Electromyographic activity, pain, disability, and improvement perception in chronic neck pain after multimodal physiotherapy

Actividad electromiográfica, dolor, discapacidad y percepción de mejoría en dolor cervical crónico en fisioterapia multimodal

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Abstract

Introduction: Few studies have explored the clinical course in patients with chronic neck pain. Understanding the clinical course can help clinicians evaluate individual patient outcomes, define goals, and establish prognosis.
Objective: To describe the clinical course of patients with non-specific chronic neck pain (NCNP) in response to a multimodal physiotherapy program.
Methodology: A total of 15 patients with NCNP participated in a six-week physiotherapy multimodal program. Baseline assessments included sociodemographic characteristics and clinical history of neck pain. The main outcome measures were cervical muscle activity, pain, disability, and global perception of improvement. The Friedman and post-hoc tests with Bonferroni correction were used for statistical analysis.
Results: All variables under study varied significantly ($p<0.001$) over the six-week physiotherapy multimodal program. In the first 3 weeks, sternocleidomastoid and anterior scalene muscles showed a significant decrease in muscle activity of 64% and 24%, respectively. All self-reported variables were also observed early significant clinical improvements, with pain and disability decreasing by 50% and 24% at the end of the 3-week intervention. Discussion: Patients with NCNP who are treated with a physiotherapy multimodal program that includes specific motor control exercises can expect a short-term influence on the muscular activity of superficial neck muscles and a reduction of symptoms. Physiotherapists may use this information to make more informed decisions when treating patients with NCNP.
Conclusions: The results of the present study may be useful in designing clinical trials to establish whether the improvements were due to the treatment provided or natural condition recovery.

Keywords

Cervical muscle activity; chronic neck pain; clinical course; disability; physiotherapy.

Resumen

Introducción: Pocos estudios han explorado el curso clínico en pacientes con dolor cervical crónico. Comprender su evolución clínica puede ayudar a los clínicos a evaluar los resultados individuales, definir objetivos y establecer un pronóstico.
Objetivo: Describir el curso clínico de pacientes con dolor cervical crónico inespecífico (DCIC) en respuesta a un programa de fisioterapia multimodal.
Metodología: Un total de 15 pacientes con DCIC participaron en un programa de fisioterapia multimodal de seis semanas. Las evaluaciones basales incluyeron características sociodemográficas e historia clínica de dolor de cuello. Las principales medidas de resultado fueron actividad muscular cervical, dolor, discapacidad y percepción global de mejoría. Se emplearon pruebas de Friedman y post hoc con corrección de Bonferroni para el análisis estadístico. Resultados: Todas las variables estudiadas variaron significativamente ($p<0,001$) a lo largo del programa. En las primeras 3 semanas, la actividad muscular del esternocleidomastoideo y del escaleno anterior disminuyó significativamente en un 64% y 24%, respectivamente. También se observaron mejoras clínicas tempranas en todas las variables autoinformadas, con una reducción del dolor y la discapacidad del 50% y 24% al final de la tercera semana de intervención.
Discusión: Pacientes con DCIC sometidos con un programa de fisioterapia multimodal que incluye ejercicios específicos de control motor pueden experimentar una influencia a corto plazo en la actividad de los músculos superficiales del cuello y una reducción de los síntomas.
Conclusiones: Los resultados del presente estudio pueden ser útiles para diseñar ensayos clínicos que determinen si las mejoras se deben al tratamiento o a la recuperación natural del estado.

Palabras clave

Actividad muscular cervical; curso clínico; discapacidad; dolor crónico de cuello; fisioterapia.

Introduction

Neck pain is among the most prevalent musculoskeletal conditions, often leading to long-term pain and disability (Bobos et al., 2016). With a global prevalence rate of 3.5%, it is the fourth leading cause of disability-adjusted life-years (DALYs) (Hoy et al., 2014; Safiri et al., 2020). It is estimated that 22% to 70% of the population will experience neck pain at some point, particularly women over 50, with the likelihood increasing with age (Blanpied et al., 2017). In Portugal, neck pain and lower back pain are the primary causes of years lived with disability and DALYs, with prevalence rates of 16.7% and 7.9%, respectively (Kislaya & Neto, 2015). Globally, neck pain is a major public health issue, contributing to substantial healthcare costs, reduced work productivity, and absenteeism (Borghouts et al., 1998; Hoy et al., 2014; Kazeminasab et al., 2022; Lauche et al., 2012; Miyamoto et al., 2019; Noori et al., 2019). Neck pain is an unpleasant sensory experience, often felt as fatigue, tension, or pain radiating to the shoulders, arms, or head without a clear anatomical cause (Bernal-Utrera et al., 2020; Kaka et al., 2018; Tsakitzidis et al., 2013). When lasting over 12 weeks, it is termed non-specific chronic neck pain (NCNP) (Bernal-Utrera et al., 2020). About 30% of the patients may experience recurrence within five years of the first episode (Blanpied et al., 2017). The tendency for recurrence and chronicity has been partly linked to persistent alterations in the activity of neck muscles (Falla et al., 2012), compromising the maintenance of balance and head movement control (Abuin et al., 2024). Over the past decades, a well-established association between neck pain and disturbed neuromuscular control of the neck muscles has been identified (Bobos et al., 2016; Falla & Farina, 2007; Jull et al., 2009). A delay or inability to recruit the deep cervical flexor muscles (longus capitis and longus colli) is also common in NCNP patients (Bobos et al., 2016; Jull et al., 2009).

To decrease the social burden of disability caused by neck pain, effective interventions targeting specific outcomes are essential (Akodu et al., 2021; Tsakitzidis et al., 2013). Increased attention has been paid to various conservative interventions physiotherapists use to manage NCNP, particularly muscular training strategies (Bertozzi et al., 2013; Bobos et al., 2016). Motor control programs focused on craniocervical flexion exercises have been shown to reduce pain and disability with promising results (Martin-Gomez et al., 2019). Clinical studies incorporating craniocervical flexion exercises have significantly reduced pain intensity and disability (Bobos et al., 2016; Domingues et al., 2019; Martin-Gomez et al., 2019; Ylinen et al., 2003). Moreover, several studies also found that patients with the least muscular activity of the deep cervical flexors showed the greatest change in muscular activation after a 6-week training program, suggesting a positive association between pain level and improved deep cervical flexor muscles (Falla et al., 2012). While these study designs assess the effectiveness of exercise training programs, observational designs with repeated measurements at frequent intervals are better suited for understanding a condition's clinical course (Walton et al., 2014). This knowledge is critical for patients, their families, healthcare providers, policymakers, and researchers (Carroll et al., 2008). Understanding the clinical course of a condition assists in treatment planning, clinical decision-making, and policy formulation (Walton et al., 2014).

Studies on the clinical course of NCNP are scarce. Long-term clinical courses have been explored more frequently than short-term studies (less than 6 weeks) (Cecchi et al., 2011; Enthoven et al., 2004; Skargren et al., 1998; Sterling et al., 2010), which are common in clinical practice (Walton et al., 2014). However, Walton et al. (2014) described the clinical course of pain and disability in response to a 4-week multimodal physiotherapy intervention for mechanical neck pain. More recently, Weigl et al. (2021) conducted an observational prospective cohort study to evaluate pain, disability, and mental health status following a 3-week multidisciplinary, biopsychosocial, rehabilitation program in women. Curiously, these studies lack information on cervical muscle function over time.

Given the established benefits of motor control programs in improving pain and disability in NSCNP patients (Bobos et al., 2016; Domingues et al., 2019; Martin-Gomez et al., 2019; Ylinen et al., 2003), there is a need to investigate the clinical course of the cervical muscle activity during the intervention program, including cranio-cervical flexion exercises. To our knowledge, no study has yet simultaneously investigated the clinical course of cervical muscular function and self-report variables in people with NCNP.

The present study aims to describe and characterise the clinical course of NCNP patients submitted to a 6-week multimodal physiotherapy program, including exercise training focused on the deep cervical

flexor muscles. The study will assess cervical muscle function, pain intensity, disability, and patient global perceived improvement. The results may provide valuable information on the evolution and behaviour of these variables over the 6-week program, including any trends or patterns, helping physiotherapists in their clinical decision-making based on the expected outcomes for patients with NCNP.

Method

A prospective cohort study with 7 repeated measurements was conducted to describe the clinical course of pain intensity, disability, global perceived improvement, and cervical muscle activity in patients with NCNP during a 6-week multimodal physiotherapy program that included motor control training exercises focused on deep cervical flexor muscles. The Ethics Committee of the Polytechnic Institute of Setúbal approved this study (74/CP/2021).

Participants

Participants were recruited from physiotherapy clinics in Estremoz, Portugal. Consecutive patients aged between 18 and 65 years (Borghouts et al., 1998; Kashfi et al., 2019) diagnosed with NCNP were included. NCNP was defined as pain in the cervical region with no specific anatomopathological diagnosis with or without arm pain for at least three months (Blanpied et al., 2017; Domingues et al., 2019). Patients also had to indicate physiotherapy treatment, including motor control training for cervical muscles (Blanpied et al., 2017), and being able to read and speak European Portuguese (Domingues et al., 2019). They were excluded if the cause of neck pain was a fracture, dislocation, disc herniation, tumor, infection (Walton et al., 2014), inflammatory disorders, pregnancy or had undergone neck surgery in the previous six months (Domingues et al., 2019) or if they participated in an exercise program for the cervical spine in the last 12 months (Falla et al., 2012). The patients' eligibility was confirmed during the first physiotherapist appointment. Those who met the criteria were referred to the study and fulfilled a standardised form to collect sociodemographic and clinical data. All patients received oral and written information about the objectives and procedures of the research and agreed to participate by signing an informed consent.

Sample Size

The sample size and power calculations were performed with ClinCal software online program (https://clincalc.com) and based on a previous study with a sample of 15 participants. The calculations were based on detecting a median difference between baseline and end-of-treatment of 10 points on the Neck Disability Index, assuming an interquartile range of 13.5, an alpha level of 0.05, a desired power of 80% and an estimated loss of follow-up of 15% (Domingues et al., 2019). These assumptions generated a sample size of a minimum of 15 participants. A sample size of 15 for this clinical course study is justified based on the nature of a pilot study, considering the main aim was to generate preliminary evidence about initial descriptive statistics and trends.

Intervention

Participants underwent a multimodal physiotherapy program based on the clinic's standards (individualised treatment for approximately 50 minutes thrice weekly). Each was individually interviewed and assessed by the same physiotherapist to confirm eligibility criteria. The treatment was tailored to each patient's clinical presentation based on the physiotherapist's clinical judgement. The intervention included a combination of electrotherapy/thermotherapy, manual therapy, massage, education, and a motor control exercise program for deep neck flexor muscles. Electrotherapy/thermotherapy and massage involve the application of a hot package followed by dynamic soft tissue mobilisation to improve pain, blood flow circulation, and relax muscles. This procedure was applied in the first week and whenever the patient reported muscle tension. Manual therapy techniques were also used in the first week for pain modulation (Shabbir et al., 2021). It includes a set of three passive physiological mobilisations in flexion, rotation, lateral flexion and extension to end-of-range in the supine position. Then, in the prone position, the patients received passive intervertebral joint mobilisations applied to stiff or painful joints in the upper and lower cervical spine (Maitland et al., 2005). The degree of vigour and duration of the technique were determined by clinical judgement within grade II or III, by 30-second applications, repeated three times at each spinal level treated (Domingues et al., 2019; Maitland et al., 2005). Patient

education sessions were tailored to match each patient's level of understanding, focusing on simplifying the instructions. A flyer previously prepared by the research team was used in all sessions. The initial 10 minutes of the first four sessions covered concepts regarding neurophysiological mechanisms of pain, misconceptions about pain, and distraction techniques. In the following 4 weeks, short sessions related to active coping strategies, promoting physical activity, and correcting inappropriate cervical posture behaviours were also addressed (Javdaneh et al., 2021).

The exercise program had three progression phases, according to Jull et al (2008). Initially, patients performed slow, controlled craniocervical flexion in the supine position to target deep neck flexor muscles (longus capitis and colli) instead of superficial flexors (SCM and AS). Patients then held inner range positions of craniocervical flexion, using feedback from an air-filled pressure unit (Stabilizer Pressure Biofeedback, Chattanooga, Hixson, TN, USA) placed behind the neck to monitor the slight flattening of the cervical lordosis during deep neck flexor contraction. Upon reaching 10 repetitions/10 seconds at the 26mmHg level, patients advanced to the program's second phase. The objective of the second phase was to start the movement in a loading position, maintaining the neutral position of the upper cervical spine. The patients continued their strength training in upper levels (28 and 30 mmHg). They performed the craniocervical rotation in a 4-point kneeling and sitting position while maintaining the cervical spine in a neutral position. The program's last stage involved higher load exercises with head weight or load in upper limb movement. The patients were asked to perform upper limb flexion and head lift to a maximum of 15 repetitions in the supine position. The exercise was conducted with prior contraction of the deep neck flexors muscles. All patients followed a general exercise program, with intensity and repetitions adjusted based on their baseline characteristics and individual responses to ensure pain-free, fatigue-free muscle training. Medication or alternative treatments for neck pain were discouraged during the 6-week study. Two physiotherapists, each with over 5 years of experience in musculoskeletal disorders, conducted the measurements and intervention. Experts specially trained them to improve measurement consistency.

Outcome Measures

The primary outcome measure was the muscular activity of both SCM and AS with superficial electromyography (sEMG). The secondary outcomes were pain intensity, neck disability and global perceived improvement change using the Numeric Rating Scale (NRS), Neck Disability Index (NDI) and Patients Global Impression of Change (PGIC), respectively. Data were collected at baseline (T0), and at the end of every week for the following 6 weeks of treatment (T1 to T6). At the initial appointment (T0), the EMG activity of the cervical muscles, pain intensity, and neck disability were collected. At the follow-up time points (T1 to T6) the same outcomes were measured, and the PGIC was added to assess the patient's global perceived improvement change (Figure 1).

Pain Intensity

Pain intensity was measured using a numeric rating scale that ranged from 0 ("no pain") to 10 ("as much pain as possible"). A change of 2 or more points was identified as the minimal clinically important difference in a sample of Portuguese patients with chronic neck pain (Cleland et al., 2008; Cruz et al., 2015)sample.

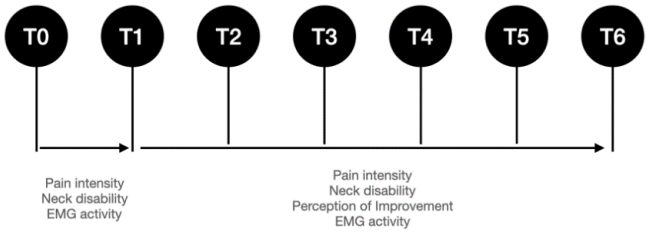
Neck disability

Neck disability was measured with the Portuguese version of the NDI (Cruz et al., 2015). It consists of a 10 self-administered questionnaire relating to daily activities due to cervical pain. Each item is scored from 0 to 5 points, with higher values representing higher levels of disability. A decrease of at least 27% in the score was identified as the minimal clinically important difference in a sample of chronic neck pain Portuguese patients (Pereira, 2012).

Patient's Global Impression of Change

The Portuguese version of the PGIC questionnaire (Domingues & Cruz, 2011) was used to determine the patient's global perceived improvement. PGIC is a 7-item verbal scale ranging from 1 (without alterations) to 7 (much improved). The PGIC has been cross-culturally adapted and validated for the European Portuguese language and has shown good psychometric properties (Domingues & Cruz, 2011).

Figure 1. Outcome measures and time points of data collection



Surface Electromyography

An sEMG system was used to measure the SCM and AS during the Craniocervical Flexion Test (CCFT) (Falla et al., 2008). Disposable pre-gelled stick-on surface electrodes with a 10 mm diameter in a bipolar configuration were placed parallel to the muscle fiber at an interelectrode distance of 20 mm. The electrodes were connected to an 8-channel EMG unit (Biosignalsplux - PLUX®) with an amplifier gain of 1000, a common mode rejection ratio of 110dB and a bandwidth of 25-500Hz. The device was used in a configuration with a 1000Hz sampling rate, 12-bit resolution and Bluetooth connection to a computer. The active electrodes for SCM and AS (bilaterally) were placed following Falla et al (2002a). A ground electrode was placed on the left wrist (ulnar styloid process). Before electrode placement, the skin was slightly abraded and cleaned with alcohol gauze pads to reduce contact impedance (Hermens et al., 2000). EMG signals were visually inspected for any background artifacts and poor electrode connection and to prevent displacement during data collection. All electrodes were fixated using Fixomull stretch plaster (BSN medical®). (Figures 2A and 2B).

The CCFT was used under a clinical protocol described by Jull et al. (2008) since its reliability has been strongly established in previous studies (Falla et al., 2003; Juul-Kristensen et al., 2013). Patients were positioned in a comfortable supine position with their knees bent and the head and neck in a mid-position. They were instructed to perform 5 incremental movements of increasing craniocervical flexion range of motion guided by visual feedback from an air-filled pressure sensor (Stabilizer, Chattanooga Group Inc. TN) initially placed behind the patient's neck and inflated to 20 mm Hg. (Figure 2B). During the test, patients were asked to perform gentle head nodding motions of craniocervical flexion to sequentially reach 5 pressure targets (increments, 2 mm Hg) between 22 to 30 mm Hg. Patients had to maintain the position at each target level for 10 seconds before resting for 5 seconds. Before the data collection, the physiotherapist gave patients a short description of the CCFT and time to practice until they demonstrated ability.

For EMG normalisation purposes, patients performed a standardised manoeuvre which involved cervical and craniocervical flexion to lift and hold the head just clear of the bed for 10 seconds (maximal voluntary contraction) (Falla et al., 2012; Jull & Falla, 2016). Good repeatability of normalised EMG amplitudes for cervical flexion contractions of SCM and AS muscles has been demonstrated previously (Falla et al., 2002b). Verbal encouragement was provided to patients to sustain and produce maximum effort. Before the normalisation task patients also performed a practical session for familiarisation and then repeated 3 times with a 30-second rest period between each repetition.

Figure 2A. EMG electrode setup

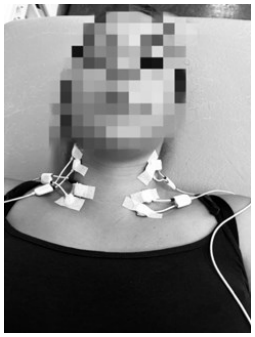
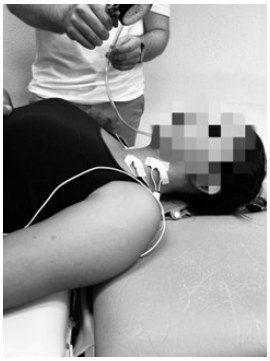


Figure 2B. Neck flexor muscles assessment during CCFT



EMG Acquisition and Processing

All EMG data was stored and identified on a personal computer and processed using OpenSignals (r)evolution software (PLUX – Wireless Biosignals®). Raw EMG signals were full wave rectified and band-pass filtered at 20 to 450 Hz (7th order Butterworth, 7 Hz at cut-off frequency). Filtered signals were smoothed by calculating a root mean squared (RMS) value over a 100-millisecond moving window to create a linear envelope. Several researchers have utilised RMS as a metric to assess EMG activities (Falla et al., 2003; Jull & Falla, 2016; Juul-Kristensen et al., 2013), further confirming its importance and widespread applicability (Okilanda et al., 2024). The peak EMG signal amplitude was recorded for each maximal voluntary contraction (MVC) repetition, with the highest value across the 3 MVC repetitions used as a reference for EMG amplitude normalisation (Falla et al., 2004). The mean RMS amplitudes for each stage of the craniocervical flexion test were then normalised to these reference values and expressed as a percentage of MVC (%MVC) for statistical analysis.

Data analysis

Data analyses were performed using IBM Statistical Package for Social Sciences (SPSS) 28.0. Descriptive statistics, including central tendency and dispersion measurements, were used to summarise the participant's sociodemographic and clinical data. Non-normal distribution was confirmed with a Shapiro-Wilk test of all outcome measures ($p > 0.05$) so data were analysed with non-parametric tests. Descriptive statistics, including central tendency and dispersion measurements, were used to summarise the participant's sociodemographic and clinical data. Friedman test was conducted for each outcome measure to determine any significant difference in the measurements over time. Bonferroni correction for p-values was used to define substantial differences between 7-time points. All data were expressed as median and interquartile ranges. The significance level was set at $\alpha = 0.05$ for all analyses.

Results

We identified 17 participants, and all completed baseline assessments with no missing data. Two participants who did not complete the course of the 6-week treatments were excluded. All participants tolerated multimodal intervention well without any adverse effects during treatment or in the follow-up periods. The baseline demographic and clinical characteristics of 15 participants are presented in Table 1. The mean age of participants was 43.73 (SD 11.71) years. Pain intensity and neck disability were 6.0 (SD 1.13) and 29.0 (SD 5.98), respectively.

Table 1. Baseline sociodemographic and clinical characterisation of the participants (n=15)

Variables	Categories	Values
Age (years), mean (SD)		43.73 (11.71)
Weight (Kg), mean (SD)		75.33 (13.24)
Height (cm), mean (SD)		167.06 (9.43)
Body Mass Index (Kg/m²), mean (SD)		27.08 (4.80)
Gender, n (%)	Male	5 (33.30%)
	Female	10 (66.70%)
Educational level, n (%)	Primary School	3 (20.00%)
	Secondary School	6 (40.00%)

	University	6 (40.00%)
Duration of pain, n (%)	3-6 months	11 (73.30%)
	6-12 months	4 (26.70%)
Pain referred to head or/and upper limb, n (%)	Yes	4 (26.70%)
	No	11 (73.3%)
Headache, n (%)	Yes	3 (20.0%)
	No	8 (80.00%)
Dizziness, n (%)	Yes	7 (46.70%)
	No	8 (53.30 %)
Pain in other regions of the vertebral column, n (%)	Yes	6 (40.00%)
	No	9 (60.00%)
Medication, n (%)	Yes	6 (40.00%)
	No	9 (60.00%)
Pain intensity (NRS), mean (SD)		6.00 (1.13)
Neck Disability (NDI), mean (SD)		29.00 (5.98)

Legend: SD=standard deviation; NRS=Numeric Rating Scale; NDI=Neck Disability Index

Clinical Course of Pain Intensity, Neck Disability and Patient Perceived Improvement

All self-reported variables gradually improved over time (Figure 3). Pain and disability decreased by 83% and 45% from the baseline to the 6-week treatment. The greatest change in neck disability occurred between T3-T4 (18%) and after the 4 weeks, no major changes were observed in both pain and disability. The median of the PGIC scores increased 5 points from the first to the last week of treatment (Figure 1). A comparison of all self-reported measures was performed using Friedman's test showing a statistically significant over the 6-week of treatment on pain intensity ($\chi2(6) = 86.399$, $p < 0.001$), neck disability ($\chi2(6) = 88.709$, $p < 0.001$), and patient-perceived improvement ($\chi2(5) = 71.175$, $p < 0.001$) (Table 2).

Figure 3. The evolution of the self-reported variables over time

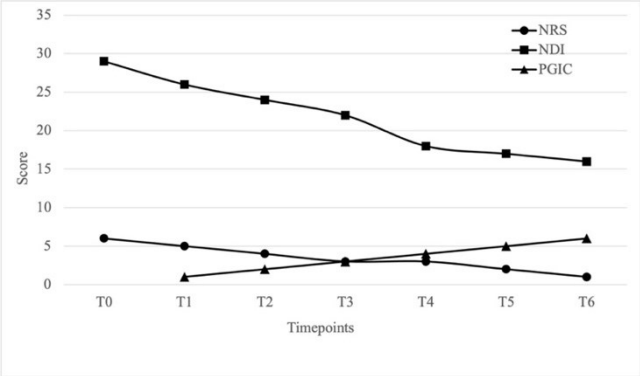


Table 2. Results of the self-reported variables at different time points

Variables	Time points of Data Collection							x^2	*p*-value
	T0	T1	T2	T3	T4	T5	T6		
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)		
Pain Intensity (NRS)	6.00 (5-7)	5.00 (5-6)	4.00 (3-5)	3.00 (3-4)	3.00 (2-3)	2.00 (1-2)	1.00 (1-2)	86.39	<0.001
Neck Disability (NDI)	29.00 (24-32)	26.00 (21-30)	24.00 (18-28)	22.00 (16-26)	18.00 (14-23)	17.00 (12-21)	16.00 (10-20)	88.70	<0.001
Global Perceived Improvement (PGIC)	-	1.00 (1-2)	2.00 (2-3)	3.00 (3-4)	4.00 (4-5)	5.00 (5-6)	6.00 (6-7)	71.17	<0.001

Legend: IQR=Interquartile Range; NRS=Numeric Rating Scale; NDI=Neck Disability Index; PGIC=Patient Global Improvement of Change; T0=baseline; T1=week 1; T2=week 2; T3=week 3; T4=week 4; T5=week 5; T6=week 6.

Post hoc analysis with Bonferroni adjustment (Table 3) revealed that compared to baseline data (T0), a significant decrease in pain and disability was already found 3 weeks after treatment ($p<0.05$). The results also showed significant differences ($p<0.05$) in the patient's perception of improvement between the first assessment moment (T1) and the 4, 5 and 6 time points.

Table 3. Multiple comparisons between moments of the self-reported variables

Self-Reported Variables	Time points	Test Statistic	*p-value*
Pain Intensity (NRS)	T6-T5	0.633	1.000
	T6-T4	1.967	0.266
	T6-T3	2.667	0.015
	T6-T2	3.767	0.000
	T6-T1	4.767	0.000
	T6-T0	5.567	0.000
	T5-T4	1.333	1.000
	T5-T3	2.033	0.209
	T5-T2	3.133	0.001
	T5-T1	4.133	0.000
	T5-T0	4.933	0.000
	T4-T3	0.700	1.000
	T4-T2	1.800	0.472
	T4-T1	2.800	0.008
	T4-T0	3.600	0.000
	T3-T2	1.100	1.000
	T3-T1	2.100	0.163
	T3-T0	2.900	0.005
	T2 T1	1.000	1.000
	T2-T0	1.800	0.472
	T1-T0	0.800	1.000
Neck Disability (NDI)	T6-T5	0.867	1.000
	T6-T4	1.767	0.527
	T6-T3	2.933	0.004
	T6-T2	3.800	0.000
	T6-T1	4.833	0.000
	T6-T0	5.867	0.000
	T5-T4	0.900	1.000
	T5-T3	2.067	0.185
	T5-T2	2.933	0.004
	T5-T1	3.967	0.000
	T5-T0	5.000	0.000
	T4-T3	1.167	1.000
	T4-T2	2.033	0.209
	T4-T1	3.067	0.002
	T4-T0	4.100	0.000
	T3-T2	0.867	1.000
	T3-T1	1.900	0.336
	T3-T0	2.933	0.004
	T2-T1	1.033	1.000
	T2-T0	2.067	0.185
	T1-T0	1.033	1.000
Patient Global Improvement of Change (PGIC)	T1-T2	-0.867	1.000
	T1-T3	-1.867	0.094
	T1-T4	-2.767	0.001
	T1-T5	-3.800	0.000
	T1-T6	-4.700	0.000
	T2-T3	-1.000	1.000
	T2-T4	-1.900	0.081
	T2-T5	-2,.33	0.000
	T2-T6	-3.833	0.000
	T3-T4	-0.900	1.000
	T3-T5	-1.933	0.070
	T3-T6	-2.833	0.001
	T4-T5	-1.033	1.000
	T4-T6	-1.933	0.070
	T5-T6	-0.900	1.000

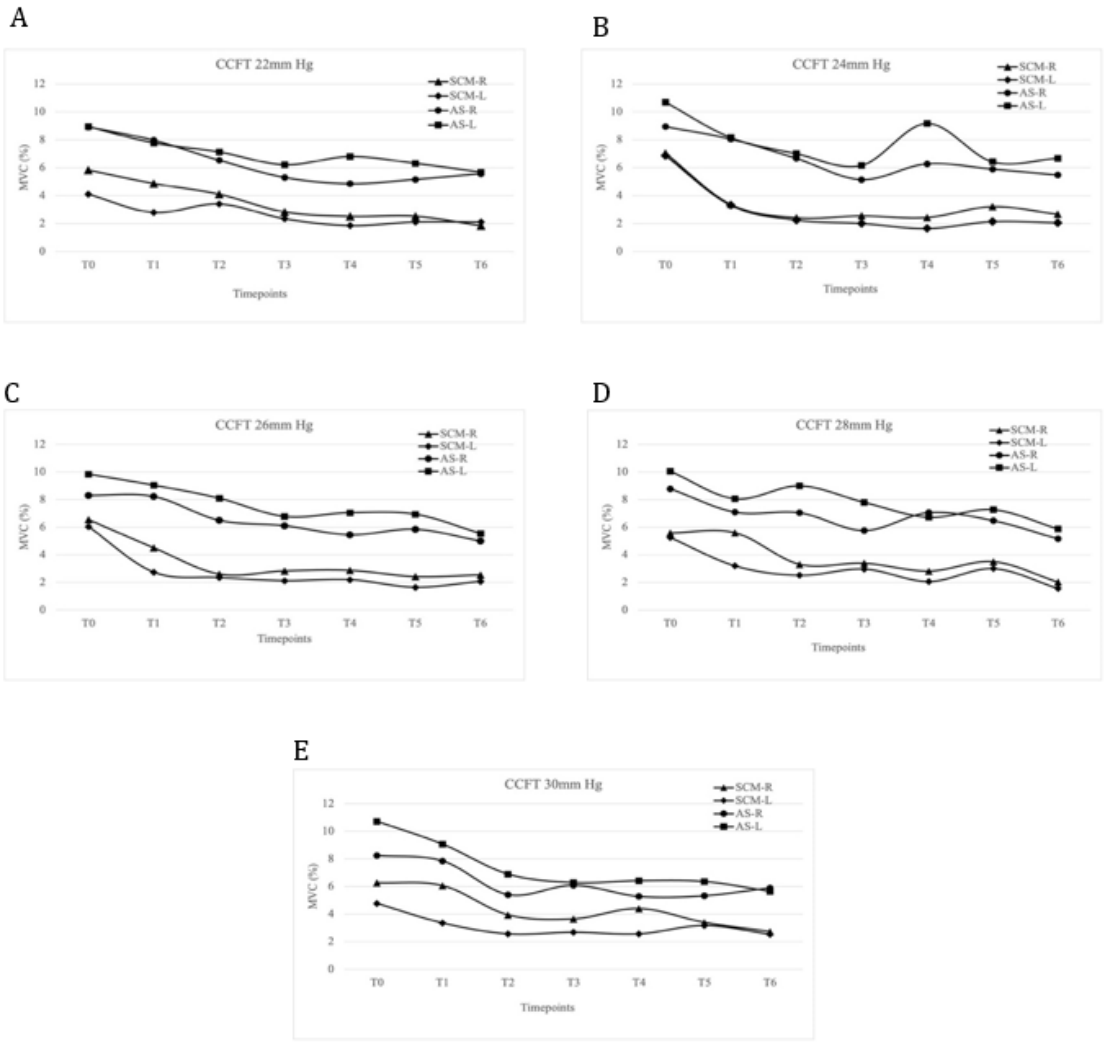
Multiple comparisons between time point moments applying Friedman test with Bonferonni correction. Significant differences ($p < 0.05$) are highlighted in bold.

Clinical Course of Cervical Flexor Muscle Activity

Figures 4A to 4E summarise the muscular activity of the superficial neck flexor muscles. The results exhibit a progressive decrease of the EMG activity from baseline to 6 weeks of the program at all CCFT

stages. The greatest changes were observed in both SCM at 24mm Hg and 26mm Hg levels, with a decrease of over 60% between baseline (T0) and the third assessment moment (T2) (Figures 4B and 4C, Table 4).

Figure 4. Superficial neck flexor muscle activity at the different stages of the CCFT in all assessment time points.



AS muscles were continuously more active than SCM muscles. The left portion of the AS and the right portion of the SCM were always dominant compared to their counterparts, particularly at the 26, 28 and 30mm Hg stages of the cervical flexions. The contraction levels of the AS-R and AS-L ranged between 8.94 and 4.57 (%MVC) and 10.72 and 5.55 (%MVC), respectively, while the SCM-R and SCM-L contraction levels varied between 7.04 and 1.84 (%MVC) and 6.87 and 1.56 (%MVC), respectively (Table 4). According to the Friedman test, both portions of the AS and SCM muscles varied significantly at all CCFT levels throughout the 6-weeks of intervention, except for AS-R ($\chi 2(6) = 11.120$, $p = 0.085$) in craniocervical flexion of 26mm Hg (Table 4).

Using the pairwise comparison method with Bonferroni correction, the assessment moments were identified between which there were statistically significant differences in the activity of the cervical muscles under study. According to the application of the test, there seems to be a greater tendency for results with statistical significance ($p<0.05$) between the first two (T0 and T1) and the last two assessment moments (T5 and T6). This aspect was more evident in AS-L at levels 26, 28 and 30mm Hg, in SCM-R at 22mm Hg and in SCM-L at 28mm Hg. Conversely, there was a greater tendency for results without statistical significance between the baseline (T0) and the T1, T2 and T3 moments. Examples of exceptions were found between the first three weeks of intervention (T0 to T3), where the SCM-R significantly decreased its activity at 22mm Hg ($p=0.021$), at 24mm Hg ($p<0.001$) and 26mm Hg ($p=0.037$) as well as EA-D ($p=0.006$) and AS-L ($p=0.021$) at 24mm Hg.

Table 4. Results of the activity of superficial neck flexor muscle at different levels of the CCFT over the 6 weeks of intervention (values expressed in %MVC).

CCFT Stages	Muscle	Time points							x^2	*p value*
		T0	T1	T2	T3	T4	T5	T6		
		Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)		
22mm Hg	SCM-R	5.83 (3.75-8.58)	4.87 (3.75-5.35)	4.10 (2.91-4.85)	2.83 (1.87-4.80)	2.51 (1.30-4.20)	2.52 (1.78-3.29)	1.84 (1.33-2.45)	45.97	<0.001
	SCM-L	4.11 (2.50-8.05)	2.80 (2.00-4.40)	3.41 (2.30-3.95)	2.35 (1.93-3.44)	1.86 (1.35-3.25)	2.12 (1.86-4.47)	2.12 (1.35-2.72)	27.22	<0.001
	AS-R	8.92 (6.87-11.41)	7.96 (5.59-11.23)	6.53 (4.70-8.47)	5.30 (3.42-7.92)	4.85 (3.92-5.81)	5.16 (3.37-6.26)	4.57 (3.26-6.17)	23.05	<0.001
	AS-L	8.95 (7.34-15.50)	7.77 (6.67-11.15)	7.13 (6.26-8.92)	6.21 (5.40-7.83)	6.80 (5.24-7.85)	6.31 (5.62-7.33)	5.68 (5.21-6.77)	26.91	<0.001
24mm Hg	SCM-R	7.04 (5.85-7.94)	3.37 (2.45-5.24)	2.42 (1.65-3.69)	2.55 (2.09-3.77)	2.44 (1.18-4.85)	3.23 (2.73-3.59)	2.67 (1.88-3.60)	32.85	<0.001
	SCM-L	6,87 (2.18-8.56)	3.32 (2.31-5.54)	2.26 (1.32-3.00)	2.02 (1.77-3.55)	1.66 (1.40-3.04)	2.15 (1.60-3.01)	2,07 (1.81-3.50)	20.02	0.003
	AS-R	8.94 (7.12-9.76)	8.05 (6.13-9.30)	6.66 (5.47-7.57)	5.14 (4.00-7.75)	6.27 (4.38-9.09)	5.89 (4.90-6.78)	5.47 (4.00-6.95)	23.65	<0.001
	AS-L	10.70 (7.31-13.69)	8.15 (7.05-11.40)	7.00 (5.88-9.24)	6.16 (5.25-8.06)	9.16 (5.86-10.36)	6.42 (4.51-8.09)	6.66 (5.04-7.18)	24.20	<0.001
26mm Hg	SCM-R	6.55 (4.90-8.19)	4.51 (2.70-6.61)	2.60 (1.95-3.69)	2.83 (2.31-4.25)	2.87 (1.56-5.23)	2.42 (1.23-4.59)	2.54 (1.86-3.11)	31.702	<0.001
	SCM-L	6.05 (2.51-6.33)	2.75 (1.81-4.93)	2.36 (1.40-3.14)	2.12 (1.70-2.54)	2.20 (1.80-3.22)	1.65 (1.18-2.67)	2.07 (1.45-2.85)	30.857	<0.001
	AS-R	8.13 (6.94-11.75)	8.23 (3.84-10-40)	6.50 (6.20-7.20)	6.11 (4.34-7.84)	5.45 (4.81-6.32)	5.85 (4.60-8.25)	5.00 (4.36-6.80)	11.120	0.085
	AS-L	9.85 (7.50-14.78)	9.05 (7.72-10.50)	8.10 (7.80-8.86)	6.78 (6.03-8.00)	7.05 (5.41-7.85)	6.94 (4.66-8.09)	5.55 (4.83-6.88)	31.886	<0.001
28mm Hg	SCM-R	5.58 (3.52-8.02)	5.59 (2.88-6.61)	3.31 (2.32-4.50)	3.39 (2.51-5.55)	2.82 (2.45-5.42)	3.50 (2.29-4.00)	2.02 (1.61-3.30)	31.759	<0.001
	SCM-L	5.25 (2.77-7.67)	3.20 (2.37-5.54)	2.51 (1.91-3.65)	2.97 (2.35-3.50)	2.06 (1.60-4.85)	3.00 (2.21-4.19)	1.56 (1.27-2.07)	30.514	<0.001
	AS-R	8.78 (7.05-10.43)	7.09 (3,69-9.82)	7.05 (6.04-7.60)	5.76 (4.40-7.42)	7.06 (5.14-7.59)	6.47 (5.26-7.41)	5.16 (4.40-6.26)	13.086	0.042
	AS-L	10.05 (8.56-11.33)	8.06 (7.36-10.80)	9.00 (8.18-9.29)	7.80 (7.14-8.75)	6.72 (6.30-7.33)	7.27 (5.88-7.83)	5.87 (4.75-6.90)	46.314	<0.001
30mm Hg	SCM-R	6.27 (3.67-7.27)	6.06 (4.10-6.63)	3.94 (3.56-4.89)	3.65 (3.36-5.49)	4.40 (2.81-5.23)	3.39 (2.29-3.83)	2.73 (1.57-3.83)	28.257	<0.001
	SCM-L	4.77 (3.13-7.37)	3.36 (2.66-8.00)	2.57 (1.96-3.56)	2.69 (2.23-3.95)	2.57 (1.50-4.54)	3.18 (2.10-4.01)	2.54 (1.96-3.75)	19.400	0.004
	AS-R	8.25 (7.61-9.66)	7.85 (5.05-9.47)	5.41 (3.82-8.45)	6.09 (5.10-7.36)	5.28 (4.92-7.50)	5.33 (4.52-5.66)	5.90 (3.66-7.25)	18.314	0.005
	AS-L	10.72 (7.64-12.58)	9.07 (7.32-11.00)	6,90 (6.16-7.68)	6.28 (5.51-7.50)	6.42 (5.68-6.66)	6.36 (5.36-7.16)	5.65 (5.21-7.66)	40.770	<0.001

Legend: CCFT=Craniocervical Flexion Test; IQR=Interquartile Range; T0=baseline; T1=week 1; T2=week 2; T3=week 3; T4=week 4; T 5=week 5 T6=week 6; SCM-R=right sternocleidomastoid; SCM-L= left sternocleidomastoid; AS-R=right anterior scalene; AS-L=left anterior scalene; x^2=qu square.

Discussion

To our knowledge, this was the first study to prospectively describe the activity of superficial neck muscles, pain intensity, functional disability, and global perceived improvement in patients with NCNP throughout the implementation of a multimodal physiotherapy intervention program. This study found that most patients had similar characteristics to those in other studies (Leaver et al., 2013; Walton et al., 2014). The majority were female (67%) with an average age of slightly over 40 years, 25% had symptoms for more than 6 months, and 60% managed their symptoms with medication. We also observed that these patients sought physiotherapy care with moderate to high pain levels (6.0 ± 1.13) and moderate disability (29.0 ± 5.98), as noted in previous studies (Domingues et al., 2019; Leaver et al., 2013).

The results show that only after three weeks of treatment (T0-T3) there was a significant reduction in self-reported variables, particularly pain (p=0.005) and functional disability (p=0.004), with a decrease of 3 points on the NRS and 7 points on the NDI, respectively. However, given that the minimally clinically

important difference on the NRS is 2 points (Cleland et al., 2008; Cruz et al., 2015) and on the NDI is 5 points (Pereira, 2012), we can assume there was a clinically important change as early as the second week of treatment, even though the differences between the two assessment points (T0-T2) were not statistically significant. The results also showed a progressively positive perception of the patients regarding their condition, which was also substantial (p=0.001) after three weeks of treatment (T1-T4). These findings appear to be aligned with the studies by Walton et al, (2014), Leaver et al (2013) and Weigl et al (2021), which also observed a reduction in pain and disability in response to multimodal programs. Despite similarities in study design, methodological differences (e.g., sample size and characteristics, instruments used) limit assumptions or direct comparisons with our results. However, it is interesting to note that all studies achieved significant results between three and four weeks of treatment, as reported in previous studies (Price et al., 2020). Although speculative, one possible explanation is related to the similarities in the programs used, where all authors included specific exercises for the cervical spine.

In this study, structured and progressive motor control exercise training was included, resulting in significant changes in cervical muscle activity at nearly all levels of cervical flexion. Interestingly, alongside reductions in pain and functional disability, the activity of the studied muscles also decreased significantly within the first three weeks of treatment. These findings are supported by several previous studies, where the increased activity of the deep cervical muscles led to reductions in pain, disability, and quality of life in patients with NCNP (Domingues et al., 2019; Falla et al., 2013; Jones et al., 2024; Rasmussen-Barr et al., 2023) and a history of whiplash (Sterling et al., 2003). Specifically, our study observed a significant decrease in activity in the four portions of the superficial muscles (SCM and AS), suggesting that the training may have increased deep muscle activity. Electrotherapy, massage, manual therapy, and education may have contributed to alleviating initial symptoms, such as pain and muscular tension. However, the known effects of those interventions are typically transient and do not directly act on muscle function or motor patterns. Therefore, the lasting improvements in pain, functional disability, and EMG activity of the cervical muscles strongly suggest that motor control exercises could be the main driver of success. Still, these exercises address the underlying mechanisms directly, while the other interventions provide more superficial or complementary support. This assumption is confirmed by the studies of Jull & Falla (2016) and Falla et al (2012), which concluded that low levels of superficial flexor muscle activity suggest increased deep muscle activity.

The clinical program involves training the deep muscles independently of the superficial muscles, based on motor learning principles that emphasise initial part-task training over whole movement (Falla et al., 2012). According to several authors, neuromuscular control changes can appear soon after the onset of cervical symptoms (Price et al., 2020; Sterling et al., 2003), which aligns with the behaviour of the deep muscles observed in this study. Since all participants reported symptoms for more than three months at baseline, and after three weeks of treatment, they experienced significant reductions in symptoms and superficial muscle activity, it is believed that repetitive muscle training quickly developed the neuromuscular adaptations necessary to optimise deep muscle function. Falla et al. (2012) explain that this approach involves repeated activation of the deep cervical flexor muscles to induce neuroplastic changes, improving muscle recruitment for various daily tasks. Other authors with longer training durations reported peripheral adaptations, such as increased muscle cross-sectional area and pennation angle (Kosek et al., 2006; Seynnes et al., 2007). Although not analysed in this study, it was observed that not all patients achieved the highest performance levels (10 seconds with 10 repetitions of cervical flexion at 30 mm Hg) by the end of the six weeks, contrary to the literature (Jull et al., 2009). Neuromuscular adaptation capacities can vary among individuals, explaining why not everyone reaches the expected levels within six weeks and might require more extended training or intervention.

In our opinion, this study's greatest strength is its strong relationship with the standard of care in clinical practice. It enhances its external validity as the multimodal intervention and outcome measures used (perhaps except for EMGs) reflect the usual practice of Portuguese physiotherapists treating patients with NCNP. The heterogeneity of the participants is another positive aspect, as differences in the type and location of symptoms did not affect the results, making them generalisable to a broader group of NCNP patients. However, the study also has some limitations. Although the sample size was calculated beforehand, administrative issues prevented us from recruiting the planned number of participants, weakening the consistency and robustness of our results. In addition to a small sample size, the lack of

a control group limits our understanding of whether the outcome improvements were due to the intervention plan or casual (e.g., over time). The results are limited to a short-term period of six weeks, so we could not determine if the treatment effects were sustained in the medium or long term. Another limitation is that data collection was partly conducted by the principal investigator, which could have influenced the results. Additionally, all participants were motivated volunteers, which might have positively affected the outcomes.

Assessing muscle activity through EMGs presents a limitation common to all studies (O'Sullivan et al., 2010), and we acknowledge that our data might have been influenced by crosstalk from adjacent muscles. However, we tried to minimise this factor through proper skin preparation, using small-diameter electrodes placed close together, consistently applied by the same examiner, and secured with tape to prevent movement of the electrodes (Hermens et al., 2000; Hermens et al., 1999). Despite the examiners' experience identifying cervical muscles and extensive EMG data collection training, crosstalk between muscles might have occurred. Despite these limitations, the results of this study provide useful and important information about the progression and behaviour of symptoms and cervical muscle activity in NCNP patients in response to treatment. This information can assist physiotherapists in their clinical decision-making.

Conclusions

This study indicates that a multimodal program including specific motor control exercises appears to prospectively influence cervical muscle activity and contribute to significant changes in pain, disability, and perceived improvement in patients with NCNP. Significant improvements were found in all self-reported variables after three weeks of intervention, coinciding with a decrease in cervical muscle activity compared to the start of treatment. These results suggest that the multimodal program may play an important role in NCNP patients, with benefits becoming evident after just three weeks. Although it might be presumptive, we believe the motor control exercise program was a key factor in these outcomes. Thus, the results of our study could be valuable for physiotherapists in making treatment decisions for NCNP patients. However, more studies of this nature are needed to enhance the clinical applicability of the results.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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