > Control (mD −0.1)
Bernal-Utrera et al., 2020 and 2022 (7/10)	69 adults with CNP 'CEM—N' group (*n* = 23): LL progressive exercises for CEM, deep CFM, LFM and rotator muscles. 'Other' (*n* = 23): MT including thoracic manipulation on T4, upper	1. Disability [NDI (%)] 2. Pain intensity [VAS (0–100)] Outcome assessments: 4 assessments (baseline, 2 weeks, 4 weeks, 12 weeks)	1. SFU: CEM—N (mD −18.1*) = Other (mD −15.5*) > Control (mD 1.8) LFU: CEM—N (mD −14.9*) = Other (mD −16.1*)

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
	cervical articular mobilization (2 Hz, 2 min X 3 series), sub-occipital muscle inhibition (3 min) (once/week) Control group (n = 23): Sham treatment including simulation of the sub-occipital muscle inhibition technique (3 min) and 10 s cervical laser therapy (laser pointer off) (once/week) Intervention period: 6 weeks		> Control (mD 0.5) 2. SFU: CEM—N (mD −30.3 mm*) = Other (mD −26.1 mm*) > Control (mD 0.8 mm) LFU: CEM—N (mD −23.7 mm*) = Other (mD −23.7 mm*) > Control (mD −1.1 mm)
Chung and Jeong, 2018 (7/10)	41 adults with CNP 'CEM—N' group (n = 19): Progressive HL exercises for CEM, CFM, LFM, postural education 'Other' group (n = 22): Progressive LL exercises for deep CFM Intervention period: 8 weeks	1. Disability [NDI (%)] 2. Pain intensity [VAS (0–10)] Outcome assessments: 3 assessments (baseline, 4 weeks, 8 weeks)	1. SFU: CEM—N (mD –5.9*) < Other (mD −8.2*) 2. SFU: CEM—N (mD −1.3 cm*) < Other (mD −2.1 cm*)
Khan et al., 2014 (7/10)	68 adults with CNP 'CEM—N1' group (n = 34): HL static exercises for CEM, CFM, LF and rotator muscles 'CEM—N2' group (n = 34): LL ROM exercises for CEM, CFM, LF and rotator muscles Intervention period: 12 weeks	1. Disability [NPQ (%)] 2. Pain intensity [VAS] Outcome assessments: 2 assessments (baseline, 12 weeks)	1. SFU: CEM—N1 (mD −9.4*) > CEM – N2 (mD −4.0*) 2. SFU: CEM—N1 (mD −2.6*) > CEM – N2 (mD – 1.7*)
Falla et al., 2013 (8/10)	46 women with CNP 'CEM—N' group (n = 23): LL exercises for CEM and deep CFM, progressed towards HL exercises Control group (n = 23): No intervention but no interdiction from seeking treatment	1. Disability [NDI (0–50) and PSFS (0–10)] 2. Pain intensity [VAS (0–10)] Outcome assessments: 2 assessments (baseline, 8 weeks)	1. SFU: CEM—N (mD NDI −4.1*) > Control (mD NDI −1.0) CEM—N (mD PSFS 1.1*) > Control (mD PSFS 0.08) 2. SFU: CEM—N (mD −1.7 cm*) > Control (mD −0.3 cm)

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
	Intervention period: 8 weeks		
Landén Ludvigsson et al., 2015, 2016[2], 2018[3], 2020[4] and Peterson et al., 2015 (8,7[2–4]/10)	216 adults with CWAD 'CEM—N' group (*n* = 76): LL progressed towards HL exercises for CEM and deep CFM, postural control. 'CEM—A/P' group (*n* = 71): LL progressed towards HL exercises for CEM and deep CFM; Behavioural interventions (pain management, relaxation, activity goal setting) Control group (*n* = 69): Individual general physical activity programme at home (for instance, aerobic exercises) based on physical examination and motivational interview (1 or 2 sessions with a physiotherapist) Intervention period: 12 weeks	1. Disability [NDI (0–50)] 2. Pain intensity [VAS (0–100)] Outcome assessments: 5 assessments (baseline, 3 months, 6 months, 12 months, 24 months)	1. SFU: CEM—N (mD −2.2*) = CEM – A/P (mD −2.7*) = Control (mD −0.3) CEM—A/P (mD −2.7*) > Control (mD −0.3) LFU: CEM—N (mD −1.8*) = CEM – A/P (mD −3.7*) = Control (mD 0.6) CEM – A/P (mD −2.7*) > Control (mD 0.6) 2. SFU: CEM—N (mD −10 mm) = CEM – A/P (mD −9 mm) = Control (mD −2 mm) CEM—A/P (mD −9 mm) = Control (mD −2 mm) LFU: CEM—N (mD −14 mm*) = CEM – A/P (mD −14 mm*) = Control (mD −10 mm) CEM—A/P (mD −14 mm*) = Control (mD −10 mm)
Rodriguez-Sanz et al., 2021 (8/10)	58 adults with CNP 'CEM—N' group (*n* = 29): LL progressed towards HL exercises for CEM and CFM 'CEM—N/P' group (*n* = 29): LL progressed towards HL exercises for CEM and CFM combined with manipulation and/or mobilization of upper cervical segments Intervention period: 4 weeks	1. Disability [NDI] 2. Pain intensity [NPRS (0–10)] Outcome assessments: 4 assessments (baseline, 4 weeks, 3 months, 6 months)	1. SFU: CEM—N < CEM – N/P LFU: CEM—N < CEM – N/P 2. SFU: CEM—N (mD −0.8) < CEM – N/P (mD −3.4*) LFU: CEM—N (mD −0.4) < CEM – N/P (mD −2.9*)
Cervical extensor muscle exercises combined with other neck and shoulder exercises (CEM—A)			
	32 women with CNP	1. Pain and disability [NPDQ (%)]	

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
Mehri et al., 2020 (5/10)	'CEM—A' group (n = 16): LL progressed towards HL exercises for CEM, CFM and SGM Control group (n = 16): Advice to stay active as usual in home and workplace, and manuscript including postural corrections Intervention period: 8 weeks	Outcome assessments: 2 assessments (baseline and 8 weeks)	1. SFU: CEM—A (mD −5.4*) > Control (mD −0.9)
Ask et al., 2009 (7/10)	25 adults with subacute WAD 'CEM—A1' group (n = 11): LL exercises for CEM, deep CFM, SGM 'CEM—A2' group (n = 14): Progressive HL exercises for CEM, CFM, LFM, SGM Intervention period: 6 weeks	1. Disability [NDI 0–50)] 2. Pain intensity [VAS (0–100)] Outcome assessments: 3 assessments (baseline, 6 weeks, 12 months)	1. SFU: CEM—A1 (MD −9*) = CEM – A2 (MD −7*) LFU: CEM—A1 (MD −4*) = CEM – A2 (MD −4*) 2. SFU: CEM—A1 (MD −35 mm*) = CEM – A2 (MD −28 mm*) LFU: CEM—A1 (MD −8.5 mm*) = CEM – A2 (MD −21.5 mm*)
Cervical extensor muscle exercises combined with other neck muscles exercises and passive interventions (CEM—N/P)			
Bobos et al., 2016 (5/10)	60 adults CNP 'CEM—N/P' group (n = 20): Home exercise programme (ROM exercises, LL multidirectional neck exercises, stretching; 30–40 min, twice/week), progressive HL exercises in all neck directions 'Other' group (n = 20): Home exercise programme (ROM exercises, LL multidirectional neck exercises, stretching; 30–40 min, twice/week), LL progressive exercises for deep CFM Control group (n = 20): Home exercises programme (ROM exercises, LL multidirectional neck exercises, stretching; 30–40 min, twice/week) Intervention period: 7 weeks	1. Disability [NDI (%)] 2. Pain intensity [NPRS (0–10)] minimal (min), maximal (max) and current (cur) Outcome assessments: 2 assessments (baseline, 7 weeks)	1. SFU: CEM—N/P (mD −4.1*) = Other (mD −11.6*) > Control (mD −2.3*) 2. SFU: CEM—N/P (mDmin −0.7*) = Other (mDmin −1.7*) = Control (mDmin −0.2) CEM—N/P (mDmax −2.0*) = Other (mDmax −2.6*) = Control (mDmax −2.0*) CEM—N/P (mDcur −1.6*) < Other (mDcur −3.5*) = Control (mDcur −1.0*)
	218 adults with CNP	1. Disability [NPQ (0–4)]	1. SFU: CEM—N/P (mD −0.39*) =

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
Chiu et al., 2005a and 2005b[2] (7,6[2]/10)	'CEM—N/P' group (*n* = 67): Advice on neck care, infrared irradiation (20 min) and progressive LL exercises for CEM and CFM 'Other' group (*n* = 73): Advice on neck care, infrared irradiation (20 min) and conventional TENS to the neck region (30 min) (twice/week) Control group (*n* = 78): Advice on neck care and infrared irradiation to the neck region (20 min, twice/week) Intervention period: 6 weeks	2. Pain intensity [NPRS (0–10)] Outcome assessments: 3 assessments (baseline, 6 weeks, 6 months)	Other (mD −0.38*) > Control (mD −0.23*) LFU: CEM—N/P (mD −0.37*) = Other (mD −0.36*) > Control (mD −0.20*) 2. SFU: CEM—N/P (mD −1.6*) = Other (mD −0.6*) = Control (mD −0.3) LFU: CEM—N/P (mD −1.6*) = Other (mD −1.3*) = Control (mD −0.7)
Rodriguez-Sanz et al., 2021 (8/10)	See Rodriguez-Sanz et al., 2021, in 'CEM—N' classification		
Cervical extensor muscle exercises combined with other active and passive interventions (CEM—A/P)			
Cetin et al., 2022 (5/10)	41 adults with CNP 'CEM—A/P 1' group (*n* = 20): LL progressed towards HL exercises for CEM, CFM and SGM, stretching and postural corrections (40 min) 'CEM—A/P 2' group (*n* = 21): LL progressed towards HL exercises for CEM, CFM and SGM, stretching, postural corrections (20 min) and virtual reality exercises aiming multidirectional neck movements (20 min) Intervention period: 6 weeks	1. Disability [ProFitMap-Neck (%)] 2. Pain intensity [VAS (0–10)] Outcome assessments: 2 assessments (baseline and 6 weeks)	1. SFU: CEM—A/P 1 (mD −10.59*) = CEM – A/P 2 (mD −12.97) 2. SFU: CEM—A/P 1 (mD −2.44*) = CEM – A/P 2 (mD −3.69*)
Jordan et al., 1998 (5/10)	119 adults with CNP 'CEM—A/P' group (*n* = 40): LL exercises for CEM, CFM, LFM; HL exercises for SGM, chest; stretching, ergocycle; home exercises, ergonomic advice, one theoretical and practical session of 'neck school'	1. Disability [Disability index (0–30)] 2. Pain intensity [NPRS (0–30)] Outcome assessments: 4 assessments (baseline, 6 weeks, 4 months, 12 months)	1. SFU: CEM—A/P (MD −3) = Other-PT (MD −5) = Other—chiro (MD −4) LFU: CEM—A/P (MD −3) = Other-PT (MD −3) = Other—chiro (MD −3)

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
	'Other—PT' group (*n* = 39): Hot packs, massage, US, MT (traction and mobilization); same home exercises; one theoretical and practical session of 'neck school' 'Other—chiro' group (*n* = 40): Cervical spine manipulations, MT (traction and manual treatment of muscle tenderness); one theoretical and practical session of 'neck school' Intervention period: 6 weeks		2. SFU: CEM—A/P (MD −6*) = Other-PT (MD −6*) = Other—chiro (MD −7*) LFU: CEM—A/P (MD −6*) = Other-PT (MD −4*) = Other—chiro (MD −7*)
Kim and Kwag, 2016 (5/10)	28 adults with CNP 'CEM—A/P' group (*n* = 14): Unclear description of neck exercises intensity for CEM, CFM, LFM; stretching in several neck directions. 'Other' group (*n* = 14): Deep CFM exercises Intervention period: 4 weeks	1. Disability [NDI] 2. Pain intensity [NPRS (0–10)] Outcome assessments: 3 assessments (baseline, 4 weeks, 8 weeks)	1. SFU: CEM—A/P (mD −1.9) = Other (mD −1.9) LFU: CEM—A/P (mD −2.6*) < Other (mD −3.8*) 2. SFU: CEM—A/P (mD −1.3) = Other (mD −1.7) LFU: CEM—A/P (mD −2.0*) < Other (mD −3.5*)
Ris et al., 2016 (6/10)	200 adults with CNP (>6 months) 'CEM—A/P' group (*n* = 101): Pain management programme; progressive and tailored exercises (unclear intensity) for CEM, deep CFM, SGM, balance, and graded physical training Control group (*n* = 99): Pain management programme (4 sessions, 90 min/session, once/month) Intervention period: 4 months	1. Disability [NDI (0–50) and PSFS (0–10)] Outcome assessments: 2 assessments (baseline, 4 months)	1. SFU: CEM—A/P (mD NDI −1.3) = Control (mD NDI −1.1) CEM—A/P (mD PSFS 0.7) = Control (mD PSFS 0.5)
Jull et al., 2007 (7/10)	71 adults with CWAD 'CEM—A/P' group (*n* = 36): Progressive LL exercises for CEM, CFM, SGM, CSPR, MT, education and advice	1. Disability [NPQ (%)] Outcome assessments: 2 assessments (baseline, 10 weeks)	1. SFU: CEM—A/P (mD −10.4) > Other (mD −4.6)

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
	'Other' group (*n* = 35): Self-management programme documented in a booklet including education, advice and description of an exercise programme (encouragement to perform exercises twice/ day) Intervention period: 10 weeks		
Lytras et al., 2023 (7/10)	80 women with CNP 'CEM—A/P 1' group: LL and HL exercises for CEM, CFM, LF, SGM, neck and upper limb muscles stretching 'CEM—A/P 2' group: LL and HL exercises for CEM, CFM, LF, SGM, neck and upper limb muscles stretching, neuromuscular inhibitory techniques 'CEM—A/P 3' group: LL and HL exercises for CEM, CFM, LF, SGM, neck and upper limb muscles stretching, massage and mobilisation and/or manipulation Control group: Home-based general exercises sheet Intervention period: 10 weeks	1. Disability [NDI (0–50)] 2. Pain intensity [VAS (0–100)] Outcome assessments: 5 assessments (baseline, 2 weeks, 4 weeks, 6 weeks, 10 weeks, 6 months)	1. SFU: CEM—P 2 (mD NDI −13.19) / CEM A/P 3 (mD NDI −17.45) > CEM—A/P 1 (mD NDI −11.1) > Control (mD NDI −2.9) LFU: CEM—A/P 2 (mD NDI −13.9) / CEM A/P 3 (mD NDI −13.55) > CEM—A/P 1 (mD NDI −6.1) > Control (mD NDI −2.6) 2. SFU: CEM—A/P 2 (mD −37.76) / CEM A/P 3 (mD −32.1) > CEM—A/P 1 (mD −25.42) > Control (mD −7.42) LFU: CEM—A/P 2 (mD −33.97) / CEM A/P 3 (mD −35.43) > CEM—A/P 1(mD −21.35) > Control (mD −6.42)
Ylinen et al., 2003, 2006[2] and 2007[3] (7,5[2,3]/10)	179 women with constant or frequently occurring neck pain 'CEM—A/P' group (*n* = 60): 10 supervised sessions in 12 days to learn the 1 year-home exercises programme (HL strength exercises for CEM, CFM, LFM, SGM, leg, trunk, stretching, aerobic training; 45 min), neck school education and PT (MT/massage) 'Other' group (*n* = 59): 10 supervised sessions in 12 days to learn the 1 year-home exercises programme (HL	1. Disability [NDI (%)] 2. Pain intensity [VAS (0–100)] Outcome assessments: 2 assessments (baseline, 12 months, 36 months)	1. SFU: Other (MD −8*) > Control (MD −3) CEM—A/P (MD −9*) > Control (MD −3) LFU: other (MD −6*) = CEM – AP (MD −10*) 2. SFU: Other (MD −35 mm*) > Control (MD −16 mm) CEM—A/P (MD −40 mm*) > Control (MD −16 mm)

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
	endurance exercises for CFM, SGM, leg, trunk, stretching, aerobic training; 60 min), neck school education and PT (MT/massage) Control group (n = 60): 1 supervised session to learn the 1 year-home exercises programme (stretching, aerobic exercise; 90 min, 3 times/week) Intervention period: 12 months		LFU: other (MD −38 mm*) = CEM – AP (MD −44 mm*)
Landén Ludvigsson et al., 2015, 2016[2], 2018[3], 2020[4] and Peterson et al., 2015 (8,7[2–4]/10)	See Landén Ludvigsson et al., 2015, 2016[2], 2018[3], 2020[4] and Peterson et al., 2015, in 'CEM—N' classification		
Lytras et al., 2020 (8/10)	40 adults with CNP 'CEM—A/P 1' group: LL and HL exercises for CEM, CFM, LF, SGM, neck and upper limb muscles stretching 'CEM—A/P 2' group: LL and HL exercises for CEM, CFM, LF, SGM, neck and upper limb muscles stretching, neuromuscular inhibitory techniques Intervention period: 10 weeks	1.Disability [NDI (0–50)] 2.Pain intensity [VAS (0–100)] Outcome assessments: 7 assessments (baseline, 2 weeks, 4 weeks, 6 weeks, 10 weeks, 14 weeks, 22 weeks, 34 weeks)	1. SFU: CEM—A/P 1(mD NDI −7.75) < CEM A/P 2 (mD NDI −13.05) LFU: CEM—A/P 1(mD NDI −3.5) < CEM A/P 2 (mD NDI −9.45) 2. SFU: CEM—A/P 1 (mD −24.4) < CEM A/P 2 (mD −38.16) LFU: CEM—A/P 1 (mD −20.77) < CEM A/P 2 (mD −34.58)
Michaleff et al., 2014 (8/10)	170 adults with CWAD 'CEM—A/P' group (n = 85): Tailored LL progressed towards HL exercises for CEM, CFM, SGM, postural and sensorimotor exercises (CSPR, balance, EMC), MT and graded activity programme Control group (n = 85): Advice by a physiotherapist and an educational booklet (1 session, 30 min) Intervention period: 12 weeks	1. Disability [NDI (%), PSFS (0–10) and Whiplash Disability Questionnaire (WDQ) (0–130)] 2. Pain intensity (NPRS) Outcome assessments: 4 assessments (baseline, 14 weeks, 6 months, 12 months)	1. SFU: CEM—/AP (mD NDI −7.2) = Control (mD NDI −6.4) CEM—A/P (mD PSFS 1.9) > Control (mD PSFS 0.9) CEM—A/P (mD WDQ −12.1) = Control (mD WDQ −14.8) LFU: CEM—A/P (mD NDI −8.4) = Control (mD NDI −7.7) CEM—A/P (mD PSFS 2.3) = Control (mD PSFS 1.7) CEM—A/P (mD WDQ −14.8) =

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
			Control (mD WDQ −18.1) 2. SFU: CEM—A/P (mD −1.6) = Control (mD −1.5) LFU: CEM—A/P (mD −1.8) = Control (mD −1.5)
Sremakaew et al., 2022 (8/10)	152 adults with idiopathic CNP 'CEM—A/P 1' group (*n* = 38): Tailored LL progressed towards HL exercises for CEM, CFM, SGM, postural exercises and MT 'CEM—A/P 2' group (*n* = 38): Tailored LL progressed towards HL exercises for CEM, CFM, SGM, postural exercises and MT + progressed CSPR and EMC exercises 'CEM—A/P 3' group (*n* = 38): Tailored LL progressed towards HL exercises for CEM, CFM, SGM, postural exercises and MT + progressed balance exercises 'CEM—A/P 4' group (*n* = 38): Tailored LL progressed towards HL exercises for CEM, CFM, SGM, postural exercises and MT + progressed CSPR, EMC and balance exercises. Intervention period: 6 weeks	1. Disability [NDI (%), PSFS (0–10)] 2. Pain intensity [VAS (0–10)] Outcome assessments: 4 assessments (baseline, 6 weeks, 3 months, 6 months, 12 months)	1. SFU: CEM— A/P 1 (mD NDI −15.1*) = CEM – A/P 2 (mD NDI −15.8*) = CEM—A/P 3 (mD NDI −15.5*) = CEM—A/P 4 (mD NDI −17.9*) CEM—A/P 1 (mD PSFS −3.4*) = CEM – A/P 2 (mD PSFS −3.5*) = CEM—A/P 3 (mD PSFS −3.5*) = CEM—A/P 4 (mD PSFS −3.7*) LFU: CEM—A/P 1 (mD NDI −10.3*) < CEM – A/P 2 (mD NDI −14.5*) < CEM—A/P 3 (mD NDI −14.8*) < CEM—A/P 4 (mD NDI −18.2*) CEM—A/P 1 (mD PSFS −3.2*) = CEM – A/P 2 (mD PSFS −3.4*) = CEM—A/P 3 (mD PSFS −2.6*) = CEM—A/P 4 (mD PSFS −3.5*) 2. SFU: CEM—A/P 1 (mD −4.1*) = CEM – A/P 2 (mD −4.0*) = CEM—A/P 3 (mD −3.7*) = CEM—A/P 4 (mD −4.7*) LFU: CEM—A/P 1 (mD −2.8*) > CEM – A/P 2 (mD −3.3*) > CEM—A/P 3 (mD −3.5*) > CEM—A/P 4 (mD −4.3*)
Sterling et al., 2015 (9/10)	80 adults with CNP 'CEM—A/P' group (*n* = 40): Tailored LL exercises for CEM, CFM and SGM, postural and sensorimotor exercises and DN to posterior neck muscles 'CEM—ShamDN' group (*n* = 40):	1. Disability [NDI (%), PSFS (0–10) and Whiplash Disability Questionnaire (WDQ) (0–130)] 2. Pain intensity [VAS (0–10) one week and 24 h]	1.SFU: CEM—A/P (mD NDI −10.7) = CEM – ShamDN (mD NDI −10.2) CEM—A/P (mD PSFS 2.2) = CEM – ShamDN (mD PSFS 1.6) CEM—A/P (mD WDQ −19.5) =

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Table 2. (Continued)

Study (PEDro score(s))	Compared interventions	Outcome(s)	Results (SFU = short follow-up, LFU = long follow-up)
	Identical exercise programme and sham DN Intervention period: 6 weeks	Outcome assessments: 5 assessments (baseline, 6 weeks, 12 weeks, 6 months, 12 months)	CEM – ShamDN (mD WDQ −17.2) LFU: CEM—A/P (mD NDI −15.6) > CEM – ShamDN (mD NDI −8.8) CEM—A/P (mD PSFS 3.5) = CEM – ShamDN (mD PSFS 1.6) CEM—A/P (mD WDQ −29) = CEM – ShamDN (mD WDQ −20.8) 2.SFU: CEM—A/P (mD 1wk −2.4 cm) = CEM – ShamDN (mD 1wk −2.2 cm) CEM—A/P (mD 24 h −2.0 cm) = CEM – ShamDN (mD 24 h −1.9 cm) LFU: CEM—A/P (mD 1wk −2.8 cm) = CEM – ShamDN (mD 1wk −2.1 cm) CEM—A/P (mD 24 h −2.5 cm) = CEM – ShamDN (mD 24 h −2.2 cm)

Notes: Results in bold indicate significant differences between groups. * indicates results with significant differences from baseline values reported by authors for the same intervention group.indicates results for which between groups differences were not reported by the authors. Underlined assessment time points identify the respective times of SFU and/or LFU. Outcomes are provided without units if this information was not provided by the authors. If PEDro scores for follow-up studies differed from the reference study, the follow-up study's score is referenced by a superscript number.
CNP: chronic neck pain; CWAD: chronic whiplash-associated disorders; SCe: semispinalis cervicis; CES: cervical erector spinae muscles; mD: mean difference; MD: median difference; NPRS: numeric pain rating scale; VAS: visual analogue scale; NDI: neck disability index; NPQ: Northwick Park Neck Pain Questionnaire; NPDQ: Neck Pain and Disability Questionnaire; PSFS: Patient-Specific Function Scale; CEET: Cervical Extensor Endurance Test; ROM: range of motion; MVC: maximum voluntary contraction; sEMG: surface electromyography; LL: low load; HL: high load; CEM: cervical extensor muscles; SGM: shoulder girdle muscles; CFM: cervical flexor muscles; LFM: lateral flexion muscles; MT: manual therapy; PT: physiotherapy; CSPR: cervical spine proprioceptive retraining; EMC: eye movement control; DN: dry needling; PPT: pressure point threshold.

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The PEDro criteria and final scores assigned to each article are presented in Supplemental Table 1. They range from 5/10 to 9/10. None of the therapists in the studies could be blinded to the intervention arm because of the nature of exercise interventions. Nine articles had a score of 5/10, and all the others ($n = 26$) were of 'moderate to high' quality (PEDro score ≥ 6/10).

CHARACTERISTICS OF INCLUDED ARTICLES

The year of publication ranged from 1998[41] to 2023.[42,43] The number of participants ranged from 25[44] to 218,[45] and the mean age of the participants ranged from 20[46] to 50 years.[43,47] Eight studies included only female participants.[43,46,48–53]

The 27 studies included a total of 2409 participants with neck pain, either of non-traumatic onset,[41–43,46,47,51,52,54–59] traumatic onset (whiplash related),[44,60–64] a mix of traumatic and non-traumatic onset[65] or work-related neck pain[48,50]; the cause was not reported in four studies.[49,53,66,67] All randomised controlled trials included people with chronic symptoms, except one that included people with subacute whiplash-associated disorders.[44] Some studies used the same participant samples for different follow-up sessions (Landen Ludvigsson et al.,[61,64,68,69] Bernal-Utrera et al.,[66,70] Ylinen et al.[51,71,72]) or for complementary analyses (Landen Ludvigsson et al.,[61,73] Chiu et al.[45,58]). The main demographic characteristics of each group are presented in Supplemental Table 2.

The frequency of the supervised intervention ranged from five times per week for two weeks[51] to less than once per week for 16 weeks.[65] The session time ranged from 10 min of specific semispinalis cervicis isometric exercises[55] to 90 min of combined treatment that included cervical extensor muscle exercises.[63,65] The total duration of supervised rehabilitation ranged from 1 h[66] to 40 h,[43,59] spread out over 2 weeks[51,71,72] to 16 weeks.[65] Home exercises, used either as the main intervention[51] or in combination with supervised exercises, were included in the programme in 16 studies[42,44,46–48,51–53,55,56,60–62,65,66,74] and were performed from twice per week[74] to two to five times per day,[47] over 3 weeks[66] to 1 year.[51]

Regarding the components of the neck pain rehabilitation programmes that included cervical extensor muscle exercises, the modalities and type of control intervention were very heterogeneous across studies. Five main categories of programmes involving cervical extensor muscle exercises could be distinguished: (1) interventions involving cervical extensor muscle exercises only;[53,55] (2) interventions involving cervical extensor muscle exercises and other neck muscle exercises;[46–48,50,52,56,57,61,64,66,68–70,73] (3) interventions involving cervical extensor muscle exercises combined with other neck and shoulder girdle muscle exercises;[44,49] (4) interventions involving cervical extensor muscle exercises combined with other neck muscle exercises and passive interventions such as manual techniques, dry needling, etc.;[47,58,74] and (5) interventions involving cervical extensor muscle exercises combined with other active and passive interventions.[41–43,51,54,59–65,67–69,71–73,75] Whereas most studies compared a neck pain rehabilitation programme involving cervical extensor muscle exercises to an intervention without cervical extensor muscle exercises or to a control group (no, or minimal, intervention), some studies compared two cervical extensor muscle intervention groups classified within a same category[42–44,48,50,53,54,56,59,67] or different categories.[47,61]

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Among the 27 studies, nine interventions consisted of a low load programme[41,44,53,55,56,58,60,63,66] and eight of a high load programme.[44,50,51,53,56,57,67,74] In 21 interventions,[42–44,46–50,52,54,57–59,61,62,67,74] the cervical extensor muscle exercises were progressive; in 16 interventions, the programme progressed from a low load to a high load programme.[42,43,47–50,52,54,59,61,62,67] In three studies, the intensity of the cervical extensor muscle exercises was unclear.[46,65,75] Table 1 shows the characteristics of the cervical extensor muscle exercises used in the studies.

EFFECTIVENESS OF CERVICAL EXTENSOR MUSCLE INTERVENTIONS

All but one study[67] assessed at least one of the two primary outcomes of this review; the secondary outcomes assessed in some studies included cervical range of motion,[41–44,47,51,53,54,56,57,59,60,62,63,65,67] cervical extensor muscle strength[41,43,50–52,54,55,58,67] or endurance,[41,44,52,61,65] local pressure pain threshold[43,47,50,53,54,59,63,65,66,74] and muscle activation measured with surface electromyography.[48,49,52] Each outcome was assessed at baseline and at the end of the intervention (corresponding to the short-term follow-up), except for three studies in which the assessment was conducted a few weeks after the intervention.[51,62,66] Sometimes a long-term follow-up assessment was performed (up to 36 months after the start of the intervention, such as in the study by Ylinen et al.[72]).

Among the 27 original studies, 25 reported significant improvements in at least one primary outcome for the intervention group that performed cervical extensor muscle exercises. Table 2 provides a description of the comparison interventions and results for the primary outcomes at the short- and long-term follow-ups (when available) according to the same cervical extensor muscle intervention classification used in Table 1. Among the 27 original studies, 20 reported significant improvements in at least one secondary outcome for the intervention group that performed cervical extensor muscle exercises. The results for the secondary outcomes at the different follow-up time points are provided in Supplemental Table 3.

Interventions consisting on cervical extensor muscle exercises alone were evaluated in only two studies. Suvarnnato et al.[55] reported significantly greater improvements in pain ([0–10]NPRS mean difference: −2.5) and disability ([%]NDI mean difference: −16.7) at the short follow-up in the intervention group than in the usual care group, but no difference was found between the cervical extensor muscle intervention group and the deep cervical flexor muscle intervention group (except for cervical extensor muscle strength). Similar results were found at the long follow-up except that pain intensity no longer differed between groups. Gimenez-Costa et al. compared two cervical extensor muscle interventions (low load versus high load exercises) and reported significant and similar improvements in both groups for pain intensity ([0–100]VAS mean differences ranging from −18.0 to 20.9), disability ([%]NDI mean differences ranging from −9.4 to 12.2), pressure point threshold ([KPa]PPT mean differences ranging from 39.7 to 90.8) and cervical range of motion ([°]inclinometer mean differences ranging from 8.1 to 17.7).[53]

Cervical extensor muscle exercises combined with other neck exercises interventions were evaluated in nine studies. Cervical extensor muscle exercises were usually combined with exercises for the deep or superficial cervical flexor muscles and sometimes the cervical lateral flexor and cervical rotator muscles. These interventions were compared to several interventions, for example, another cervical extensor combined with other neck muscles[48,50,56] that could even be coupled with passive

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interventions,[47] deep cervical flexor muscle interventions,[46,57] passive interventions,[66] general physical activity,[61,64,68,69,73] information[50] or no intervention.[48,52] Regarding the intensity of the cervical extensor muscle exercises used in these interventions, although a few randomised controlled trials focused on either low load or high load exercises, the others progressed from low load to high load exercises. Significantly greater improvements were reported for disability ([%]NDI mean differences ranging from −8.2 to −27), pain intensity ([0–100]VAS mean differences ranging from −17 to −44.6) and pressure point threshold in all cervical extensor muscle intervention groups compared to sham or no-intervention groups. However, when compared to another intervention (such as deep cervical flexor muscles or manual therapy), cervical extensor muscle exercises combined with other neck exercise interventions did not usually result in significantly better outcomes. Although cervical range of motion also improved (p-value < 0.05) after cervical extensor and other neck muscle exercise interventions,[56,57] it appeared that the addition of manual techniques could further improve range of motion, as well as pain intensity and disability.[47]

Two studies evaluated cervical extensor muscle exercises combined with other neck and shoulder girdle muscle exercises. Ask et al.[44] compared two interventions which differed in exercise intensity and reported similar and significant improvements in pain and disability in both groups at the short-term ([0–100]VAS median difference ranging from −3.5 to −28; [%]NDI median difference ranging from −18 to −14) and 12-month follow-ups, but no improvement in neck extensor muscle endurance. Mehri et al.[49] also reported significantly greater improvements in pain and disability ([%]Neck Pain and Disability Scale mean difference: −5.4) in an intervention group than in a control ([%]NPQD mean difference: −0.9) group who received advice and postural information in a booklet.

Three studies included cervical extensor muscle exercises combined with other neck exercises and various passive modalities (i.e. manual therapy, neck stretching or infrared irradiation), which were the main part of the rehabilitation programme. Significant improvements in pain ([0–100]NPRS mean difference ranging from −16 to −34) and disability ([%]NDI mean difference: −4.1) were reported in the three studies.[47,58,74] The improvement in disability was significantly greater in the cervical extensor muscle intervention groups than in the control groups; however, except for the study by Rodriguez-Sanz et al.,[47] it was not greater than in the other intervention groups.

Thirteen studies evaluated interventions combining cervical extensor muscle exercises with numerous passive (hot packs, massage, manual therapy, education/pain management programme, stretching, dry needling, graded activity, ischaemic compression or relaxation) and active (neck/trunk/shoulder girdle/lower extremity exercises, postural or sensorimotor exercises, virtual reality neck exercises) therapeutic modalities. Most of the cervical extensor muscle exercises were low load (n = 3) or low load progressing towards high load (n = 7). These interventions were compared to passive (manual therapy, physiotherapy, ischaemic compression), active (deep cervical flexor muscle exercises) or self-management interventions that combined active and passive modalities. The effects of this category of cervical extensor muscle interventions on pain outcomes were heterogeneous. They improved pain-related outcomes ([%]NDI median difference: −9, [0–100]VAS median difference: −40) significantly more than stretching[51] ([%]NDI median difference: −3, [0–100]VAS median difference: −16), a self-management programme[60] or a pain management programme.[65] Other interventions from this cervical extensor muscle exercises category did not improve pain-related outcomes or cervical range of motion more than other interventions, although some of them resulted in significant improvements

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in baseline outcomes.[41,42,54,61,75] Cervical extensor muscle endurance was only assessed in three studies that reported significantly greater improvements after the cervical extensor muscle exercises combined with other active and passive intervention than after mainly passive treatment[41] or a pain management programme,[65] but no difference when compared with an intervention combining cervical extensor muscle exercises to other neck muscle exercises.[61]

Discussion

The results of this systematic review highlight the current lack of knowledge of the effectiveness of cervical extensor muscle exercises for neck pain rehabilitation and the optimal way to use such exercises. Only two studies[53,55] investigated the effectiveness of a neck pain rehabilitation programme based on cervical extensor muscle exercises alone. In most studies, cervical extensor muscle exercises were one component of a varied mix of therapeutic exercises. Furthermore, the dosage of the exercises, including the cervical extensor muscle exercises, varied greatly (i.e. intensity of the exercises and frequency and duration of sessions and the treatment programme). Regardless of the combination of therapeutic modalities or dosage parameters, we found that several forms of exercise therapy that included cervical extensor muscle exercises could reduce pain and disability in individuals with chronic neck pain.

Although this systematic review is original and provides useful information, some limitations should be acknowledged. First, the lack of trials designed to specifically assess the effectiveness of cervical extensor muscle exercises in the management of neck pain, and the large variability of the content of the neck pain rehabilitation programmes, prevented strong conclusions being drawn about the effectiveness of these exercises or the optimal way to use them. Furthermore, this large variability prevented us from conducting a meta-analysis, since the results would have been irrelevant.[76] Second, our search strategy was specific to studies about cervical extensor muscle exercises published in English or French. Therefore, we might have missed some studies that less explicitly included such exercises or published in another language. Third, although the PEDro assessment scale used in the present review is a specialised methodological assessment tool for randomised clinical trials that is frequently used in physiotherapy-related trials,[77] it does not take into account the statistical power of a trial. Fourth, although we obtained additional information by contacting several authors, poor reporting may have led to misunderstanding of the cervical extensor muscle exercise dosages. Finally, except for four studies, all participants included had chronic neck pain; therefore, we did not take into account any confounding factors that might have influenced the effectiveness of the interventions (such as aetiology[78] or baseline symptoms[79]).

As mentioned above, cervical extensor muscle exercises were combined with other therapeutic interventions for all but two of the included studies. Therefore, most trials corresponded to our cervical extensor muscle exercises category, combining them with other active and passive interventions. They included a wide range of active interventions (targeting coordination between the different neck muscles and/or the different shoulder muscles or muscle endurance/strength, as well as postural balance, oculomotor control or aerobic capacity), combined with various passive interventions (such as massage, dry-needling, manual therapy, therapeutic education, ergonomics, stretching, etc.). Such

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multimodal treatment is recommended for subacute and chronic neck pain.[30] Indeed, although the strongest treatment effects are produced by interventions that include exercise,[29] the addition of passive interventions (such as manual therapy, ischaemic compression or education) to exercise seems to enhance the effect of exercise therapy,[80–83] as observed by Lytras et al.[59] More studies are needed to determine the effect of cervical extensor muscle exercises within multimodal programmes.

Although clinical practice guidelines for chronic neck pain management recommend the use of an individualised and progressive exercise programme,[30] the optimal dosage parameters for the use of exercise therapy, including cervical extensor muscle exercises, remain unclear.[28,84] This may explain the wide variety of exercise dosage parameters found in the 27 trials included in the present review in terms of intensity (from low load to high load), frequency (from one session per day to one session per month) and duration (from 2 weeks to 16 weeks). However, according to our results, most studies used one session per week of progressive low to high load exercises over 6 weeks in combination with twice-daily home exercises. One included study[53] found a similar reduction of neck pain intensity and disability using isolated low load cervical extensor muscle exercises (specific exercise with resistance applied to C2 to specifically activate the semispinalis cervicis muscle, which is likely to be impaired in people with neck pain[13,16,85]) or high load cervical extensor muscle exercises (with resistance applied to the occiput). Similar results have been found for cervical flexor muscle interventions.[33] Furthermore, several recent meta-analyses concluded that both low and high load exercises could reduce pain and disability to a similar extent.[26,28,29,86] Much less is known about the influence of the other dosage parameters, such as duration or frequency, on outcomes. O'Riordan et al.,[87] based on its meta-analysis, suggest that an optimal exercise intervention for chronic neck pain should last between 30 to 45 min, three times a week, during at least 6 weeks. The more recent meta-analysis by Polaski et al.[88] reported a significant, positive correlation between exercise therapy duration (in weeks) and reduction in pain in people with neck pain. Furthermore, they developed a predictive model that indicated that increasing in the number of sessions per week should increase the analgesic effect.

With regard to the primary aim of this review that was to determine the specific effect of cervical extensor muscle exercises on neck pain, few conclusions can be drawn. Giménez-Costa et al.[53] found a significant reduction in pain immediately after a 6-week intervention composed of either high or low load cervical extensor muscle exercises and a reduction in disability that was maintained 6 months after the intervention. Suvarnnato et al. also found similar reductions in pain intensity and disability after low load cervical extensor muscle exercises and deep cervical flexor muscle exercises.[55] Furthermore, the effects of both interventions were greater than that of usual care. However, the study was of low quality (Pedro score 5/10). Although these results need to be confirmed in high-quality studies, they suggest that cervical extensor muscle exercises could contribute to improve outcomes in people with chronic neck pain. It is not possible to determine from the other studies included in this systematic review whether the addition of cervical extensor muscles within a multimodal neck pain rehabilitation programme improved outcomes since none evaluated this.

These results suggest that cervical extensor muscle exercises, either alone or combined with other active or passive interventions, could contribute to reducing pain intensity and disability in individuals with neck pain or whiplash-associated disorders. The analgesic effect could be attributed to several factors. Firstly, both low load and high load exercises[86,89] could drive a systemic analgesic process[90] that is mediated by central[91] and peripheral mechanisms.[92] Secondly, low load exercises seem to more

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effectively improve muscle coordination by either reducing superficial muscle activity[33] or, as shown in one of the studies included, increasing the directional specificity of muscle activity.[52] This can lead to a more economical[52] and efficient use of the muscles in the area. Thirdly, exercising could reduce psychosocial factors involved in pain, such as anxiety[93] or kinesiophobia.[73] Although most studies included in this review reported improvements in several outcomes, the magnitude of change, both at the short-term and long-term follow-ups, was often statistically significant but clinically small. This is consistent with the report by Sterling et al.[29] that exercise therapy has only modest effects on pain and disability in individuals with chronic neck pain. Therefore, further efforts are needed to improve the effectiveness of neck pain rehabilitation programmes. This might be done by considering the specific bio-psycho-social contributors to the symptoms and the functional aims and expectations of each individual when determining individual management programmes, as proposed by Booth et al.[94] Regarding neck exercise prescription, the muscles targeted (neck flexors and/or extensors and/or shoulder girdle muscles) and the intensity and duration of the exercise programme should be adapted to the functionally relevant muscle impairments[89] and should be in line with the individual's preferences[28] and functional goals. Further studies are needed to investigate the potentially greater effectiveness of such individualised exercise therapy which should be included within a multimodal management strategy as recommended by the clinical guidelines.

Clinical Messages

• Cervical extensor muscle exercises (low load and/or high load) could reduce neck pain and disability in adults with chronic neck pain.

• As the optimal dosage parameters for neck pain rehabilitation remain unclear, neck muscle exercise should be individualised and guided by the therapeutic goals.

• As chronic neck pain is multifactorial, cervical extensor muscle exercises should probably be more specifically considered in the presence of their functional impairments, being a part of a multimodal rehabilitation programme.

• Effectiveness of neck pain rehabilitation programmes might be improved if individualised based on clinical assessment.

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Author contributions

DC and ND developed the search strategy and adapted it to the two databases screened. In October 2019, DC and OS screened the references, assessed the methodological quality of the articles and

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extracted the data with the help of CD. In April 2022, DC and SG screened the references, assessed the methodological quality of the articles and extracted the data with the help of CD. DC wrote the whole manuscript with help and proofreading from CD, ND, MV, BC, SG and JFK.

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ORCID iD

David Colman https://orcid.org/0000-0001-6757-914X

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References

1. van Randeraad-van der Zee CH, Beurskens AJHM, Swinkels RAHM, et al. The burden of neck pain: its meaning for persons with neck pain and healthcare providers, explored by concept mapping. *Qual Life Res* 2016; 25: 1219–1225.

2. Côté P, van der Velde G, Cassidy JD, et al. The burden and determinants of neck pain in workers. Results of the bone and joint decade 2000–2010 task force on neck pain and its associated disorders. *J Manipulative Physiol Ther* 2009; 32: S70–S86.

3. Kazeminasab S, Nejadghaderi SA, Amiri P, et al. Neck pain: global epidemiology, trends and risk factors. *BMC Musculoskelet Disord* 2022; 23: 1–13.

4. Hurwitz EL, Randhawa K, Yu H, et al. The global spine care initiative: a summary of the global burden of low back and neck pain studies. *Eur Spine J* 2018; 27: 796–801.

5. Luime JJ, Koes BW, Miedem HS, et al. High incidence and recurrence of shoulder and neck pain in nursing home employees was demonstrated during a 2-year follow-up. *J Clin Epidemiol* 2005; 58: 407–413.

6. Sterling M, Jull G, Vicenzino B, et al. Development of motor system dysfunction following whiplash injury. *Pain* 2003; 103: 65–73.

7. Christensen SW, Hirata RP and Graven-nielsen T. Bilateral experimental neck pain reorganize axioscapular muscle coordination and pain sensitivity. *Eur J Pain* 2017; 21: 681–691.

8. Falla D, O'Leary S, Farina D, et al. Association between intensity of pain and impairment in onset and activation of the deep cervical flexors in patients with persistent neck pain. *Clin J Pain* 2011; 27: 309–314.

9. Boudreau SA and Falla D. Chronic neck pain alters muscle activation patterns to sudden movements. *Exp Brain Res* 2014; 232: 2011–2020.

10. Park KN, Kwon OY, Kim SJ, et al. Asymmetry of neck motion and activation of the cervical paraspinal muscles during prone neck extension in subjects with unilateral posterior neck pain. *J Back Musculoskelet Rehabil* 2017; 30: 751–758.

11. Falla D, Bilenkij G and Jull G. Patients with chronic neck pain demonstrate altered patterns of muscle activation during performance of a functional upper limb task. *Spine* 2004; 29: 1436–1440.

12. Cheng CH, Cheng HYK, Chen CPC, et al. Altered co-contraction of cervical muscles in young adults with chronic neck pain during voluntary neck motions. *J Phys Ther Sci* 2014; 26: 587–590.

13. Schomacher J, Farina D, Lindstroem R, et al. Chronic trauma-induced neck pain impairs the neural control of the deep semispinalis cervicis muscle. *Clin Neurophysiol* 2012; 123: 1403–1408.

14. Falla D and Gallina A. New insights into pain-related changes in muscle activation revealed by high-density surface electromyography. *J Electromyogr Kinesiol* 2020; 52: 102422.

15. Gizzi L, Muceli S, Petzke F, et al. Experimental muscle pain impairs the synergistic modular control of neck muscles. *PLoS ONE* 2015; 10: 1–19.

16. O'Leary S, Cagnie B, Reeve A, et al. Is there altered activity of the extensor muscles in chronic mechanical neck pain? A functional magnetic resonance imaging study. *Arch Phys Med Rehabil* 2011; 92: 929–934.

17. Schomacher J, Boudreau SA, Petzke F, et al. Localized pressure pain sensitivity is associated with lower activation of the semispinalis cervicis muscle in patients with chronic neck pain. *Clin J Pain* 2013; 29: 898–906.

18. Cagnie B, Cools A, De Loose V, et al. Differences in isometric neck muscle strength between healthy controls and women with chronic neck pain: the use of a reliable measurement. *Arch Phys Med Rehabil* 2007; 88: 1441–1445.

19. Lindstrøm R, Schomacher J, Farina D, et al. Association between neck muscle coactivation, pain, and strength in women with neck pain. *Man Ther* 2011; 16: 80–86.

Published in: Clinical Rehabilitation (2023), vol. 37, n°12, pp. 1579 – 1610
DOI: 10.1177/0269215523118497
Status: Postprint (Author's version)

20. Peolsson A and Kjellman G. Neck muscle endurance in nonspecific patients with neck pain and in patients after anterior cervical decompression and fusion. *J Manipulative Physiol Ther* 2007; 30: 343–350.

21. Snodgrass SJ, Croker C, Yerrapothu M, et al. Cervical muscle volume in individuals with idiopathic neck pain compared to asymptomatic controls: a cross-sectional magnetic resonance imaging study. *Musculoskelet Sci Pract* 2019; 44: 102050.

22. Elliott J, Pedler A, Kenardy J, et al. The temporal development of fatty infiltrates in the neck muscles following whiplash injury: an association with pain and posttraumatic stress. *PLoS ONE* 2011; 6: 2–7.

23. Smith AC, Albin SR, Abbott R, et al. Confirming the geography of fatty infiltration in the deep cervical extensor muscles in whiplash recovery. *Sci Rep* 2020; 10: 1–8.

24. Abbott R, Peolsson A, West J, et al. The qualitative grading of muscle fat infiltration in whiplash using fat and water magnetic resonance imaging. *Spine J* 2018; 18: 717–725.

25. Snodgrass SJ, Stanwell P, Weber K, et al. Greater muscle fat infiltrate in the cervical spine extensor muscles in individuals with chronic idiopathic neck pain compared to matched asymptomatic controls: a cross-sectional study. 2022 [cité 12 avr 2023]; Disponible sur: https://www.researchsquare.com/article/rs-1634066/v1

26. Garzonio S, Arbasetti C, Geri T, et al. Effectiveness of specific exercise for deep cervical muscles in nonspecific neck pain: a systematic review and meta-analysis. *Phys Ther* 2022; 102: 1–13.

27. Bertozzi L, Gardenghi I, Turoni F, et al. Effect of therapeutic exercise on pain and disability in the management of chronic nonspecific neck pain: systematic review and meta-analysis of randomized trials. *Phys Ther* 2013; 93: 1026–1036.

28. Wilhelm MP, Donaldson M, Griswold D, et al. The effects of exercise dosage on neck-related pain and disability: a systematic review with meta-analysis. *J Orthop Sports Phys Ther* 2020; 50: 607–621.

29. Sterling M, de Zoete RMJ, Coppieters I, et al. Best evidence rehabilitation for chronic pain part 4: Neck Pain. *J Clin Med* 2019; 8: 1219.

30. Blanpied PR, Gross AR, Elliott JM, et al. Clinical practice guidelines linked to the international classification of functioning, disability and health from the orthopaedic section of the American physical therapy association. *J Orthop Sports Phys Ther* 2017; 47: A1–83.

31. Gross A, Kay TM, Paquin JP, et al. Exercises for mechanical neck disorders. *Cochrane Database Syst Rev* 2015; 1: 1–193.

32. O'Leary S, Jull G, Kim M, et al. Training mode-dependent changes in motor performance in neck pain. *Arch Phys Med Rehabil* 2012; 93: 1225–1233.

33. Jull G, Falla D, Vicenzino B, et al. The effect of therapeutic exercise on activation of the deep cervical flexor muscles in people with chronic neck pain. *Man Ther* 2009; 14: 696–701.

Published in: Clinical Rehabilitation (2023), vol. 37, n°12, pp. 1579 – 1610
DOI: 10.1177/0269215523118497
Status: Postprint (Author's version)

34. Schomacher J, Petzke F and Falla D. Localised resistance selectively activates the semispinalis cervicis muscle in patients with neck pain. *Man Ther* 2012; 17: 544–548.

35. Rivard J, Unsleber C, Schomacher J, et al. Activation of the semispinalis cervicis and splenius capitis with cervical pulley exercises. *Musculoskelet Sci Pract* 2017; 30: 56–63.

36. Price J, Rushton A, Tyros V, et al. Expert consensus on the important chronic non-specific neck pain motor control and segmental exercise and dosage variables: an international e-Delphi study. *PLOS ONE* 2021; 16: e0253523.

37. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA2020 statement: An updated guideline for reporting systematic reviews. *Br Med J* 2021; 372: n71.

38. de Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother* 2009; 55: 129–133.

39. Maher CG, Sherrington C, Herbert RD, et al. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther* 2003; 83: 713–721.

40. Maher CG. A systematic review of workplace interventions to prevent low back pain. *Aust J Physiother* 2000; 46: 259–269.

41. Jordan A, Bendix T, Nielsen H, et al. Intensive training, physiotherapy, or manipulation for patients with chronic neck pain. *Spine* 1998; 23: 311–318.

42. Sremakaew M, Jull G, Treleaven J, et al. Effectiveness of adding rehabilitation of cervical related sensorimotor control to manual therapy and exercise for neck pain: a randomized controlled trial. *Musculoskelet Sci Pract* 2023; 63: 102690.

43. Lytras D, Sykaras E, Iakovidis P, et al. Comparison of two different manual techniques for an exercise program for the management of chronic neck pain: a randomized clinical trial study. *J Back Musculoskelet Rehabil* 2023; 36: 199– 216.

44. Ask T, Strand LI and Sture Skouen J. The effect of two exercise regimes; motor control versus endurance/ strength training for patients with whiplash-associated disorders: a randomized controlled pilot study. *Clin Rehabil* 2009; 23: 812–823.

45. Chiu TTW, Hui-Chan CWY and Cheing G. A randomized clinical trial of TENS and exercise for patients with chronic neck pain. *Clin Rehabil* 2005; 19: 850–860.

46. Hingarajia D, Dey S and Tejwani N. Effect of deep cranio-cervical flexors training over isometric neck exercises in chronic neck pain. *Occup Ther* 2012; 6: 48–53.

47. Rodríguez-Sanz J, Malo-Urriés M, Lucha-López MO, et al. Comparison of an exercise program with and without manual therapy for patients with chronic neck pain and upper cervical rotation restriction. Randomized controlled trial. *PeerJ* 2021; 9: e12546.

48. Borisut S, Vongsirinavarat M, Vachalathiti R, et al. Effects of strength and endurance training of superficial and deep neck muscles on muscle activities and pain levels of females with chronic neck pain. *J Phys Ther Sci* 2013; 25: 1157–1162.

Published in: Clinical Rehabilitation (2023), vol. 37, n°12, pp. 1579 – 1610
DOI: 10.1177/0269215523118497
Status: Postprint (Author's version)

49. Mehri A, Letafatkar A and Khosrokiani Z. Effects of corrective exercises on posture, pain, and muscle activation of patients with chronic neck pain exposed to anterior-posterior perturbation. *J Manipulative Physiol Ther* 2020; 43: 311–324.

50. Li X, Lin C, Liu C, et al. Comparison of the effectiveness of resistance training in women with chronic computer-related neck pain: a randomized controlled study. *Int Arch Occup Environ Health* 2017; 90: 673–683.

51. Ylinen J, Takala EP, Nykänen M, et al. Active neck muscle training in the treatment of chronic neck pain in women: a randomized controlled trial. *J Am Med Assoc* 2003; 289: 2509–2516.

52. Falla D, Lindstrøm R, Rechter L, et al. Effectiveness of an8-week exercise programme on pain and specificity of neck muscle activity in patients with chronic neck pain: a randomized controlled study. *Eur J Pain U K* 2013; 17: 1517–1528.

53. Giménez-Costa M, Schomacher J, Murillo C, et al. Specific versus non-specific exercises for the neck extensor muscles in women with chronic idiopathic neck pain : a randomized controlled trial. *Musculoskelet Sci Pract* 2022; 60: 102561.

54. Cetin H, Kose N and Oge HK. Virtual reality and motor control exercises to treat chronic neck pain: a randomized controlled trial. *Musculoskelet Sci Pract* 2022; 62: 102636.

55. Suvarnnato T, Puntumetakul R, Uthaikhup S, et al. Effect of specific deep cervical muscle exercises on functional disability, pain intensity, craniovertebral angle, and neck-muscle strength in chronic mechanical neck pain: a randomized controlled trial. *J Pain Res* 2019; 12: 915–925.

56. Khan M, Soomro R and Ali SS. The effectiveness of isometric exercises as compared to general exercises in the management of chronic non-specific neck pain Muhammad. *Pak J Pharm Sci* 2014; 27: 1719–1722.

57. Chung S and Jeong YG. Effects of the craniocervical flexion and isometric neck exercise compared in patients with chronic neck pain: a randomized controlled trial. *Physiother Theory Pract* 2018; 34: 916–925.

58. Chiu TTW, Lam TH and Hedley AJ. A randomized controlled trial on the efficacy of exercise for patients with chronic neck pain. *Spine* 2005; 30: 1–7.

59. Lytras DE, Sykaras EI, Christoulas KI, et al. Effects of exercise and an integrated neuromuscular inhibition technique program in the management of chronic mechanical neck pain: a randomized controlled trial. *J Manipulative Physiol Ther* 2020; 43: 100–113.

60. Jull G, Sterling M, Kenardy J, et al. Does the presence of sensory hypersensitivity influence outcomes of physical rehabilitation for chronic whiplash? - A preliminary RCT. *Pain* 2007; 129: 28–34.

61. Ludvigsson ML, Peterson G, O'Leary S, et al. The effect of neck-specific exercise with, or without a behavioral approach, on pain, disability, and self-efficacy in chronic whiplash-associated disorders: a randomized clinical trial. *Clin J Pain* 2015; 31: 294–303.

62. Michaleff ZA, Maher CG, Lin CWC, et al. Comprehensive physiotherapy exercise programme or advice for chronic whiplash (PROMISE): a pragmatic randomised controlled trial. *The Lancet* 2014; 384: 133–141.

Published in: Clinical Rehabilitation (2023), vol. 37, n°12, pp. 1579 – 1610
DOI: 10.1177/0269215523118497
Status: Postprint (Author's version)

63. Sterling M, Vicenzino B, Souvlis T, et al. Dry-needling and exercise for chronic whiplash-associated disorders: a randomized single-blind placebo-controlled trial. *Pain* 2015; 156: 635–643.

64. Landén Ludvigsson M, Peterson G and Peolsson A. Neck-specific exercise may reduce radiating pain and signs of neurological deficits in chronic whiplash - analyses of a randomized clinical trial. *Sci Rep* 2018; 8: 1–10.

65. Ris I, Søgaard K, Gram B, et al. Does a combination of physical training, specific exercises and pain education improve health-related quality of life in patients with chronic neck pain? A randomised control trial with a 4-month follow up. *Man Ther* 2016; 26: 132–140.

66. Bernal-Utrera C, Gonzalez-Gerez JJ, Anarte-Lazo E, et al. Manual therapy versus therapeutic exercise in non-specific chronic neck pain: a randomized controlled trial. *Trials* 2020; 21: 1–10.

67. Willaert W, Malfliet A, Coppieters I, et al. Does pain neuroscience education and cognition-targeted motor control training improve cervical motor output? Secondary analysis of a randomized clinical trial. *Pain Pract* 2020; 20: 600–614.

68. Landen Ludvigsson ML, Peterson G, Dedering Å, et al. One- and two-year follow-up of a randomized trial of neck-specific exercise with or without a behavioural approach compared with prescription of physical activity in chronic whiplash disorder. *J Rehabil Med* 2016; 48: 56–64.

69. Ludvigsson ML, Peterson G and Peolsson A. Neck-specific exercise for radiating pain and neurological deficits in chronic whiplash, a 1-year follow-up of a randomised clinical trial. *Sci Rep* 2020; 10: 1–11.

70. Bernal-Utrera C, Anarte-Lazo E, Gonzalez-Gerez JJ, et al. Effect of combined manual therapy and therapeutic exercise protocols on the postural stability of patients with nonspecific chronic neck pain. a secondary analysis of randomized controlled trial. *J Clin Med* 2022; 11: 84.

71. Ylinen JJ, Häkkinen AH, Takala EP, et al. Effects of neckmuscle training in women with chronic neck pain: one-year follow-up study. *J Strength Cond Res* 2006; 20: 6–13.

72. Ylinen JJ, Häkkinen AH, Nykänen M, et al. Neck muscletraining in the treatment of chronic neck pain a three-year follow-up study. *Eur Medicophysica* 2007; 43: 161–169.

73. Peterson GE, Landén Ludvigsson MH, O'Leary SP, et al. The effect of 3 different exercise approaches on neck muscle endurance, kinesiophobia, exercise compliance, and patient satisfaction in chronic whiplash. *J Manipulative Physiol Ther* 2015; 38: 465–476.e4.

74. Bobos P, Billis E, Papanikolaou DT, et al. Does deep cervical flexor muscle training affect pain pressure thresholds of myofascial trigger points in patients with chronic neck pain? A prospective randomized controlled trial. *Rehabil Res Pract* 2016; 2016: 1–8.

75. Kim J and Kwag K. Clinical effects of deep cervical flexor muscle activation in patients with chronic neck pain. *J Phys Ther Sci* 2016; 28: 269–273.

76. Demoulin C, Bruyère O, Somville PR, et al. Low backpain-related meta-analysis: caution is needed when interpreting published research results. *World J Meta-Anal* 2015; 3: 93.

Published in: Clinical Rehabilitation (2023), vol. 37, n°12, pp. 1579 – 1610
DOI: 10.1177/0269215523118497
Status: Postprint (Author's version)

77. Ma LL, Wang YY, Yang ZH, et al. Methodological quality(risk of bias) assessment tools for primary and secondary medical studies: what are they and which is better? *Mil Med Res* 2020; 7: 7.

78. Anstey R, Kongsted A, Kamper S, et al. Are people with whiplash-associated neck pain different from people with nonspecific neck pain? *J Orthop Sports Phys Ther* 2016; 46: 894–901.

79. Weigl M, Letzel J and Angst F. Prognostic factors for the improvement of pain and disability following multidisciplinary rehabilitation in patients with chronic neck pain. *BMC Musculoskelet Disord* 2021; 22: 330.

80. Hidalgo B, Hall T, Bossert J, et al. The efficacy of manual therapy and exercise for treating non-specific neck pain: a systematic review. *J Back Musculoskelet Rehabil* 2018; 30: 1149–1169.

81. Miller J, Gross A, D'Sylva J, et al. Manual therapy and exercise for neck pain: a systematic review. *Man Ther* 2010; 15: 334–354.

82. Yu H, Côté P, Southerst D, et al. Does structured patient education improve the recovery and clinical outcomes of patients with neck pain? A systematic review from the Ontario Protocol for Traffic Injury Management (OPTIMa) Collaboration. *Spine J* 2016; 16: 1524–1540.

83. Haines T, Gross AR, Burnie S, et al. A cochrane review of patient education for neck pain. *Spine J* 2009; 9: 859–871.

84. Price J, Rushton A, Tyros I, et al. Effectiveness and optimal dosage of exercise training for chronic non-specific neck pain: a systematic review with a narrative synthesis. PloS One 2020; 15: e0234511.

85. Rahnama L, Peterson G, Kazemnejad A, et al. Alterations in the mechanical response of deep dorsal neck muscles in individuals experiencing whiplash-associated disorders compared to healthy controls: an ultrasound study. *Am J Phys Med Rehabil* 2018; 97: 75–82.

86. De Zoete RMJ, Armfield NR, McAuley JH, et al. Comparative effectiveness of physical exercise interventions for chronic non-specific neck pain: a systematic review with network meta-analysis of 40 randomised controlled trials. *Br J Sports Med* 2021; 55: 730–742.

87. O'Riordan C, Clifford A, Van De Ven P, et al. Chronic neck pain and exercise interventions: frequency, intensity, time, and type principle. *Arch Phys Med Rehabil* 2014; 95: 770–783.

88. Polaski AM, Phelps AL, Kostek MC, et al. Exercise-induced hypoalgesia: a meta-analysis of exercise dosing for the treatment of chronic pain. *PLOS ONE* 2019; 14: e0210418.

89. Villanueva-Ruiz I, Falla D and Lascurain-Aguirrebeña I. Effectiveness of specific neck exercise for nonspecific neck pain; usefulness of strategies for patient selection and tailored exercise-a systematic review with meta-analysis. *Phys Ther* 2022; 102: 1–11.

90. Kroll HR. Exercise therapy for chronic pain. *Phys Med Rehabil Clin N Am* 2015; 26: 263–281.

91. Lima LV, Abner TSS and Sluka KA. Does exercise increase or decrease pain? Central mechanisms underlying these two phenomena. *J Physiol* 2017; 595: 4141–4150.

92. Cooper MA, Kluding PM and Wright DE. Emerging relationships between exercise, sensory nerves, and neuropathic pain. *Front Neurosci* 2016; 10: 1–12.

Published in: Clinical Rehabilitation (2023), vol. 37, n°12, pp. 1579 – 1610
DOI: 10.1177/0269215523118497
Status: Postprint (Author's version)

93. Nazari G, Bobos P, Billis E, et al. Cervical flexor muscle training reduces pain, anxiety, and depression levels in patients with chronic neck pain by a clinically important amount: a prospective cohort study. *Physiother Res Int* 2018; 23: 1–6.

94. Booth J, Moseley GL, Schiltenwolf M, et al. Exercise for chronic musculoskeletal pain: a biopsychosocial approach. *Musculoskeletal Care* 2017; 15: 413–421.

Published in: Clinical Rehabilitation (2023), vol. 37, n°12, pp. 1579 – 1610
DOI: 10.1177/02692155231118497
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Appendix

APPENDIX 1: SEARCH STRATEGIES

(A) MEDLINE:

1.	Physical Therapy Modalities/
2.	Physical Therapy Specialty/
3.	Exercise Movement Techniques/
4.	Exercise Therapy/
5.	Muscle Stretching Exercises/
6.	Manipulation, Orthopedic/
7.	Manipulation, Spinal/
8.	Therapy, Soft Tissue/
9.	REHABILITATION/
10.	Musculoskeletal Manipulations/
11.	Physical therap*.ti,ab,kf.
12.	Exercise*.ti,ab,kf.
13.	stretching.ti,ab,kf.
14.	(Manipulati* adj2 (cervical or spinal or orthopedic or therap* or musculoskeletal)).ti,ab,kf.
15.	soft tissue therapy.ti,ab,kf.
16.	rehabilitation.ti,ab,kf.
17.	manual therap*.ti,ab,kf.
18.	physiotherap*.ti,ab,kf.
19.	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18
20.	Muscle Weakness/
21.	Muscular Atrophy/
22.	Muscular Disorders, Atrophic/
23.	CONTRACTURE/
24.	Musculoskeletal Abnormalities/
25.	(Musc* adj2 Weakness*).ti,ab,kf.
26.	((Musc* or disuse) adj4 Atroph*).ti,ab,kf.
27.	Contracture*.ti,ab,kf.

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28. (musc* adj2 abnormalit*).ti,ab,kf.
29. neural control.ti,ab,kf.
30. sensorimotor control.ti,ab,kf.
31. movement control.ti,ab,kf.
32. motor control.ti,ab,kf.
33. neuromuscular adaptation*.ti,ab,kf.
34. (musc* adj2 dysfunction*).ti,ab,kf.
35. 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34
36. Whiplash Injuries/
37. Neck Muscles/
38. NECK/
39. Neck Pain/
40. Whiplash.ti,ab,kf.
41. neck.ti,ab,kf.
42. cervical.ti,ab,kf.
43. semispinalis cervicis.ti,ab,kf.
44. splenius capitis.ti,ab,kf.
45. cervicalgia*.ti,ab,kf.
46. cervicodynia*.ti,ab,kf.
47. neckache*.ti,ab,kf.
48. 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47
49. 19 and 35 and 48

(B) Scopus:

1. exercise
2. physical therap
3. stretching
4. (manipulati AND (cervical OR spinal OR orthopedic OR therap OR musculoskeletal))
5. soft tissue therapy
6. rehabilitation
7. manual therap

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8. physiotherapy
9. 1 OR 2 OR 3 OR 4
10. 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8
11. musc AND weakness
12. (musc OR disuse) AND atroph
13. contracture
14. musc AND abnormality
15. neural control
16. sensorimotor control
17. movement control
18. motor control
19. neuromuscular adaptation
20. musc AND dysfunction
21. 11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20
22. whiplash
23. neck
24. cervical
25. semispinalis cervicis
26. splenius capitis
27. cervicalgia
28. cervicodynia
29. neckache
30. 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29
31. 10 AND 21 AND 30

APPENDIX 2: LIST AND REFERENCES OF EXCLUDED ARTICLES

The following studies were excluded for reasons listed below:

- Wrong study design (*n* = 7): 1–7
- Wrong intervention (*n* = 36): 8–43
- Wrong population (*n* = 10): 44–53
- Wrong outcome (*n* = 1): 54

References list:

1/ Lee J, Kim D, Yu K, Cho Y, You JH. Comparison of isometric cervical flexor and isometric cervical extensor system exercises on patients with neuromuscular imbalance and cervical crossed syndrome associated forward head posture. *Biomed Mater Eng.* 2018;29(3):289–298.

2/ Rupesh P, Roshma FJ, Jayavel A. Immediate effect of neck stabilization exercise on neck repositioning accuracy in chronic neck pain patients. *Int J Clin Ski.* 2017;11(2):68–72.

3/ Zauderer J, Lefèvre-Colau MM, Davoine É, et al. Exercise therapy program using immersive virtual reality for people with non-specific chronic neck pain: A 3-month retrospective open pilot and feasibility study. *Ann Phys Rehabil Med.* 2022;65(2):101527–101527.

4/ Nijs J, Ickmans K. Chronic whiplash-associated disorders: to exercise or not? *Lancet Br Ed.* 2014;384(9938):109–111.

5/ Sterling M. Physiotherapy management of whiplash-associated disorders (WAD). *J Physiother.* 2014;60(1):5–12.

6/ Kaljić E, Hadž ipašić E, Jaganjac A, Trtak N, Katana B, Pecar M. The effect of physical therapy in daily life and work activities for people with chronic cervical pain syndrome. *J Health Sci.* 2021;11(2):78–83

7/ Świątczak M, Janiak R, Leszczyńska A, et al. The effectiveness of rehabilitation by exercising central stability of the cervical spine in cognitive phase in patients with neck pain (pilot study). *Fizjoterapia Pol.* 2021;21(3):102–112.

8/ Park SH, Lee MM. Effects of lower trapezius strengthening exercises on pain, dysfunction, posture alignment, muscle thickness and contraction rate in patients with neck pain; randomized controlled trial. *Med Sci Monit.* 2020;26:920208-920208.

9/ Sjögren T, Nissinen KJ, Järvenpää SK, Ojanen MT, Vanharanta H, Mälkiä EA. Effects of a workplace physical exercise intervention on the intensity of headache and neck and shoulder symptoms and upper extremity muscular strength of office workers: A cluster randomized controlled cross-over trial. *Pain Amst.* 2005;116(1):119–128.

10/ Vikne J, Oedegaard A, Laerum E, Ihlebaek C, Kirkesola G. A randomized study of new sling exercise treatment vs traditional physiotherapy for patients with chronic whiplash-associated disorders with unsettled compensation claims. *J Rehabil Med.* 2007;39(3):252–259.

11/ Rittig-Rasmussen B, Kasch H, Fuglsang-Frederiksen A, Jensen TS, Svensson P. Specific neck training induces sustained corticomotor hyperexcitability as assessed by motor evoked potentials. *Spine.* 2013; 38(16):979–984.

12/ Svedmark Å, Djupsjöbacka M, Häger C, Jull G, Björklund M. Is tailored treatment superior to non-tailored treatment for pain and disability in women with non-specific neck pain? A randomized controlled trial. *BMC Musculoskelet Disord.* 2016;17(1):1–14.

13/ Tsang SMH, So BCL, Lau RWL, Dai J, Szeto GPY. Comparing the effectiveness of integrating ergonomics and motor control to conventional treatment for pain and functional recovery of work-related neck–shoulder pain: A randomized trial. *Eur J Pain*. 2019;23(6):1141–1152.

14/ Uthaikhup S PhD, Assapun J MSc, Watcharasaksilp K MD, Jull G PhD. Effectiveness of physiotherapy for seniors with recurrent headaches associated with neck pain and dysfunction: a randomized controlled trial. *Spine J.* 2016;17(1):46–55.

15/ Tsang SMH, So BCL, Lau RWL, Dai J, Szeto GPY. Effects of combining ergonomic interventions and motor control exercises on muscle activity and kinematics in people with work-related neck–shoulder pain. *Eur J Appl Physiol.* 2018;118(4):751–765.

16/ So BCL, Szeto GPY, Lau RWL, Dai J, Tsang SMH. Effects of ergomotor intervention on improving occupational health in workers with work-related neck-shoulder pain. *Int J Environ Res Public Health.* 2019;16(24):5005.

17/ Senthilkumar RS, Parthiban B, Parghavi M. Evaluation of work related musculoskeletal disorders in shoulder and neck with ergonomic intervention among school teachers. *Res J Pharm Technol.* 2019;12(8):3726–3730.

18/ Leaver AM. Interpreting the evidence on motor control exercises for neck pain. *Phys Ther Rev.* 2010;15(5):418–419.

19/ Martín-Rodríguez A, Sáez-Olmo E, Pecos-Martín D, Calvo-Lobo C. Effects of dry needling in the sternocleidomastoid muscle on cervical motor control in patients with neck pain: a randomised clinical trial. *Acupunct Med J Br Med Acupunct Soc.* 2019;37(3):151–163.

20/ Äng B, Monnier A, Harms-Ringdahl K. Neck/ Shoulder exercise for neck pain in air force helicopter pilots: A randomized controlled trial. *Spine.* 2009;34(16):E544–E551.

21/ Andersen LL, Andersen JL, Suetta C, Kjaer M, Sogaard K, Sjogaard G. Effect of contrasting physical exercise interventions on rapid force capacity of chronically painful muscles. *J Appl Physiol.* 2009;107(5):1413–1419.

22/ Malátová R, Puč elík J, Rokytová J, Kolář P. The objectification of therapeutical methods used for improvement of the deep stabilizing spinal system. *Neuro-Endocrinol Lett.* 2007;28(3):315–320.

23/ Moustafa I, Youssef ASA, Ahbouch A, Harrison D. Demonstration of autonomic nervous function and cervical sensorimotor control after cervical lordosis rehabilitation: A randomized controlled trial. *J Athl Train.* 2021;56(4):427–436.

24/ Stewart MJ, Maher CG, Refshauge KM, Herbert RD, Bogduk N, Nicholas M. Randomized controlled trial of exercise for chronic whiplash-associated disorders. *Pain Amst.* 2007;128(1):59–68.

25/ Dareh-deh HR, Hadadnezhad M, Letafatkar A, Peolsson A. Therapeutic routine with respiratory exercises improves posture, muscle activity, and respiratory pattern of patients with neck pain: a randomized controlled trial. *Sci Rep.* 2022;12(1):4149–4149.

26/ Abadiyan F, Hadadnezhad M, Khosrokiani Z, Letafatkar A, Akhshik H. Adding a smartphone app to global postural re-education to improve neck pain, posture, quality of life, and endurance in people with nonspecific neck pain: a randomized controlled trial. *Trials.* 2021;22(1):274–274.

27/ Gupta B, Aggarwal S, Gupta B, Gupta M, Gupta N. Effect of deep cervical flexor training vs. conventional isometric training on forward head posture, pain, neck disability index in dentists suffering from chronic neck pain. *J Clin Diagn Res.* 2013;7(10):2261–2264.

28/ Rudolfsson T, Djupsjöbacka M, Häger C, Björklund M. Effects of neck coordination exercise on sensorimotor function in chronic neck pain: a randomized controlled trial. *J Rehabil Med.* 2014;46(9):908–914.

29/ Lin, I-Hsien, Kwang-Hwa Chang, Tsan-Hon Liou, Chih-Min Tsou, et Yi-Ching Huang. Progressive shoulder-neck exercise on cervical muscle functions in middle-aged and senior patients with chronic neck pain. *Eur J Phys Rehabil Med.* 2018;54(1):13–21.

30/ Harman, K, Cheryl L., Heather B. Effectiveness of an exercise program to improve forward head posture in normal adults: A randomized, controlled 10-week trial. *J Man Manip Ther.* 2005;13 (3): 163-176.

31/ CüzdanN, Doğ an Ş K, Evcik D, Ay S. The effectiveness of portable audio biofeedback device in myofascial pain syndrome in neck and upper trapezius muscles. *J Musculoskeletal Pain.* 2013; 21(3): 217-223.

32/ Brage K., I. Ris, D. Falla, K. Søgaard, et B. Juul-Kristensen. Pain education combined with neck- and aerobic training is more effective at relieving chronic neck pain than pain education alone – a preliminary randomized controlled trial. *Man Ther.* 2015;20 (5): 686-693.

33/ Abd El-Azeim AS, Mahmoud AG, Mohamed MT, El-Khateeb YS. Impact of adding scapular stabilization to postural correctional exercises on symptomatic forward head posture: a randomized controlled trial. *Eur J Phys Rehabil Med.* 2022;58 (5).

34/ Kanwal, N, Ain QU, Shehzadi T, Faisal S, Fatima A, Waris M. Effect of proprioceptive exercises on pain and function in non-specific chronic neck pain. *Med Forum Monthly.* 2022;33 (3): 73-76.

35/ Roshdy, HS, Elkeblawy MA, Rezkallah S, Elkeblawy MM. Muscle energy technique versus static stretch on forward head posture in patients with mechanical neck pain: randomized controlled trial. *Fizjoter Pol.* 2020;20(5): 208-214.

36/ Pathan H, Pawar A, Rao R, Phansopkar P, Chitale N, Arora SP. A structured exercise program for upper cross syndrome. *J Med Pharma Sci.* 2022;11: 259-263.

37/ Abdel-Aziem AA, Mohamed RR, Draz AH, Azab AR, Hegazy FA, Diab RH. The effect of mckenzie protocol vs. deep neck flexor and scapulothoracic exercises in subjects with chronic neck pain – a randomized controlled study. *Eur Rev Med and Pharmacol Sci.* 2022;26(9): 3138-3150.

38/ Rajalaxmi V, Niranjana R, Nathan CVS, Kumar GM. Efficacy of physiotherapy intervention on craniovertebral and craniohorizontal angle using on protractor mobile app and neck muscle strength in chronic nonspecific neck pain. *Biomedicine* 2022;42(3): 589-593.

39/ Rani M, Kaur J. Effectiveness of spinal mobilization and postural correction exercises in the management of cervicogenic headache: A randomized controlled trial. *Physiother theory pract.* 2022; (9015520): 1-15.

40/ Tahir R, Sohail MMA, Ul Ain N, Ul Aine Q, Mannan Q, Maqbool A. Comparative effect of upper thoracic spine mobilization with mobility exercises and upper cervical spine mobilization with stabilization exercises in mechanical neck pain: a randomized clinical trial. *Anaesth Pain Intensive Care*. 2022;26(4): 488-495.

41/ Onan, D.; Ulger, O.; Martelletti, P. Effects of spinal stabilization exercises delivered using telerehabilitation on outcomes in patients with chronic neck pain: a randomized controlled trial. *Expert Rev. Neurother.* 2023;23(3):269–280.

42/ Suwaidi, A.S.A.; Moustafa, I.M.; Kim, M.; Oakley, P.A.; Harrison, D.E. A Comparison of Two Forward Head Posture Corrective Approaches in Elderly with Chronic Non-Specific Neck Pain: A Randomized Controlled Study. *J. Clin. Med.* 2023;12(2).

43/ Gumuscu, B.H.; Kisa, E.P.; Kaya, B.K.; Muammer, R. Comparison of three different exercise trainings in patients with chronic neck pain: a randomized controlled study. Korean J. *Pain* 2023;36(2):242–252.

44/ Conley MS, Stone MH, Nimmons M, Dudley GA. Resistance training and human cervical muscle recruitment plasticity. *J Appl Physiol.* 1997;83(6):2105–2111.

45/ Morales Tejera D, Fernandez-Carnero J, Suso-Martí L, et al. Comparative study of observed actions, motor imagery and control therapeutic exercise on the conditioned pain modulation in the cervical spine: a randomized controlled trial. *Somatosens Mot Res.* 2020;37(3):138–148.

46/ Pekyvas NO, Saygili F, Yuruk ZO, Sahim FN. The effects of exercise and lifestyle modification on pain and function in mobile phone users: a randomized controlled study. *Acta Medica Mediterr.* 2021;37:1803–1809.

47/ Yaowaluk Jaroenrungsup, Siriluck Kanchanomai, Santhanee Khruakhorn. Effects of self-posture correction exercise in forward head posture of smartphone users. *Wārasān Songkhlā Nakharin.* 2021;43(2):439–447.

48/ Randløv A, Østergaard M, Manniche C, et al. Intensive dynamic training for females with chronic neck/shoulder pain. A randomized controlled trial. *Clin Rehabil.* 1998;12(3): 200–210.

49/ Murray M, Lange B, Nørnberg BR, Søgaard K, Sjøgaard G. Self-administered physical exercise training as treatment of neck and shoulder pain among military helicopter pilots and crew: a randomized controlled trial. *BMC Musculoskelet Disord.* 2017;18(1): 147.

50/ Hidalgo-Peréz A, Fernández-García A, López-de-Uralde-Villanueva I, Gil-Martínez A, Paris-Alemany A, Fernández-Carnero J, La Touche R. Effectiveness of a motor control therapeutic exercise program combined with motor imagery on the sensorimotor function of the cervical spine: a randomized controlled trial. *Int J Sports Med.* 2015;10(6):878.

51/ Yu LJ, Gu Q, Kim TH. Effects of cervical stabilization exercises with thoracic spine extension exercises on the cervical range of motion of men and women with forward head posture. *J Pharm Negat Results.* 2022;13: 3380-3386.

52/ Llamas-Ramos R, Barrero-Santiago L, Llamas-Ramos I, Montero-Cuadrado F. Effects of a family caregiver care programme in musculoskeletal pain and disability in the shoulder-neck region—a randomised clinical trial. *Int J Environ Res Public Health*.2023;20(1).

Published in: Clinical Rehabilitation (2023), vol. 37, n°12, pp. 1579 – 1610
DOI: 10.1177/0269215523118497
Status: Postprint (Author's version)

53/ Joshi S, Kamboj R, Pawalia A. Effect of interferential therapy and elastic band exercises on subjects with round shoulder and forward head posture: a randomized trial. *J of the Dow Univ Health Sci.* 2022;16(2): 59-65.

54/ Salo PK, Häkkinen AH, Kautiainen H, Ylinen JJ. Effect of neck strength training on health-related quality of life in females with chronic neck pain: A randomized controlled 1-year follow-up study. *Health Qual Life Outcomes.* 2010;8(1):48–48.