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CERVICAL EXTENSOR MUSCLE ACTIVITY DURING NECK TASKS IN INDIVIDUALS WITH AND WITHOUT NECK PAIN: A SYSTEMATIC REVIEW

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ABSTRACT

Background: In the context of neck pain, neck muscle activity adapts through diverse regional coordination modifications during tasks. Although patterns of cervical flexor muscle impairment are well-documented, patterns in the cervical extensor muscles are less clear, hindering assessment and treatment. Despite studies revealing adaptations in the cervical extensor muscles, outcome measure heterogeneity complicates interpretation, particularly between superficial and deep muscles. To address this, we conducted a systematic review comparing neck extensor muscle activity between symptomatic and asymptomatic groups during tasks, aiming to inform clinical practice.

Objectives: To compare the cervical extensor muscle activity during neck tasks between symptomatic and asymptomatic groups, using complementary examination tools.

Methods: Up to January 2024, experimental studies assessing cervical extensor muscle activity during neck tasks in adults with idiopathic or traumatic neck pain, or cervicogenic headache compared to healthy controls were included. Study selection involved 2 blinded reviewers. Electronic databases (Medline, Scopus, and Embase), reference lists, and relevant reviews were screened. Data extraction focused on the results of the between-group motor activity comparisons. Critical appraisal used the JBI appraisal checklist for analytical cross-sectional studies.

Results: Twenty-three studies met the inclusion criteria, involving 932 participants and reporting 170 comparative assessments of 8 muscle groups, encompassing 4 main motor activity outcomes: recruitment, timing, fatigue, and directional activation. Significant differences were noted for motor recruitment in 51 % of comparisons, for timing in 35 %, and fatigue in 33 %, with consistent differences in directional activation. Impaired activity in individuals with neck pain compared to those without was found in 47 % of comparisons for superficial muscles and 65 % for deep muscles.

Conclusions: Motor activity adaptations during neck tasks appear to be unpredictable in individuals with neck pain, with a tendency for change in the deep cervical extensor muscles. Further high-quality studies are needed to confirm these findings, considering various contraction parameters, multiple muscle analyses, and several motor activity outcomes.

Trial registration: PROSPERO International Prospective Register of Systematic Review CRD42022285864

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Introduction

Neck pain is a common musculoskeletal disorder [1,2] that can significantly impact function and quality of life [3]. The 12-month prevalence of neck pain in adults ranges from around 30 % to 50 %[1], and the 12-month incidence of neck pain episodes is 17 % [4]. Neck pain is considered as a multidimensional pain experience [5] with physical, emotional and psychological moderators that can be influenced by social, work or lifestyle drivers. The multidimensional nature of pain makes it challenging to treat and many people experience recurrent pain. One study found that only 6 % of individuals who experienced neck pain in the previous year reported that their pain was non-recurrent [6].

One of the contributors to chronic neck pain is a lack of cervical extensor muscle endurance [7,8]. Additionally, nociceptive inputs in the neck region can induce motor adaptations [9,10] that may cause persistent, non-specific neck pain [11,12] and/or cervicogenic headaches [13]. Such maladaptive changes include altered local muscle coordination, ie, increased muscle coactivation [14], decreased specificity of muscle activity [15], decreased deep muscle activity [15], delayed onset of activity [16,17], altered muscle relaxation [18], and lower extent of adaptation of muscle activation [19]). These changes are present during neck [15], shoulder [20] and functional tasks [21]. However, not all of these adaptations contribute to chronic neck pain; symptoms may resolve despite their persistence [22,23].

The characteristic patterns of cervical flexor muscle impairment in neck pain are well known, and specific assessments [24,25] and exercises [26] have been developed. In contrast, the patterns of cervical extensor muscle impairment in neck pain conditions remain quite unclear; therefore, assessment methods [27] and rehabilitation programs may not be specifically tailored to the deficits and functional aims [28]. Various complementary examinations (ultrasound, electromyography, etc.), each with their own specificities and limitations, have identified motor adaptations of the cervical extensor muscles in neck pain. However, the heterogeneity of muscle activity outcome measures [10,15,29] complicates the interpretation of these results, as the results of motor activity analyses may also differ between the superficial and deep cervical extensor muscles. These complexities hinder clear guidance for clinicians in cervical extensor muscle assessment.

To our knowledge, motor adaptations of the cervical extensor muscles in people with neck pain have not been reviewed to date. Identifying characteristic patterns of muscular adaptations to pain would help guide clinical tests and improve rehabilitation strategies. This systematic review aimed to compare the motor activity of the neck extensor muscles analysed using complementary examinations between symptomatic and asymptomatic individuals during neck tasks.

Materials and methods

This review was conducted according to a registered protocol (PROSPERO: CRD42022285864) that was updated in February 2024. It is reported in accordance with The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines [30]. The completed PRISMA 2020 checklist is provided in Appendix A.

Eligibility criteria

Studies were included if (a) the groups of interest were composed of adults (ie, 18 years old) with non-specific neck pain, whiplash associated disorders, or cervicogenic headache, (b) the control group was composed of asymptomatic adults with no neck pain, (c) the participants underwent complementary examination(s) to assess the activity of at least 1 cervical extensor muscle, during neck tasks, (d) cervical extensor muscle activity was reported with a between-group comparison (neck pain group versus control group) concerning outcomes, (e) they were observational/cross-sectional experimental or case control (with at least 5 participants in each group) studies, and (f) the article was written in English or French. Only studies meeting all these criteria were included.

Information sources and search strategy

An extensive literature search was conducted through MEDLINE (Ovid), Scopus (Elsevier) and EMBASE (Elsevier) up to the 10th of January 2024. The search strategies for these databases were developed in collaboration with an expert in systematic reviews, using a combination of Mesh terms and free terms as appropriate. The search strategies for Medline (Ovid), Scopus (Elsevier) and Embase (Elsevier) are provided in Appendices B1, B2, B3, respectively.

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Furthermore, the reference lists of all included studies and relevant reviews were screened to identify additional studies. Additionally, to ensure comprehensive coverage and minimise potential biases, input from 2 experts in the fields was incorporated.

Study selection

Following the search, all identified citations were collated and uploaded into Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia) and duplicates were removed. Then, titles and abstracts were screened by 2 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 2 reviewers. Any disagreements that arose between the reviewers were resolved through discussion or with a third reviewer (CD).

Data extraction

Data extraction was performed by DC. The data extracted included demographic characteristics and specific condition details about the participants (age, sex, disability questionnaire scores, aetiology and duration of neck pain), the complementary examinations (type of complementary examination and the specific outcomes), the muscles assessed and the spinal level of the assessment, the details of the neck task performed for the muscle activity assessment (intensity, direction, modality of muscle contractions, and muscle role), and the main results corresponding to the between-group comparisons. If required, the authors of the articles included were contacted to request missing or additional data.

Assessment of methodological quality

Selected articles were critically appraised for methodological quality using the JBI appraisal checklist for analytical cross-sectional studies [31]. This checklist is recommended for assessing the quality of analytical cross-sectional studies [32] and is designed for use in systematic reviews. The purpose of this appraisal is to assess the methodological quality of a study and to determine the extent to which a study has addressed the possibility of bias in its design, conduct and analysis. It is a multi-item scale that consists of 8 items that address various aspects of the study methodology. The result of this appraisal can then be used to inform synthesis and interpretation of the results of the study even though no classification was proposed according to the total score.

Two reviewers (DC and SG) were involved in the methodological assessment. They were blinded to each other's data for the first 10 % of references included. As their assessments for these first references showed >80 % of agreement, the remaining references were assessed exclusively by the main investigator of the team review (DC). Any issues were resolved through discussion between DC and SG, or with a third reviewer (CD).

Data synthesis and analysis

Data and results of the selected studies were collected and analysed according to the review aim. We reported the following information in the form of descriptive statistics: population characteristics, muscle assessed using different complementary examination tools (ultrasound, electromyography or functional magnetic resonance imaging), parameters of the studied muscle activity (intensity, direction, modality of muscle contractions, and muscle role). We also reported the results of the between-group comparisons by distinguishing 4 main categories of muscle activity outcomes: motor recruitment, timing, fatigue and directional activation (which is the ability to produce a well-defined muscular contraction that appropriately reflects the anatomical position of a muscle relative to the spine during the performance of circular isometric contractions). Where appropriate, the results are presented in tables.

Results

The electronic database search yielded 4191 citations (1003 from Medline, 1731 from Scopus and 1457 from Embase) and 1 was found through other resources, leading to a total of 4192 references. After removing duplicate records (n = 2094) and screening titles and abstracts, 72 articles remained. Fig. 1 shows the study flow diagram. Of these, 23 fulfilled the inclusion criteria [14,15,33-53]. The list of the 50 excluded studies and reasons for exclusion can be found in Appendix C.

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The results of the JBI appraisal checklist for analytical cross-sectional studies assigned to each article are presented in Table 1. Among the 8 criteria evaluated, only criterion 3 was considered "not applicable (NA)" for all the articles. Criteria 1, 4, 5 and 8 were met for all or most articles. In contrast, criteria 2, 6 and 7 differed between articles. These criteria are related respectively to the details of the experimental phase (time-period, location, or demographic characteristics), the strategies implemented to manage confounding factors (presence of subgroups, use of matching between the 2 populations on characteristics), and the validity and reproducibility of the outcome measurements (experience of the examiner or the use of standardisation for studies using electromyography).

Table 1.Results of the JBI assessment for the included studies.

Study	1.	2.	3.	4.	5.	6.	7.	8.
Amiri et al. (2018) [33]	Y	Y	NA	Y	Y	Y	Y	Y
Ang et al. (2005) [51]	Y	N	NA	Y	Y	Y	UN	Y
Bonilla-Barba et al. (2020) [34]	Y	Y	NA	Y	Y	Y	Y	Y
Cheng et al. (2010) [35]	Y	N	NA	Y	Y	Y	UN	Y
Descarreaux et al. (2007) [36]	Y	UN	NA	Y	Y	UN	UN	Y
Edmonston et al. (2011) [52]	Y	UN	NA	Y	Y	UN	UN	Y
Ezzati et al. (2021) [37]	Y	Y	NA	Y	Y	UN	Y	Y
Gogia et al. (1994) [53]	Y	N	NA	N	N	N	Y	Y
Gras et al. (2018) [38]	Y	Y	NA	Y	Y	UN	UN	Y
Lascurain-Aguirrebena et al. (2018) [39]	Y	Y	NA	Y	Y	Y	UN	Y
Lecompte et al. (2008) [40]	Y	N	NA	Y	Y	N	UN	Y
Lindstroem et al. (2011) [14]	Y	N	NA	Y	Y	Y	UN	Y
Maroufi et al. (2012) [41]	Y	N	NA	Y	Y	Y	UN	Y
Nobe et al. (2022) [42]	Y	Y	NA	UN	Y	UN	Y	Y
O'Leary et al. (2011) [43]	Y	N	NA	Y	Y	N	UN	Y
Park et al. (2017) [50]	Y	N	NA	Y	Y	Y	UN	Y
Peolsson et al. (2016) [44]	Y	UN	NA	Y	Y	Y	Y	Y
Rahnama et al. (2018) [45]	Y	N	NA	Y	Y	Y	UN	Y
Schomacher et al. (2013) [46]	Y	N	NA	Y	Y	Y	UN	Y
Schomacher et al. (2012) [15]	Y	N	NA	Y	Y	UN	N	Y
Tsang et al. (2018) [47]	Y	Y	NA	Y	Y	Y	Y	Y
Vikne et al. (2013) [48]	Y	N	NA	Y	Y	Y	N	Y
Yan et al. (2023) [49]	Y	Y	NA	Y	Y	Y	Y	UN

N, no; NA, not applicable, UN, unclear, Y, yes.

Fig. 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources, showing the study selection process.

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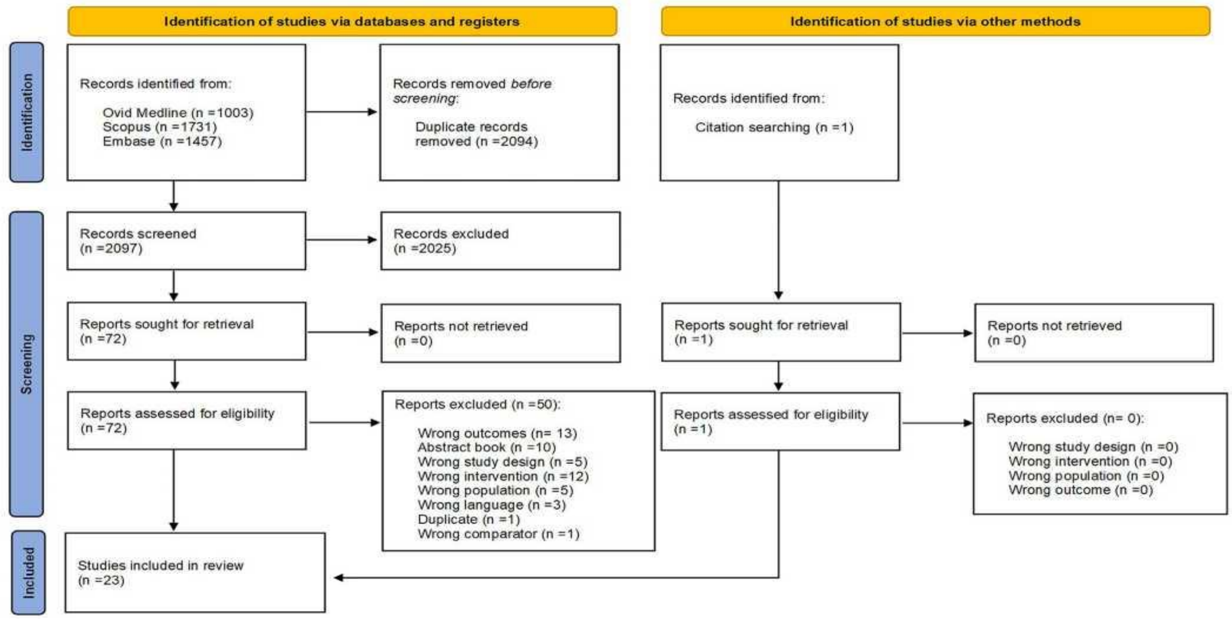

Characteristics of included articles

The studies included a total of 932 participants, comprising 460 asymptomatic participants and 472 participants with neck pain. We identified 15 studies of non-specific neck pain [14,33-35,38 -43,46,47,49-51], 5 studies of traumatic neck pain [15,36,44,45,48], 1 study of "postural neck pain" [52], 1 study of "osteoarthritis-related neck pain" [53], and 1 study of "upper trapezius myofascial pain syndrome" [37]. All studies included people with chronic symptoms (≥3 months duration), except for 2 studies, 1 that did not specify the duration of complaints [50], and another that included people with episodic complaints of neck pain [40]. The main demographic characteristics of each group are presented in Table 2.

Among the 23 articles included in this review, the observations of motor activity were primarily done by surface electromyography [14,34-36,38-42,47-53] but also intramuscular electromyography [15,46], ultrasound [33,37,44,45], and functional magnetic resonance imaging [43]. These assessments were performed across 8 different muscles or muscle groups: the upper trapezius muscle [34,37,39,41,44,45,47,49,53], the splenius capitis [14,34,35,43 -45,48,49], the semispinalis cervicis [15,43-46], the cervical erector spinae group [38,39,41,42,47,50,52,53], the multifidus [33,43-45], the semispinalis capitis [35,43-45], the "paraspinal muscles" group [36,40], and the "upper neck extensors overlying splenius capitis" group [51]. The number of muscles assessed also differed across studies, with functional magnetic resonance imaging and ultrasound assessing up to 4 [43] or 5 [44,45] different muscles simultaneously, respectively. In contrast, studies using electromyography targeted no >2 muscles at a time.

The assessments were conducted during muscle tasks with varying contraction parameters such as contraction modality (isometric [14,15,33,36-38,40-43,45,46,51-53] or dynamic [34,35,37,39,41,42,44,47-50]), muscle role (agonist [14,33,35 -38,40,41,43-45,47-53], antagonist [14,34,48], and mixed roles for multi-directional tasks [14,15,39,42,46,47]), and contraction intensity (submaximal [14,15,33-39,41-53] or maximal efforts [33,37,40,53]).

Among the various complementary examination methods used, we pooled the assessments of motor activity into 4 main categories: 1/ motor recruitment [14,15,33-49], 2/ timing [36,45,47,50], 3/ fatigue [51-53], 4/ directional activation [14,15,46]. All studies and their specific muscular activity outcomes related to the complementary examination are listed in Table 2.

Between-group motor activity comparisons

In most cases, the authors reported multiple results for the muscles assessed, different motor activity outcomes (such as motor recruitment and timing), phases of movement, varying contraction intensities, or different segmental levels studied. Additionally, a few authors also distinguished muscle laterality in their results. For the analysis and synthesis of the results obtained from the 23 studies of comparative muscle assessments, we considered each of the results reported by the authors. In total, among the 23 studies, we identified 170 between-group comparisons related to muscle assessments. The results of these comparisons are listed in Table 2.

Motor recruitment

We identified 136 between-group comparisons related to motor recruitment (see Figs. 2a, 2b and Appendix D), in 7 different muscle groups, mainly during isometric submaximal agonistic contractions. Sixty-seven comparisons did not report any between-group differences in motor recruitment [14,33-43,43-45,47,48]. However, the neck pain group showed a significant increase in muscle activity in 53 between-group comparisons [14,34-36,41,42,44,45,49] and a decrease in 16 comparisons [15,43,46-49]. Both superficial and deep muscles exhibited similar motor recruitment between groups for approximatively half of the comparisons, with 55 out of 110 and 12 out of 26 comparisons, respectively.

Timing

Between-group comparisons regarding timing were performed 20 times in 7 different muscles, mainly during isometric submaximal agonistic contractions, and focused on 4 different outcomes (Fig. 3 and Appendix E). Some authors considered onset time [50], while others concentrated on burst duration [36,47], time to peak force [36], or deformation rate, which provide information about the speed at which deformation or movement occurs within the muscle tissue [45]. Thirteen assessments out of 20 did not report any intergroup differences. However, a few studies reported some significant changes between groups: onset time contractions of superficial muscles was significantly delayed [50] in symptomatic conditions, whereas deformation rate was reported to be significantly higher [45], but only for deep muscles. Furthermore, Tsang et al. [47] reported a significant delayed offset in the neck pain group but only for unilateral upper trapezius. Finally, Descarreaux et al. [36] demonstrated that the time to peak force was significantly higher for the neck pain group, both to reach 50 % and 75 % of the maximal voluntary force.

Fatigue

Comparative assessments of muscle fatigue were performed in 6 studies [51-53], in 3 different superficial muscles ("upper neck extensors overlying splenius capitis" group, cervical erector spinae and upper trapezius muscle) during exclusively isometric agonistic contractions (Fig. 4 and Appendix F). The only between-group difference was highlighted by Gogia et al. [53], revealing that the upper trapezius muscle in the neck pain group exhibited a significantly higher slope of median electromyographic frequency, but only at high force levels (80 % and 100 % of the maximal voluntary contraction).

Directional activation

Comparative muscular assessments of directional activation were performed 8 times [14,15,46], in 2 different muscles (Splenius capitis and Semispinalis cervicis) during exclusively isometric multi-directional contractions (see Fig. 5 and Appendix G). All assessments revealed a significant decrease in directional activation for the neck pain group [14,15,46], indicating a reduced ability to recruit a specific muscle in the expected force direction.

Discussion

The comparison between individuals with non-specific or post- traumatic neck pain and asymptomatic individuals regarding motor activity of the neck extensor muscles during neck tasks showed impaired motor activity in those with neck pain in 51 % of the between-group comparisons. When distinguishing between the superficial and deep extensor neck muscles, the results revealed a tendency for deep muscle impairment (65 % of comparisons) in people with neck pain, contrasting with the superficial muscles that exhibited similar behaviour between the 2 groups in 53 % of the between-group comparisons, drawing from the entirety of motor activity assessments.

Motor recruitment

Our findings suggest that the adaptation of motor recruitment of the cervical extensor muscles in neck pain conditions appears to be particularly unpredictable. Indeed, half of the comparative assessments showed a significant between-group difference. Moreover, when modifications occurred, they could manifest as either an increase or a decrease in muscle activity. This is consistent with the theory proposed by Hodges and Tucker [54], which suggests that changes in motor activity during pain may vary in extent between individuals and are not predictable. Evidence suggests individualspecific variability in response to pain conditions as well as intermuscular variability [55]. Our findings suggest that in painful conditions, when motor recruitment alteration occurs, there is a notable increase in recruitment for the superficial muscles, whereas changes in deep muscle recruitment are more frequently associated with a reduction. These modifications involve changes at multiple levels of the motor system [22,56] and are still not fully understood [54]. This complexity may be more pronounced for the cervical extensors

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because of their greater number compared to the flexors and the multidirectional complexity inherent in the cervical region, imposing a certain functional redundancy on local muscles and their functional relations to shoulder girdle muscles, contributing to a more complex pattern in the individual response to neck pain conditions. Most studies limited assessment to a restricted number of muscles for a given task, which limits the ability to identify potential changes across all cervical
extensor muscles. Furthermore, parameters characterizing muscle tasks (intensity, contraction modalities, duration, agonist or antagonist role, movement speed, etc.) could also influence muscle activity. Additionally, factors such as anxiety, fear of movement/pain [57,58], the level of functional disability [59,60] or neck pain intensity during contractions [16,58,61] could influence motor recruitment. Clinically, these changes in motor recruitment might manifest as a reduction in muscle strength, and/or by an increase in antagonistic activity, associated with higher levels of pain and disability [14]. This reduction in strength might not be readily apparent, as the deficit in recruitment could be compensated by an increased activity in synergistic muscles [56,62].

Timing

The timing of muscle activation was observed across 3 different aspects and through various means, both in terms of outcomes and during different muscular tasks. The results related to muscle onset timing revealed conflicting findings, showing both delayed [50] or unchanged onsets [45] for superficial muscles. The delayed onset was observed only on the painful side, potentially explained by reduced local muscle activity aiming to minimize mechanical stress. Additionally, the deep muscles exhibited a faster contraction capacity in cervical pain conditions [45], possibly explained by findings suggesting motor control alterations aiming to enhance spinal protection. However, this observation contradicts previous studies that demonstrated delayed onset for both deep and superficial muscles [17,63]. This discrepancy may arise from variations in techniques employed to analyse the onset timing of deep muscles, as Rahnama et al. [45] employed deformation rate, which can be influenced by neighbouring muscle/tissue deformation.

The offset timing was only studied twice [36,47] for various superficial muscles during different neck tasks; but few significant between-group differences were observed, and differences were only unilateral for 1 of the 2 muscles assessed and for 2 out of 3 movements. A reduced ability of the upper trapezius to relax in neck pain has been reported before, but mainly in studies examining its activity during upper limb tasks [21,59]. This prolonged activation might correlate with the perceived level of pain [64].

Finally, in people with whiplash associated disorders, the superficial extensor muscles also exhibited a prolonged time to reach a specific force level [36], while demonstrating equivalent accuracy in controlling the applied force. However, people with neck pain are known to have impaired spatial accuracy [22]. This discrepancy accounts for the increased time to reach peak force, as it aims to maintain precise control of the applied force.

The presence of neck pain appears to influence various temporal aspects of muscle activation, albeit without following a stereotypical pattern. This variability might be attributed to inter-individual differences including the perceived level of pain among affected individuals [16] and the variability in the contraction parameters across numerous tasks.

Fatigue

Among the few studies examining the muscle fatigue of the extensor muscles [51-53], the only study that identified more pronounced signs of fatigue in cervical pain conditions reported a between-group difference exclusively for high force levels (80 % of maximal voluntary force) up to maximal levels [53]. The increases in the slope of median frequency, reflecting muscle fatigue, have previously been correlated with an increased accumulation of metabolites, reduced concentration of calcium ions, decreased intramuscular pH, and slowed intramuscular conduction velocity [65]. The force levels employed in other studies might not have been sufficient to generate these intramuscular metabolic changes. However, it seems that the strength and endurance of the cervical extensor muscles may be compromised to varying degrees in cases of cervical pain, possibly explaining the variable findings observed across studies assessing these parameters [36,66-69]. Some authors [58,66,70] have suggested that fear avoidance levels, as well as current pain and neck disability levels, could contribute to the reduction in strength and endurance.

Directional activation

The findings consistently indicated a unanimous result: a reduction in directional activity within the cervical

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muscles in the presence of neck pain, affecting both the deep and superficial cervical extensor muscles [14,15,46]. These findings suggest that pain significantly disrupts the ability of the cervical muscles to contract at the expected direction in the presence of pain. Similar findings were previously noted for the sterno-cleido-mastoid muscle, also during isometric multidirectional contractions; wherein a decrease in directional activity coincided with an increase in motor recruitment amplitude [71]. This corroborated exactly the results found for the splenius capitis in the study by Lindstrom et al. [14]. However, for the deep
muscles, the decrease in directional activity appears to be associated with a reduction in motor recruitment amplitude [15,46], indicating a moderate correlation of 41 %. Similarly, Schomacher et al. [46] found a significant correlation between the mean activity of the semi- spinalis cervicis and its directional activity. Clinically, the combined decrease in directional activity and motor recruitment of muscles contributing to cervical segmental stability [72,73] could compromise active cervical spine stability, thereby increasing the risk of pain and injury [74].

Interestingly, this reduction in directional activity does not solely stem from a muscle's diminished ability to contract in the expected direction or an expanded range within which it can contract. It also involves an increase in its activity in an antagonistic role. This increase in antagonistic co-activation has already been reported [14,75] and might reflect an attempt to enhance cervical spine stability. However, this could potentially lead to a reduction in maximum strength and/or range of motion and an increase in tissue loading [54].

Limitations

Despite offering original and valuable insights, this systematic review has some limitations. First, the studies included in this review exhibited considerable heterogeneity in muscle contraction patterns during various cervical tasks, encompassing static and dynamic activities, as well as a wide range of intensities, with muscles playing different roles as agonists or antagonists. Second, within the studies encompassed by our review, we observed a significant heterogeneity in the descriptors employed to analyse differences in muscle activity between groups with and without neck pain. Third, most studies in this review only analysed the activity of 1 or 2 muscles, which is relatively limited considering the large number of extensor muscles. The heterogeneity of contraction parameters and descriptors used to analyse muscle activity outcomes, the limited number of muscles studied simultaneously, and the aetiological heterogeneity (we considered individuals suffering from both traumatic and idiopathic neck pain), hinder firm conclusions about the neck extensor muscle activity in neck pain conditions. Furthermore, this large variability prevented us from conducting a meta-analysis, since the results would have been irrelevant [76]. Moreover, our observations are primarily based on chronic neck pain (21 out of 23 included studies) with mainly idiopathic aetiology. Therefore, the motor activity adaptations we observed may not fully represent those of people with other characteristics or types of neck pain. Fourth, our search strategy focused specifically on studies of cervical extensor muscles in clinical neck pain conditions published in English or French, potentially omitting reports on experimental neck pain, or studies published in other languages. However, we do not believe that this limitation significantly impacted the conclusion of our systematic review [77]. Additionally, data extraction was performed by a single researcher. Lastly, despite attempting to gather additional information by contacting several authors, poor reporting might have led to confusion regarding outcome classification or between-group comparison results.

Conclusions

Our findings suggest that individuals with neck pain do not systematically exhibit significant alterations in cervical extensor muscle activity. Each individual may present no changes or a unique mix of adaptations. These changes might specifically pertain to certain muscular abilities, involve specific muscles, and be limited to particular contraction modalities. The fact that these muscular adaptations are neither systematic nor predictable, points out the relevance of identifying individuals for whom these adaptations play significant roles. Identifying if motor impairments contribute to the symptoms could allow exercises targeting the deficits and functional aims to be proposed, leading to a reduction in the persistence of pain. Further studies focusing more on deep cervical extensor muscles and other muscular activity outcomes than motor recruitment are needed. Ideally, these studies should employ complementary examination tools capable of assessing both the deep and superficial muscles simultaneously and investigating the relationships between these examinations and clinical tests.

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Table 2. Main results of motor activity comparisons by categories.

Author (year)	Population Healthy control (n)	Participants with neck pain (n)	Muscle assessed (spine level(s))	Compl. Exam.	Outcome(s)	Experimental procedure	Main results
MOTOR RECRUITEMENT							
Amiri et al. females (2018) [33]	25 healthy (age: 31.8 (5.6))	25 NSCNP females (age: 33.6 (7.1); NDI: 23.2 (11.3))	MF (C4), unilaterally	US	Thickness: 1. Shape ratio 2. Multiplied linear dimensions	Isometric Ext at 50 % and 100 % of the MVC.	1.MFat50%and 100 % MVC: NSCNP = HC 2.MFat50%and 100 % MVC: NSCNP = HC
Bonilla-Barba et females al. (2020) [34]	30 healthy (age: 33 (11))	30 CMNP females (age: 30 (11); NDI: 11 (8))	UT (C7), SpC (C4)	sEMG	Average EMG activity	Dynamic Fl during the craniocervical flexion test (CCFT) over five incremental stages	UT: MNP > HC in all CCFT stages; SpC: MNP > HC in 22, 28 and 30 mmHg stages.
Cheng et al. (5 (2010) [35] age: 24.9 (1.8))	12 healthy adults females, 7 males;	12 NSCNP adults (6 females, 6 males; age: 25.4 (2.1); NDI: 20.8 (10); duration of symptoms: 4.4 (2.2) yrs)	SpC (C7), SspC (C2), bilaterally	sEMG	Average EMG activity	Dynamic Ext from flexed to neutral position	SspC: NSCNP=HC; SpC: NSCNP > HC
Descarreaux et al. (2007) [36]	14 healthy adults (age: 24.6 (4.2))	17 WAD I - II adults (age: 23.9 (5.8); NDI: 16.1 (11.4); time since injury: 20.2 (16.6) months)	Para (C4), bilaterally	sEMG	Integrated EMG activity	Isometric Ext at 50 % and 75 % of the MVC	Left Para at 50 % and 75 % MVC: WAD > HC; right Para at 50 % and 75 % MVC: WAD = HC
Ezzati et al. (2021) [37]	20 healthy adults (age: 25.1 (4.6))	20 UTMCPS adults (age: 25.2) (4.8))	UT (C7)	US	Thickness	1. Dynamic Ext against gravity 2. In prone, isometric maximal Ext	1. UT: UTMCPS=HC. 2. UT: UTMCPS=HC.
Gras et al. (28 (2018) [38] age: 19.58 (1.32))	34 healthy adults females, 6 males;	43 CMNP adults (38 females. 5 males; age: 19.9 (1.2); NDI: 29.5 (10.8))	CES (C2), bilaterally	sEMG	Average EMG activity	Isometric Ext against gravity during 5 to 7 s	CES: CMNP = HC
Lascurain-Aguir- (5 rebena et al. males; (2018) [39]	20 healthy adults females, 15 age: 43 (13))	20 CNP adults (17 females, 3 males; age: 45 (13); NDI: 26 (10)); Symptoms since: 10 (8) yrs)	CES (C4-5), UT (C6), bilaterally	sEMG	Average EMG activity	Dynamic Fl, Ext, left and right Rot, left and right SB without resistance	In all directions: UT and CES: CNP = HC
Lecompte et al. (10 (2008) [40] non-pilots)	18 healthy males fighter pilots, 8	9 episodic NP male fighter pilots (age: 39 (3); NPDS: 20.8 (17))	Para (C3-4), bilaterally	sEMG	Max EMG activity	Maximal Isometric in Ext and SB	Para for Ext and SB: NP = HC
Lindstroem et al. (2011) [14]	10 healthy females (age: 33.1 (9.3))	13 CNP females (age: 37.7 (7.8); NDI: 43.2 (16.8), symptoms since: 7.1 (6.1) yrs)	SpC (C2-3), bilaterally	sEMG	Average EMG activity	1.Fl 2. Ext Isometric submaximal Fl and Ext ramped from 10 % to 50 % MVC	1. SpC: CNP > HC (at all force levels for the right SpC and from 20 % to 50% force levels for the left SpC) 2. SpC: CNP > HC across all force levels for both SpC
Maroufi et al. females (2012) [41]	21 healthy (age: 23.48 (1.8))	22 NSCNP females (8 females, 16 males; age: 47.5 (15.5); NDI: 21.6 (9.4))	CES (C4), UT (C7) bilaterally	sEMG	Average EMG activity	1. Maintain the starting neutral position 2. Dynamic Fl from neutral to full Fl 3. Hold cervical full Fl for 4 s 4. Dynamic Ext from full Fl to the starting neutral position	1. CES: NSCNP > HC; UT: NR 2. CES: NSCNP > HC; UT: NR 3. CES: NSCNP > HC; UT: NR 4. CES: NSCNP = HC; UT: NR

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Nobe et al. (2022) [42]	24 healthy adults (17 females, 7 males; age: 20.5 (1.4))	24 NSCNP (8 females, 16 males; age: 47.5 (15.5); NDI: 21.6 (9.4))	CES (C4), bilaterally	G	sEM	Average EMG activity	Dynamic and isometric: 1/ Fl/Ext a) From neutral to maximum b) Hold at the maximum c) From maximum to neutral d) Right and left SB a) From neutral to maximum b) Hold at the maximum c) From maximum to neutral d) Right and left Rot a) From neutral to maximum b) Hold at the maximum c) From maximum to neutral	1/ Right and left CES during Fl a) NSNP= HC b) NSNP= HC c) NSNP > HC Right and left CES during Ext: a) NSNP > HC b) NSNP > HC c) NSNP > HC d) Right CES during right SB and left CES during left SB: a) NSNP > HC b) NSNP > HC c) NSNP > HC Right CES during left SB and left CES during right SB: a) NSNP > HC b) NSNP > HC c) NSNP > HC d) Right CES during right Rot and left CES during left Rot: a) NSNP > HC b) NSNP= HC c) NSNP= HC Right CES during left Rot and left CES during right Rot: a) NSNP > HC b) NSNP= HC c) NSNP > HC
O'leary et al. (2011) [43]	11 healthy adults (4 females, 7 males; age: 30.1 (5.2))	12 CNP adults (10 females, 2 males; age: 27.3 (5.4))	MF/SCe (C2-3, C5-6, C7-T1), SspC (C2-3), SpC (C2-3, C5-6, C7-T1), bilaterally	I	fMR	T2 calculation	1/ 20 % MVC isometric Ext in neutral cranio-cervical position 2/ 20 % MVC isometric Ext in cranio-cervical Ext	1/ C2-3: MF/Sce, SspC, SpC: CNP=HC C5-6: *MF/Sce:* CNP < HC, SpC: CNP=HC C7-T1: *MF/SCe, SpC:* CNP < HC 2/ C2-3: *MF/Sce, SspC, SpC*: CNP=HC C5-6: MF/SCe, SpC: CNP=HC C7-T1: MF/SCe, SpC: CNP=HC
Peolsson et al. (2016) [44]	9 healthy females (age: 38 (11.6))	9 CWAD II/III females (age: 38 (11.3); NDI: 30 (9); time since injury: 21 (5.1) months)	UT, SpC, SspC, SCe, MF (C4), unilaterally		US	Muscle deformation (shortening or elongation)	Dynamic Ext against 1 kg resistance: 1/ from neutral to 20° 2/ from 20° to neutral	1/ *UT, MF* shortening: CWAD > HC; *SpC, SspC, SCe:* CWAD=HC 2/ MF shortening: CWAD > HC; *UT, SpC, SspC, SCe:* CWAD=HC
Rahnama et al. (2018) [45]	36 healthy adults (age: 37 (10.54))	36 CWAD II/III adults (26 females, 10 males; age: 37 (10.8); NDI 32 (14.9))	UT, SpC, SspC, SCe, MF (C4), unilaterally		US	Muscle deformation	Isometric Ext against gravity and a weight of 2 kg (for females) or 4 kg (for males)	*SCe* and *MF* elongation: CWAD > HC;UT, SpC and SspC: CWAD = HC
Schomacher et al. (2013) [46]	9 healthy females (age: 27.2 (4.1))	10 CNP females (age: 34.1 (8.8); NDI: 39.2 (15); Symptoms since: 9.9 (11) yrs)	SCe (C2 and C5), unilaterally	G	nEM	Average EMG activity	Submaximal (15 N and 30 N) isometric circular contractions in both clockwise and counter-clockwise directions.	*SCe (C2* and C5) for both 15Nand 30 N: CNP < HC
Schomacher et al. (2012) [15]	10 healthy females (age: 26.8 (5.9))	10 traumatic CNP females (age: 30.4 (7); NDI: 42.4 (11.4))	SCe (C3), unilaterally	G	nEM	Average EMG activity	Submaximal (15 N and 30 N) isometric circular contractions, in both clockwise and counter-clockwise directions.	*SCe* for both 15N and 30N: traumatic CNP < HC
Tsang et al. (2018) [47]	34 healthy adults (age: 34.3 (9))	34 NSCNP adults (25 females, 9 males; age: 38.4 (10.9))	UT (C7), CES (C4), bilaterally	G	sEM	Average EMG activity	Dynamic: 1/ Fl/Ext 2/ Left and right SB 3/ Left and right Rot	1/ *CES* NSCNP < HC; *UT:* NSCNP=HC 2/ *CES* and *left UT:* NSCNP < HC; *right UT:* NSCNP= HC 3/ *CES* and *UT*: NSCNP = HC

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Vikne et al. (2013) [48]	15 healthy adults (9 females, 6 males; age: 38.7 (8.8))	15 CWAD II adults (9 females, 6 males; age: 40.1 (8.7); NDI: 43.4 (11.2); symptoms since: 22 (98) months)	SpC (C2-3), bilaterally	sEMG	Average EMG activity	1) Dynamic Fl from Ext back to neutral at 3 different speeds: (P) preferred speed, (S) slow speed, (M) maximum speed 2) Dynamic Ext from Fl back to neutral at 3 different speeds (P, S, M)	When EMG data was controlled for velocity and displacement: 1) *SpC* CWAD = HC at S and P and M conditions 2) *SpC* CWAD = HC at S and P and M conditions
Yan et al. (2023) [49]	22 healthy adults (12 females, 10 males; age: 23.6 (1.8))	22 CNP adults (12 females, 10 males; age: 23.2 (1.1))	UT (C7), SpC (C4-5), bilaterally	sEMG	Average EMG activity	1/ Dynamic Fl from neutral to Fl 2/Dynamic Ext from Fl to neutral	1/UTand SpC: CNP > HC 2/UT and SpC: CNP < HC
TIMING							
Descarreaux et al. (2007) [36]	14 healthy adults (age: 24.6 (4.2))	17 WAD I - II adults (age: 23.9 (5.8); NDI: 16.1 (11.4); time since injury: 20.2 (16.6) months)	Para (C4), bilaterally	sEMG	1/ Time to peak force 2/ Burst duration	Isometric Ext at 50 % and 75 % of the MVC	*1/Para* at 50 % and 75 % MVC: WAD > HC 2/ Para at 50 % and 75 % MVC: WAD = HC
Park et al. (2017) [50]	20 healthy adults (10 females, 10 males; age: 23.3 (2.0))	20 UPNP adults (10 females, 10 males; age: 23.5 (8.4))	CEM (C4), bilaterally	sEMG	Muscle onset time	Dynamic Ext against gravity to reach and hold during 5 s 45 ° of Ext	*CEM:* UPNP > HC (on the painful side only)
Rahnama et al. (2018) [45]	36 healthy adults (age: 37 (10.5))	36 CWAD II/III adults (26 females, 10 males; age: 37 (10.8); NDI 32 ‘14.9))	UT, SpC, SspC, SCe, MF (C4), unilaterally	US	Muscle deformation rate	Isometric Ext against gravity and a weight of 2 kg (for females) or 4 kg (for males)	*SCe* and *MF:* CWAD > HC; UT, SpC, SspC: CWAD = HC
Tsang et al. (2018) [47]	34 healthy adults (age: 34.3 (9))	34 NSCNP adults (25 females, 9 males; age: 38.4 (10.9))	UT (C7), CES (C4), bilaterally	sEMG	Burst duration	Dynamic: 1/ Fl/Ext 2/ Left and right Rot 3/ Left and right SB	1/ *CES; left UT:* NSCNP = HC; *right UT:* NSCNP > HC 2/ *CES; left UT*: NSCNP = HC; *right UT*: NSCNP > HC 3/ *CES* and *left & right UT*: NSCNP = HC
FATIGUE							
Ang et al. (2005) [51]	29 males helicopter/ fighter pilots	31 NSCNP males helicopter/ fighter pilots	Upper neck extensors overlying SpC (C2), bilarerally	sEMG	Slope of median EMG frequency	Isometric Ext at 28 Nm	*Superficial extensors*: NSCNP = HC
Edmondston et al. (2011) [52]	12 healthy females (age: 26.1 (5.3))	13 females with postural neck pain (age: 28.9 (12.6); NPAD: 34.6 (12.1); duration of symptoms: 51 (16) months)	CES (C5), bilaterally	sEMG	Slope of median EMG frequency	Isometric Ext against gravity and a weight of 2 kg (cervical extensor endurance test)	*CES*: postural neck pain=HC
Gogia et al. (1994) [53]	25 healthy adults (15 females, 10 males; age: 31.6 (5.3))	25 CNP adults (13 females, 12 males; age: 42.8 (14))	UT (between C3 and C6), bilaterally	sEMG	Slope of median EMG frequency	Isometric Ext at 20 %, 50 % (during 10 s), 80 % and 100 % (during 5 s) of the MVC	*UT* at 20 % and 50 % MVC: CNP = HC; at 80 % and 100 % MVC: CNP > HC
DIRECTIONAL ACTIVATION							
Lindstroem et al. (2011) [14]	10 healthy females (age: 33.1 (9.3))	13 CNP females (age: 37.7 (7.8); NDI: 43.2 (16.8), symptoms since: 7.1 (6.1) yrs)	SpC (C2-3), bilaterally	sEMG	Directional activity	Submaximal (at 15 N and 30 N) isometric circular contractions, in both clockwise and counterclockwise directions.	*SpC* for both intensities: CNP < HC
Schomacher et al. (2013) [46]	9 healthy females (age: 27.2 (4.1))	10 CNP females (age: 34.1 (8.8); NDI: 39.2 (15); Symptoms since: 9.9 (11) yrs)	SCe (C2 and C5), unilaterally	nEMG	Directional activity	Submaximal (15 N and 30 N) isometric circular contractions in both clockwise and counterclockwise directions.	*SCe* (C2 and C5) for both intensities: CNP < HC
Schomacher et al. (2012) [15]	10 healthy females (age: 26.8 (5.9))	10 traumatic CNP females (age: 30.4 (7); NDI: 42.4 (11.4))	SCe (C3), unilaterally	nEMG	Directional activity	Submaximal (15 N and 30 N) isometric circular contractions, in both clockwise and counterclockwise directions.	*SCe* for both intensities: traumatic CNP < HC

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Results in bold indicate significant differences (P< 0.05) between groups. CEM, Cervical Extensor Muscles, CES, Cervical Extensor Spinae, CMNPm, Chronic Mechanical Neck Pain, CNP, Chronic Neck Pain, Compl. Exam., Complementary examination, CWAD, Chronic Whiplash Associated Disorders, durations of symptoms/time since injury are reported in mean (SD) months or years, EMG, Electromyographic, Ext, Extension movement, Fl, Flexion movement, HC, Healthy Controls, MF, Multifidus muscle, MNP, Mechanical Neck Pain, MVC, Maximal Voluntary Contraction, N, Newton, NDI, Neck Disability Index in men (SD)%, NP, Neck pain, NPAD, Neck Pain And Disability Scale, NPDS, Neck Pain and Disability Scale, NR, Not Reported, NSCNP, Non Specific Chronic Neck Pain, Para, Paracervical muscles, Rot, Rotation movement, SB, Side-bending movement, SCe, Semispinalis Cervicis, sEMG, surface electromyogram, SpC, Splenius Capitis, SspC, Semispinalis Capitis, UPNP, Unilateral Posterior Neck Pain, US, ultrasound, UT, Upper Trapezius, UTMCPS, Upper Trapezius Myofascial Pain Syndrome, WAD I-IV, Classification of Wiplash Associated Disorders according to the Quebec Task Force Classification, yrs, age in mean (SD) years.

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Fig. 2. a: Results of motor recruitment comparisons during isometric contractions between individuals with and without neck pain. = indicates no significant between-group difference; + indicates a significant between-group difference, with higher values reported for the neck pain group; - indicates a significant between-group difference, with lower values reported for the neck pain group;% in intensity indicates% of maximal voluntary contraction; # = only at C7-T1 level; ## = For both C2 and C5 levels; * = not at 10 % MVIC; ** = only during extension and left and right side-bending; *** = only at C5-6 and C7-T1 levels; Ag, agonistic role; Atg, antagonistic role; fMRI, functional magnetic resonance imaging; Multi, multidirectional contractions; N, Newton; nEMG, intramuscular electromyography; NR, Not reported; sEMG, surface electromyography; US, ultrasonography. b: Results of motor recruitment comparisons during dynamic contractions between individuals with and without neck pain. = indicates no significant between-group difference; + indicates a significant between-group difference, with higher values reported for the neck pain group; - indicates a significant between-group difference, with lower values reported for the neck pain group; *: for the 22,28 and 30 mmHg incremental stages of the test; **: used to denote results from 13 out of 18 experimental phases, with details of other phases available in the main results table; Ag: agonistic role; Atg, antagonistic role; CCFT, Cranio-cervical Flexion Test; conc, concentric contraction; ecc, eccentric contraction; Ext, Extension movement; Fl, Flexion movement; Multi, multidirectional contractions; NR, Not reported; .sEMG, surface electromyography; SB, Side bending movement; ROT, Rotation movement; US, ultrasonography.

a

Outcomes (Compl. Examination)	Shape ratio (US)		Multiplied linear dimensions (US)		EMG activity (sEMG)		Thickness (US)	Average EMG activity (sEMG)	Max EMG activity (sEMG)	Average EMG activity (sEMG)		Average EMG activity (sEMG)	Average EMG activity (sEMG)	T2 calculation (fMRI)		Muscle deformation (US)	Average EMG activity (nEMG)		Average EMG activity (nEMG)	
Contraction's intensity	50%	100%	50%	100%	50%	75%	100%	Gravity	100%	10%, 20%, 30%, 40%, 50%		Gravity	Gravity	20%		Gravity + 2/4 kg	15N	30N	15N	30N
Agonist vs Antagonist vs Multidirectional	Ag				Ag		Ag	Ag	Ag	Ag	Atg	Ag	Ag/Atg	Ag	Ag	Ag	Multi		Multi	
Multifidus	=	=	=	=										- ***	=	+				
Semispinalis cervicis														- ***	=	+	- ##	- ##	-	-
Semispinalis capitis														=	=	=				
Splenius capitis										+	+ *			- #	=	=				
Upper trapezius							=					NR				=				
Cervical erector spinae								=				+	+ **							
Paraspinal muscles					+	+			=											
Authors	Amiri et al. (2018) [33]				Descarreaux et al. (2007) [36]		Ezzati et al. (2021) [37]	Gras et al. (2018) [38]	Lecompte et al. (2018) [40]	Lindstroem et al. (2011) [14]		Maroufi et al. (2012) [41]	Nobe et al. (2022) [42]	O'Leary et al. (2011) [43]		Rahnama et al. (2018) [45]	Schomacher et al. (2013) [46]		Schomacher et al. (2012) [15]	

b

Outcomes (Compl. Examination)	Average EMG activity (sEMG)	Average EMG activity (sEMG)	Thickness (US)	Average EMG activity (sEMG)	Average EMG activity (sEMG)		Average EMG activity (sEMG)	Muscle deformation (US)		Average EMG activity (sEMG)			Average EMG activity (sEMG)		Average EMG activity (sEMG)	
Contraction's intensity	CCFT	Gravity	Gravity	Gravity	Gravity		Gravity	Gravity + 1kg		Gravity			Gravity		Gravity	
Agonist vs Antagonist vs Multidirectional	Atg (ecc)	Ag (conc)	Ag (conc)	Multi (Fl, Ext, ROT, SB)	Ag (ecc)	Ag (conc)	Ag/Atg (conc/ecc)	Ag (conc)	Ag (ecc)	Multi (Fl-Ext)	Multi (ROT)	Multi (SB)	Ag (conc)	Atg (ecc)	Ag (ecc)	Ag (conc)
Multifidus								+	+							
Semispinalis cervicis								=	=							
Semispinalis capitis		=						=	=							
Splenius capitis	+ *	+						=	=				=	=	+	-
Upper trapezius	+		=	=	NR	NR		+	=	=	=	-			+	-
Cervical erector spinae				=	+	=	+ **			-	=	-				
Authors	Bonilla-Barba et al. (2020) [34]	Cheng et al. (2010) [35]	Ezzati et al. (2021) [37]	Lascurain Aguirrebena et al. (2018) [39]	Maroufi et al. (2012) [41]		Nobe et al. (2022) [42]	Peolsson et al. (2016) [44]		Tsang et al. (2018) [47]			Vikne et al. (2013) [48]		Yan et al. (2023) [49]	

Fig. 3. Results of timing comparisons between individuals with and without neck pain. = indicates no significant between-group difference; ¼ indicates a significant between-group difference;% in intensity indicates% of maximal voluntary contraction; *: only for the right side; ** only for the painful side; Ag, agonistic role; conc, concentric contraction; Ext, Extension movement; Fl, Flexion movement; Multi, multidirectional contractions; SB, Side bending movement; sEMG, surface electromyography; ROT, Rotation movement; US, ultrasonography.

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Outcomes (Compl. Examinations)	Time to peak force (sEMG)		Burst duration (sEMG)		Onset time (sEMG)	Deformation rate (US)	Burst duration (sEMG)		
Isometric vs dynamic	Isometric				Dynamic	Isometric	Dynamic		
Contraction's intensity	50%	75%	50%	75%	Gravity	Gravity + 2/4 kg	Gravity		
Agonist vs Antagonist vs Multidirectional	Ag				Ag (conc)	Ag	Multi (Fl-Ext)	Multi (ROT)	Multi (SB)
Multifidus						≠			
Semispinalis cervicis						≠			
Semispinalis capitis						=			
Splenius capitis						=			
Upper trapezius						=	≠ *	≠ *	=
Cervical erector spinae					≠ **		=	=	=
Paraspinal muscles	≠	≠	=	=					
Authors	Descarreaux et al. (2007) [36]				Park et al. (2017) [50]	Rahnama et al. (2018) [45]	Tsang et al. (2018) [47]		

Fig. 4. Results of fatigue comparisons between individuals with and without neck pain. = indicates no significant between-group difference; + indicates a significant between-group difference, with higher values reported for the neck pain group;% in intensity indicates% of maximal voluntary contraction; *: for the 80 % and 100 % of the maximal voluntary contraction; Ag, agonistic role; Nm, Newton meter; sEMG, surface electromyography.

Outcomes (Compl. Examinations)	Slope of median EMG frequency (sEMG)		
Isometric vs dynamic	Isometric	Isometric	Isometric
Contraction's intensity	28 Nm	Gravity + 2kg	20%, 50%, 80%, 100%
Agonist vs Antagonist vs Multidirectional	Ag	Ag	Ag
Upperneck extensors overlying splenius capitis	=		
Upper trapezius		=	
Cervical erector spinae			+ *
Authors	Ang et al. (2005) [51]	Edmondston et al. (2011) [52]	Gogia et al. (1994) [53]

Fig. 5. Results of directional activation comparisons between individuals with and without neck pain. - indicates a significant between-group difference, with lower values reported for the neck pain group; Multi: multidirectional contraction; N, Newton; nEMG, intramuscular electromyography; sEMG, surface electromyography.

Outcomes (Compl. Examination)	Directional activation (sEMG)		Directional activation (nEMG)		Directional activation (nEMG)	
Isometric vs dynamic	Isometric		Isometric		Isometric	
Contraction's intensity	15N	30N	15N	30N	15N	30N
Agonist vs Antagonist vs Multidirectional	Multi		Multi		Multi	
Semispinalis cervicis			-	-	-	-
Splenius capitis	-	-				
Authors	Lindstroem et al. (2011) [14]		Schomacher et al. (2013) [46]		Schomacher et al. (2012) [15]	

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Author contributions

DC and ND developed the search strategy and adapted it for the 3 databases screened.

In February 2022, DC and AD performed the reference screening, the methodological quality assessment and the data extraction, with the help of CB.

In October 2024, DC and SG performed the reference screening and the methodological quality assessment with the help of CB.

DC performed the data extraction. DC wrote the whole manuscript, with help and proof-reading from CD, SG, CS, ND, PP, CB, MV and BC.

Declaration of competing interest

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.rehab.2024.101910.

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