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Neurodynamic testing reveals early and increased muscle activation in individuals with nonspecific neck pain: A cross-sectional electromyographic study

Jaime Gascón-Jaén [a,b], Juan-José Carrasco [c], Carlos Lozano-Quijada [b], Emilio-José Poveda-Pagán [b,*], Sofía Pérez-Alenda [c]

[a] Faculty of Physiotherapy, University of Valencia, 46010, Valencia, Spain
[b] Centro de Investigación Traslacional en Fisioterapia, Department of Pathology and Surgery, Miguel Hernández University, San Juan de Alicante, Alicante, Spain
[c] Physiotherapy in Motion, Multi Speciality Research Group (PTinMOTION), Department of Physiotherapy, Faculty of Physiotherapy, University of Valencia, 46010, Valencia, Spain

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ABSTRACT

Background: Neurodynamic testing has been associated with increased muscle activity; however, differences in muscle activation between individuals with nonspecific neck pain and asymptomatic individuals during upper limb neurodynamic testing remain unexplored. This study aimed to examine differences in muscle activity during upper limb neurodynamic test 1 (ULNT1) and upper limb neurodynamic test 2A (ULNT2A) between individuals with nonspecific neck pain and asymptomatic individuals.
Methods: A cross-sectional study was conducted including 61 participants: 30 individuals with nonspecific neck pain and 31 asymptomatic individuals. Muscle activity of the upper trapezius, biceps brachii, triceps brachii, and flexor carpi radialis was recorded using surface electromyography during ULNT1 and ULNT2A maneuvers.
Findings: Individuals with nonspecific neck pain exhibited earlier onset and greater muscle activation than asymptomatic individuals across test maneuvers, particularly in the upper trapezius. In ULNT1, significant between-group differences in upper trapezius activity were observed during shoulder abduction, shoulder external rotation, and wrist extension ($P < 0.001$). In ULNT2A, differences were identified during shoulder girdle depression, elbow extension, shoulder external rotation, wrist extension, and shoulder abduction ($P \leq 0.015$). Consistent between-group differences were also observed in the triceps brachii, biceps brachii, and flexor carpi radialis across both tests.
Interpretation: Altered muscle activation patterns during upper limb neurodynamic testing indicate modified neuromuscular control in individuals with nonspecific neck pain. The earlier and increased myoelectric responses observed are consistent with a protective motor strategy in response to neural loading during neurodynamic test performance, providing novel insight into neuromuscular responses in individuals with nonspecific neck pain across muscles and test maneuvers.

1. Introduction

Nerve mechanosensitivity is defined as the responsiveness of neural tissue to mechanical stress (Asbury and Fields, 1984), and may be altered when the nerve root is susceptible to injury, compression, or ischemia (Koulidis et al., 2019). Neurodynamic tests are used to identify changes in the mechanosensitivity of the peripheral nervous system (Elvey, 1997; Koulidis et al., 2019; Schmid et al., 2009). Neurodynamic tests consist of a succession of movements applied during clinical examination to progressively induce mechanical loads in neural tissues, thereby eliciting a sensory or motor response (Elvey, 1997). Specifically, the upper limb neurodynamic test 1 (ULNT1) and the upper limb neurodynamic test 2A (ULNT2A) are commonly used neural provocation tests in clinical practice designed to increase mechanical tension on the median nerve (Lohkamp and Small, 2011; Reisch et al., 2005; Schmid et al., 2009; Shacklock, 1995; Vanti et al., 2010). Although both tests

* Corresponding author at: Center of Translational Research in Physiotherapy, Department of Pathology and Surgery. Physiotherapy Area. Miguel Hernández, University, Crta. Valencia, s/n. 03550 Sant Joan, Alicante. Spain.
E-mail address: ejpoveda@umh.es (E.-J. Poveda-Pagán).

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assess median nerve mechanosensitivity, they differ in their sequence of movements and mechanical loading characteristics (Lohkamp and Small, 2011).

In the upper limb, neurodynamic tests serve as an effective diagnostic tool for cervical radiculopathy (Grondin et al., 2021) and carpal tunnel syndrome (Talebi et al., 2012), where there is an alteration of mechanosensitivity leading to a premature sensory response during the test (Koulidis et al., 2019). Increased mechanosensitivity has been reported in individuals with neck pain, even in the absence of clear peripheral nerve involvement (Rojas et al., 2021; Yılmaz et al., 2018), with greater levels observed in those presenting neuropathic features (López-De-Uralde-Villanueva et al., 2016).

It has previously been shown that during ULNT1 performance, the elbow range of motion is limited by pain. This pain is linked to increased muscle activity in the upper trapezius and upper limb muscles, suggesting the protective response of these muscles against nerve tension (Jaberzadeh et al., 2005). Greater defensive muscle responses have also been reported in individuals with lower ULNT1 tolerance (Balster and Jull, 1997). In addition, individuals with neck pain reported symptoms earlier and more closely related to painful sensations than asymptomatic individuals (Yılmaz et al., 2018).

Previous studies have reported altered muscle activation patterns during voluntary movements in individuals with neck pain (Wannaprom et al., 2023; Wolff et al., 2022). It is plausible that situations in which nociception is present contribute to compensatory motor adaptations, which could lead to maladaptive movement strategies (Hodges and Tucker, 2011). A similar context may be present during neurodynamic testing, where mechanical loading of neural tissues can provoke symptom responses. As these tests involve mechanical loads on neural tissues that could also be present during functional movements (Ellis et al., 2022), assessing muscle activity may provide additional insight into neuromuscular responses associated with neural loading. However, it remains unclear whether these neuromuscular responses differ between individuals with nonspecific neck pain (NSNP) and asymptomatic individuals. Furthermore, comparing ULNT1 and ULNT2A may help determine whether distinct muscle activation patterns are elicited under different mechanical loading conditions.

To our knowledge, no previous studies have evaluated the activity of the upper limb muscles during ULNT1 and ULNT2A in individuals with NSNP compared to asymptomatic individuals. Therefore, the aim of this study was to examine differences in muscle activity of the upper trapezius, triceps brachii, biceps brachii, and flexor carpi radialis during ULNT1 and ULNT2A between individuals with NSNP and asymptomatic individuals. Additionally, we aimed to explore patterns of muscle activation associated with these responses. We hypothesized that individuals with NSNP would exhibit earlier and greater muscle activation than asymptomatic individuals.

2. Materials and methods

2.1. Design

The design was an observational cross-sectional study. All participants provided written informed consent after being informed about the investigation's objectives and content. The study conformed to the Declaration of Helsinki and was approved by the Ethics Committee of the University of Valencia in September 2022 (reference number: 2276381). This article adheres to STROBE guidelines (Elm et al., 2007).

2.2. Participants

The participant recruitment was conducted between May 2023 and January 2024. A total of thirty individuals with NSNP and thirty-one asymptomatic individuals (AS) as the control group participated in the study. The study was conducted at the University of Valencia and in a clinical setting.

The inclusion criteria for the NSNP group were: 1) Individuals aged between 18 and 65 years old; 2) Neck pain with a score of at least 2 on the visual analogue scale (VAS) (Scott and Huskisson, 1979) on the day of measurement; 3) A minimum score of 10 on the Neck Disability Index (NDI) (Andrade Ortega et al., 2008; Macdermid et al., 2009). The inclusion criteria for the AS group were: 1) Individuals aged between 18 and 65 years old; 2) Being pain-free at the time of assessment; 3) Absence of NSNP during the previous 12 months.

The exclusion criteria for both groups were: 1) Body Mass Index greater than 30 kg/m^2; 2) Presence of fever, active infection, or pregnancy at the time of assessment; 3) History of surgery or trauma in the cervical spine or upper limb; 4) Suffering from neurological, rheumatic, or systemic diseases, including fibromyalgia, osteoporosis, or cancer; 5) Clinical signs of cervical nerve root compression or pain involving the upper limb; 6) Having received pain-related treatment within the previous month (including physical therapy or pharmacological interventions); 7) Use of analgesics, anti-inflammatory drugs, or any medication potentially influencing pain perception prior to the assessment; 8) Pain involving the orofacial, upper limb, or upper thoracic regions within the previous 12 months, or pain affecting any other anatomical region during the previous three months.

2.3. Sample size

An a priori sample size analysis was performed in G*Power software (version 3.1.9.2; Heinrich-Heine-Universität, Düsseldorf, Germany). In a previous pilot study, small effect sizes ($f \geq 0.15$, $d \geq 0.3$) were obtained between groups and between times in the comparisons of myoelectrical activity during the tests. With the present study design ($\alpha = 0.05$, power $= 0.80$) and accounting for a 10% increase to compensate for potential data loss or recording errors, the minimum total number of participants required was 55.

2.4. Assessment

Prior to the neurodynamic tests, individuals were evaluated for mean neck pain over the last 7 days and current pain using the VAS. Neck disability was assessed with the NDI (Andrade Ortega et al., 2008; Macdermid et al., 2009) and fear of movement or kinesiophobia with the Tampa Scale of Kinesiophobia-11 (TSK-11) (Gómez-Pérez et al., 2011).

2.5. Evaluation of myoelectric activity during ULNT1 and ULNT2A

Electromyographic (EMG) activity of the upper trapezius, biceps brachii, triceps brachii and flexor carpi radialis during ULNT1 and ULNT2A was measured using the surface electromyography (sEMG) mDurance® system (mDurance Solutions SL, Granada, Spain) (ICC = 0.916; 95% CI = 0.831–0.958) (Molina-Molina et al., 2020). The positioning of the electrodes and the skin preparation followed the guidelines established by the European Society of Surface Electromyography (Hermens et al., 2000). Electrodes were placed parallel to the muscle fiber orientation. For the upper trapezius, electrodes were positioned at the midpoint between the spinous process of C7 and the acromion; for the triceps brachii, at 50% of the line between the posterior acromion and the olecranon, approximately two fingerbreadths medial to this line; and for the biceps brachii, on the line between the medial acromion and the antecubital fossa, at approximately one-third of the distance from the antecubital fossa. For the flexor carpi radialis, electrodes were positioned three to four fingerbreadths distal to the midpoint of the line between the medial epicondyle and the biceps tendon, corresponding to the muscle belly (Perotto et al., 2011). A bipolar configuration was used with a distance of 30 mm between electrode centers. The common ground electrodes were placed over the distal third of the clavicle and the medial epicondyle.

Data collection was performed at a 1024 Hz sampling rate, with a 24-bit signal resolution and an amplification of 100 to 10,000 v/v. A fourth order Butterworth bandpass filter (20–450 Hz cut-off) was applied to the raw data. The signal was smoothed using a window size of 0.025 s root mean square (RMS) window and 0.0125 s overlap between windows (Molina-Molina et al., 2020).

The myoelectric data were normalized to maximum voluntary contraction (MVC) to allow between-subject comparisons. MVCs were obtained for each muscle using standardized manual resistance tests involving maximal isometric contractions. Detailed descriptions of MVC testing positions and examiner resistance are provided in Supplementary Table S1.

Participants were instructed to perform MVCs for 5 s. Two trials were conducted for each muscle, with a 1-min rest between trials to minimize fatigue. Trials were considered valid when a stable EMG amplitude plateau was maintained for at least 1–2 s without visible compensatory movements. The highest value obtained was used for normalization. RMS was used as the main variable and was expressed as normalized RMS (nRMS).

All assessments were conducted under standardized conditions in a controlled environment, with consistent room temperature and lighting. Participants were positioned consistently and received standardized instructions. All measurements were performed by the same examiner.

The initial position for both tests was with the individual in a supine position, the arm resting in 30° abduction, 90° elbow flexion, the forearm supinated, and the hand in neutral and with the neck also in a neutral position (Jaberzadeh et al., 2005). Fig. 1 and Fig. 2 show the sequence of movements and joints in ULNT1 (Beneciuk et al., 2010; De La Rosa-Díaz et al., 2018; Elvey, 1997) and ULNT2A (Lohkamp and Small, 2011) respectively.

Each maneuver of the test was performed for 5 s, except for the final maneuver, which lasted 10 s. The final position was then held for an additional 5 s to complete a total duration of 15 s. The final maneuver of the test was performed up to the range of motion at which the participant reported a submaximal symptom sensation. A submaximal symptom sensation was defined as a clear and tolerable symptom response (e.g., stretching, discomfort, or pain) perceived by the participant as the limit for continuing the movement, beyond which the sensation would become intolerable. If submaximal symptoms were reported before completing 15 s of the final maneuver, the position in which the individual felt a submaximal symptom sensation was maintained until the 15 s were completed. A metronome was used to ensure a consistent execution rhythm across all test maneuvers. EMG activity for each maneuver was calculated as the mean nRMS value across its duration.

After each test, the individuals reported the sensation of pain they felt on a numerical rating scale (NRS) (Fraenkel et al., 2012).

2.6. Statistical analysis

IBM SPSS Statistics for Windows, Version 29.0.2.0 (IBM Corp., Armonk, NY, USA) was used for the statistical analysis. Compatibility of variables with normal distribution was investigated using visual (histogram and probability charts) and analytical methods (Shapiro-Wilk). The demographic data was given as a mean (standard deviation) or percentage as appropriate.

Linear mixed-effects models were used to analyze the EMG activity of each muscle (trapezius, biceps, triceps, and flexor). The fixed effects included group (NSNP vs. AS), test (ULNT1 vs. ULNT2A), maneuver (6 levels), and interactions. The random effect included a random intercept for each individual, accounting for individual variability. A repeated-measures structure was specified with the factors maneuver and test, using a heterogeneous autoregressive covariance structure to model within-individual correlations. The random effect used a variance components structure.

Type III sum of squares was used to test fixed effects. Degrees of freedom were estimated using the Satterthwaite approximation, and model estimation was conducted using the Restricted Maximum Likelihood (REML) method. Post-hoc multiple comparisons were adjusted using the Bonferroni correction.

Type I errors were accepted to be 0.05 for statistical significance. Effect sizes were calculated using Psychometrica (Dettelbach, Germany). The effect size was calculated using Cohen's d. A small effect size was set for values between 0.2 and 0.4, intermediate for values between 0.5 and 0.7, and large for values between 0.8 and ≥ 1.

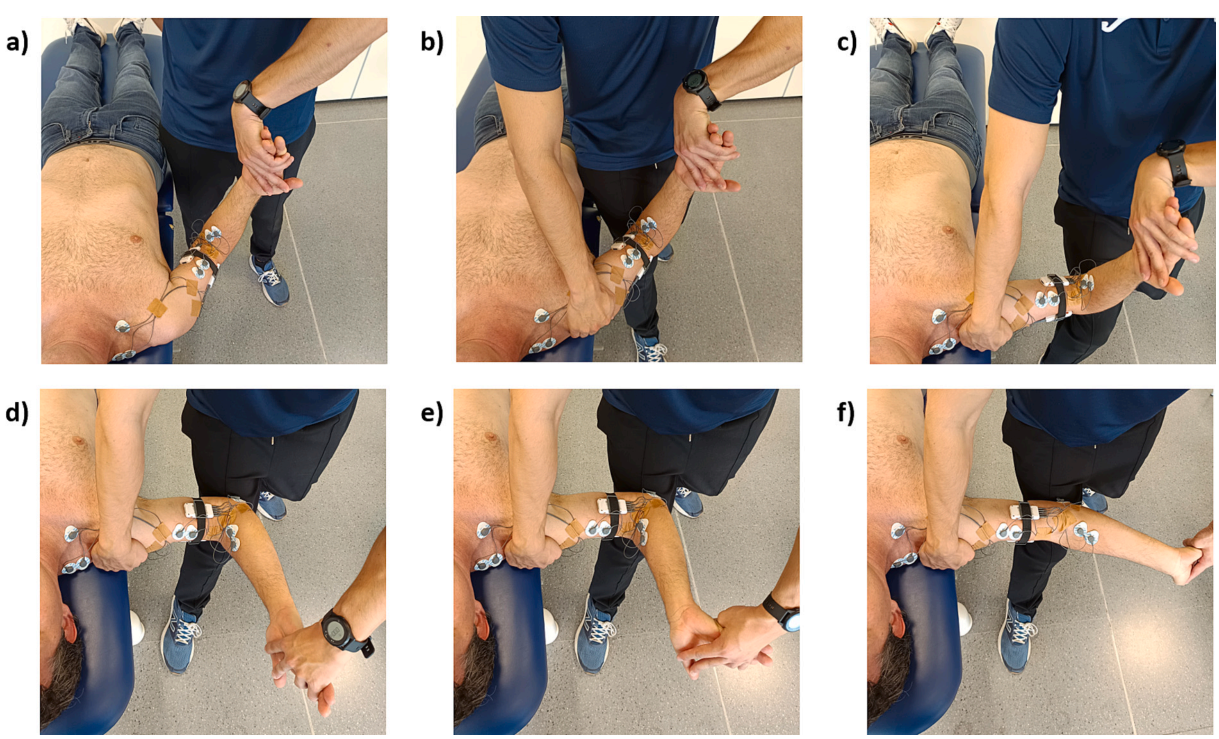

Fig. 1. ULNT1 neurodynamic test. (a) initial position; (b) shoulder girdle depression; (c) shoulder abduction to 110°; (d) shoulder external rotation; (e) forearm supination and wrist and finger extension; (f) elbow extension to submaximal sensation of symptoms.

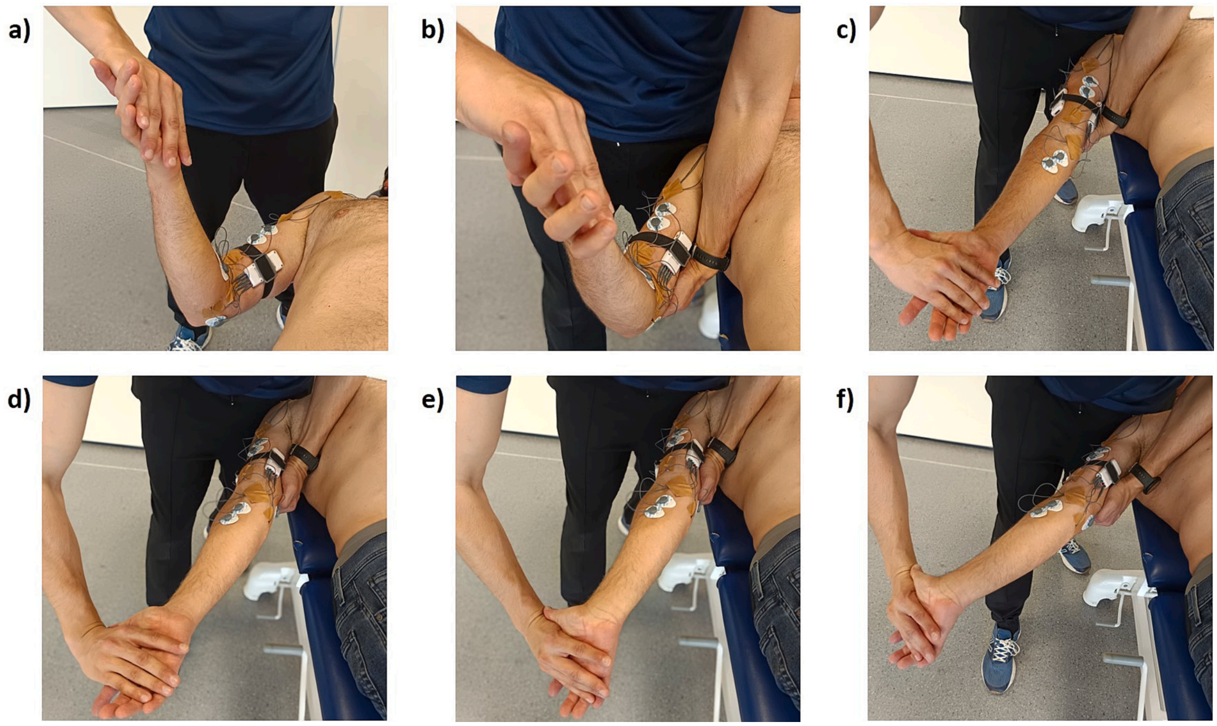

Fig. 2. ULNT2A neurodynamic test. (a) initial position; (b) shoulder girdle depression; (c) elbow extension; (d) shoulder external rotation; (e) forearm supination and wrist and finger extension; (f) shoulder abduction to submaximal sensation of symptoms.

3. Results

Fig. 3 shows the participant flow throughout the study progress.

The study included 30 individuals (21 females, 9 males) with NSNP, aged 19–53 years (mean 35.23 ± 9.60), and 31 AS (22 females, 9 males), aged 22–59 years (mean 36.16 ± 14.34). No significant differences ($P > 0.05$) were found between groups in terms of age, body mass index, height, weight, and range of motion in elbow extension and shoulder abduction. The NSNP group had higher scores ($P < 0.05$) for mean pain over the last 7 days, maximum pain over the last 7 days, current pain, neck disability and kinesiophobia compared to the AS group (Table 1).

The NSNP group reported higher pain intensity than the AS group in both tests ($P < 0.001$).

The mean nRMS values of the muscles tested during the ULNT1 and ULNT2A maneuvers are presented in Fig. 4 and detailed in the supplementary material tables (S2 to S5). Results are reported separately for each muscle.

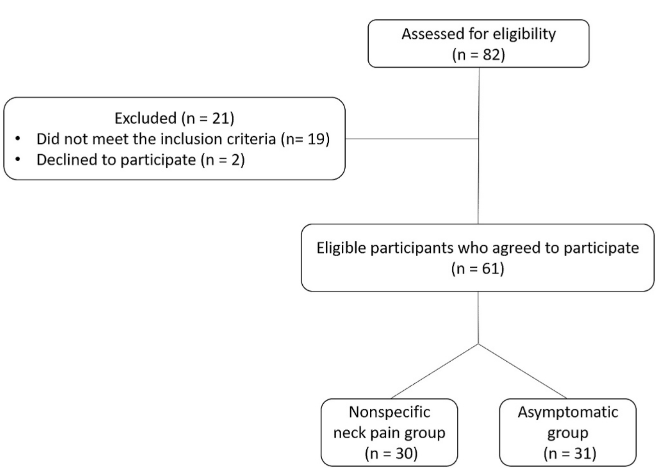

Fig. 3. Participant flow throughout the study.

Table 1
Demographic and descriptive data. Data are given as mean (standard deviation) or percentage. NSNP indicates nonspecific neck pain group; AS, asymptomatic group; BMI, body mass index; VAS, visual analog scale; VAS7d, mean pain over the last 7 days; VASmax7d, maximum pain over the last 7 days; NRS, numeric rating scale.

	NSNP ($n = 30$)	AS ($n = 31$)	*P*-value
Gender Female/male, n (%)	21 (70%)/ 9 (30%)	22 (71%)/ 9 (29%)	0.93
Age, years	35.23 (9.60)	37.03 (13.22)	0.87
Height, m	1.66 (0.09)	1.66 (0.08)	0.87
Weight, kg	65.60 (11.70)	64.00 (9.67)	0.56
BMI, kg/m^2	23.20 (3.22)	22.74 (2.71)	0.55
VAS	4.64 (1.48)	0 (0)	**<0.001**
VAS7d	6.25 (1.42)	0 (0)	**<0.001**
VASmax7	7.84 (1.44)	0 (0)	**<0.001**
Neck disability	15.70 (3.28)	0.19 (0.75)	**<0.001**
Kinesiophobia	24.70 (5.65)	18.37 (4.12)	**<0.001**
Elbow extension, degrees	0 (0)	0 (0)	1
Shoulder abduction, degrees	170.23 (5.44)	171.39 (3.69)	0.73
Pain intensity during ULNT1, NRS	7.30 (0.65)	5.87 (1.40)	**<0.001**
Pain intensity during ULNT2, NRS	7.80 (0.96)	6.35 (1.43)	**<0.001**

3.1. Upper trapezius

The mixed model analysis for the trapezius activation showed a significant main effect of group ($F(1, 140.55) = 26.67$, $P < 0.001$), time ($F(5, 132.74) = 83.03$, $P < 0.001$), as well as in the group-by-time ($P < 0.001$), test-by-time ($P = 0.008$) and group-by-test-by-time ($P < 0.001$) interactions. The first maneuver showing a significant increase in EMG activity compared to the initial position during ULNT1 occurred during shoulder abduction in the NSNP group ($P < 0.001$; $d = 0.62$), whereas in the AS group it occurred during elbow extension ($P < 0.001$; $d = 1.99$). For ULNT2A, the first maneuver showing a significant increase in EMG activity was shoulder girdle depression in the NSNP group ($P < 0.002$; d

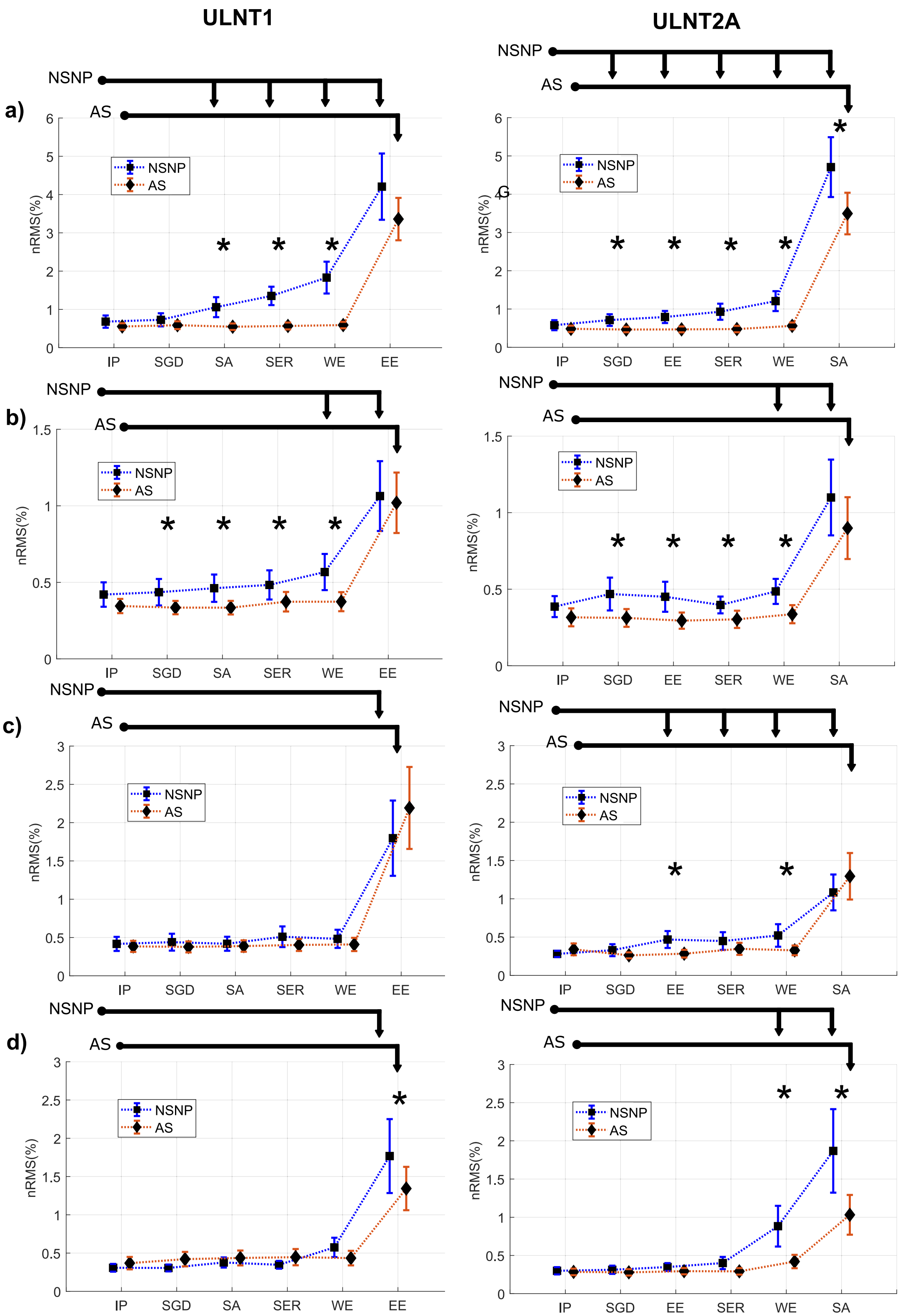

Fig. 4. Group nRMS data of the evaluated muscles during ULNT1 and ULNT2A. Each graph shows group nRMS (%) data, presented as mean (SD), for the upper trapezius a), triceps brachii b), biceps brachii c) and flexor carpi radialis d) during ULNT1 and ULNT2A. The maneuvers indicated are: initial position (IP), shoulder girdle depression (SGD), shoulder abduction to 110° (SA), shoulder external rotation (SER), forearm supination and wrist and finger extension (WE) and elbow extension (EE). Significant differences (P < 0.05) between groups are indicated by asterisks. The upper arrows indicate the maneuvers where significant differences ($P < 0.05$) were found with respect to the intra-group initial position. Symbols are slightly offset along the x-axis to prevent overlap between groups at the same time points. NSNP, nonspecific neck pain group; AS, asymptomatic group.

$= 0.35$), whereas in the AS group it was shoulder abduction ($P < 0.001$; $d = 2.18$).

Greater activation of the upper trapezius was observed in the NSNP group compared to the AS group during the ULNT1, with significant differences in shoulder abduction ($P < 0.001$; $d = 0.95$), shoulder external rotation ($P < 0.001$; $d = 1.53$), and forearm supination and wrist extension ($P < 0.001$; $d = 1.46$). The NSNP group exhibited increased upper trapezius activation compared to the AS group during the ULNT2A, with significant differences observed during shoulder girdle depression ($P = 0.003$; $d = 0.77$), elbow extension ($P < 0.001$; $d = 0.91$), shoulder external rotation ($P < 0.001$; $d = 1$), forearm supination and wrist extension ($P < 0.001$; $d = 1.23$), and shoulder abduction ($P = 0.015$; $d = 0.65$).

Regarding the comparison between tests, significant differences were observed in the NSNP group at the initial position ($P = 0.033$; $d = 0.25$) and during the second ($P = 0.001$; $d = 0.44$), third ($P < 0.001$; $d = 0.70$), and fourth ($P < 0.001$; $d = 0.64$) maneuvers. In the AS group, significant differences were found only during the first maneuver ($P = 0.003$; $d = 0.44$). In all cases, these differences corresponded to increased activation during ULNT1, which elicited higher muscle activity than ULNT2A.

3.2. Triceps brachii

The results for the triceps indicated a significant main effect of group ($F(1, 92.45) = 8.02$, $P = 0.006$), time ($F(5, 201.29) = 30.56$, $P < 0.001$), and in the group-by-time ($P = 0.012$) interaction. The first maneuver showing a significant increase in EMG activity compared to the initial position in the NSNP group was forearm supination and wrist extension during both ULNT1 ($P = 0.012$; $d = 0.55$) and ULNT2A ($P = 0.035$; $d = 0.49$). In the AS group, the first maneuver showing a significant increase in EMG activity was elbow extension during ULNT1 ($P < 0.001$; $d = 1.37$) and shoulder abduction during ULNT2A ($P < 0.001$; $d = 1.18$).

Greater activation of the triceps brachii was observed in the NSNP group compared to the AS group during the ULNT1, with significant differences in shoulder girdle depression ($P = 0.040$; $d = 0.55$), shoulder abduction ($P = 0.006$; $d = 0.58$), shoulder external rotation ($P = 0.037$; $d = 0.47$), and wrist extension ($P = 0.002$; $d = 0.73$). During the ULNT2A, significant differences were found in shoulder girdle depression ($P = 0.007$; $d = 0.72$), elbow extension ($P = 0.004$; $d = 0.64$), shoulder external rotation ($P = 0.024$; $d = 0.74$), and wrist extension ($P = 0.004$; $d = 0.76$).

When comparing tests, significant differences were observed during the third maneuver in both the NSNP group ($P = 0.011$; $d = 0.37$) and the AS group ($P = 0.031$; $d = 0.44$). Across all maneuver comparisons, ULNT1 elicited higher levels of muscle activity than ULNT2A in both groups.

3.3. Biceps brachii

Analysis for the biceps showed a significant main effect of test ($F(1, 111.93) = 21.70$, $P < 0.001$), time ($F(5, 150.80) = 32.38$, $P < 0.001$), as well as in the group-by-time ($P = 0.002$), test-by-time ($P < 0.001$) and group-by-test-by-time ($P = 0.008$) interactions. Elbow extension was the first maneuver showing a significant increase in EMG activity compared to the initial position in both the NSNP group ($P < 0.001$; $d = 1.14$) and the AS group ($P < 0.001$; $d = 1.32$) during the ULNT1. The first maneuver showing a significant increase in EMG activity during the ULNT2A was elbow extension in the NSNP group ($P < 0.001$; $d = 0.72$), whereas in the AS group it was shoulder abduction ($P < 0.001$; $d = 1.27$).

Greater activation of the biceps brachii was observed in the NSNP group compared to the AS group during the ULNT2A, with significant differences in elbow extension ($P = 0.003$; $d = 0.74$) and forearm supination and wrist extension ($P = 0.019$; $d = 0.56$).

Regarding the comparison between the tests, significant differences were observed in the NSNP group at the initial position ($P < 0.001$; $d = 0.65$) and during the first ($P = 0.006$; $d = 0.41$) and fifth ($P = 0.018$; $d = 0.48$) maneuvers. In the AS group, differences were found during the first ($P = 0.003$; $d = 0.69$), second ($P = 0.010$; $d = 0.62$), and fifth ($P = 0.03$; $d = 0.71$) maneuvers. ULNT1 elicited greater muscle activation than ULNT2A across all maneuvers in both groups.

3.4. Flexor carpi radialis

The results for the flexor carpi radialis muscle presented a significant main effect of group ($F(1, 58.02) = 5.87$, $P = 0.019$), time ($F(5, 387.52) = 116.64$, $P < 0.001$), as well as in group-by-test ($P = 0.009$) and group-by-time ($P < 0.001$) interactions. Elbow extension was the first maneuver showing a significant increase in EMG activity compared to the initial position in both the NSNP group ($P < 0.001$; $d = 1.19$) and the AS group ($P < 0.001$; $d = 1.41$) during the ULNT1. The first maneuver showing a significant increase in EMG activity during the ULNT2A was ~~the~~ wrist extension in the NSNP group ($P < 0.001$; $d = 0.89$), whereas in the AS group it was shoulder abduction ($P < 0.001$; $d = 1.14$).

Significant between-group differences were found during the elbow extension ($P = 0.001$; $d = 0.39$) maneuver in ULNT1, and during the wrist extension ($P < 0.001$; $d = 0.83$) and shoulder abduction ($P < 0.001$; $d = 0.70$) maneuvers in ULNT2A. In both tests, higher muscle activation was observed in the NSNP group.

Regarding the comparison between the tests, significant differences were observed in the NSNP group during the fourth maneuver ($P = 0.013$; $d = 0.50$), reflecting greater activation during ULNT2A. In the AS group, differences were found during the fifth maneuver ($P = 0.011$; $d = 0.42$), corresponding to higher activation during ULNT1.

4. Discussion

To our knowledge, this is the first study to assess the myoelectric activity of the upper trapezius and upper limb muscles during ULNT1 and ULNT2A in individuals with NSNP. The hypothesis of the study was confirmed; earlier and increased myoelectric activity was observed in the NSNP group during ULNT1 and ULNT2A in most of the muscles tested, compared to the AS group.

Our findings align with previous studies that compared muscle activity using EMG during ULNT1 between individuals with painful conditions and asymptomatic controls, reporting greater activation in symptomatic individuals (De La Rosa-Díaz et al., 2018; Jaberzadeh and Zoghi, 2013). Consistently, the present study identified increased myoelectric activity in individuals with NSNP during both intermediate and final maneuvers of ULNT1 and ULNT2A. However, the magnitude of upper trapezius activation observed in the present study (approximately 4.5% MVC) was lower than that reported in both individuals with carpal tunnel syndrome (Jaberzadeh and Zoghi, 2013) and asymptomatic individuals with altered mechanosensitivity (Balster and Jull, 1997). These differences may be attributed to variations in ULNT1 performance, the characteristics of the population studied, or the normalization method employed.

Consistent with previous studies assessing upper limb muscles, the upper trapezius exhibited the highest myoelectrical activity (Jaberzadeh et al., 2005; Van Der Heide et al., 2001). This could be explained by the ability of the upper trapezius to elevate the scapula and therefore reduce the proximal tension of the brachial plexus fibers. Additionally, this greater proximal muscle activity might reflect the higher longitudinal excursion of the median nerve at more proximal locations, such as the elbow, compared to distal sites like the wrist. This proximal-to-distal transmission of neural movement may influence the distribution of muscular responses observed during neurodynamic testing (Thoomes et al., 2021). The increased activation of the triceps brachii may reflect a nonspecific coactivation strategy to stabilize the elbow joint during neural loading, in line with patterns observed in pain-related motor adaptations (Jones et al., 2012; Merkle et al., 2018).

Overall, ULNT1 elicited greater muscle activation than ULNT2A, particularly in individuals with NSNP. This may be related to the earlier inclusion of shoulder abduction, increasing mechanical demand (Lohkamp and Small, 2011). However, although several differences were statistically significant, their magnitude was small and should be interpreted with caution, likely reflecting the low-intensity, non-voluntary nature of muscle activity during neurodynamic testing.

Interestingly, more between-group differences were observed during ULNT2A, suggesting that this test may be more sensitive for detecting alterations in muscle activity associated with median nerve mechanosensitivity. Taken together, the observed differences between ULNT1 and ULNT2A suggest that distinct mechanical loading conditions may elicit different neuromuscular responses, which may be considered when selecting and interpreting these tests in clinical practice.

Increased muscle activity during neurodynamic testing has been attributed to nociceptive mechanisms such as the flexor withdrawal reflex (FWR) (Balster and Jull, 1997; Jaberzadeh and Zoghi, 2013). Individuals with NSNP may exhibit greater neural mechanosensitivity, potentially leading to earlier activation of nociceptive pathways and, consequently, an earlier FWR response compared to asymptomatic individuals (Yılmaz et al., 2018). This is supported by evidence of reduced FWR activation thresholds in painful conditions (Banic et al., 2004; Desmeules et al., 2003; Wallwork et al., 2017). Higher pain intensity reported by individuals with NSNP during testing may also contribute to increased neuromuscular responses, although these differences did not exceed the minimal clinically important difference (Ostelo et al., 2008). In addition, higher kinesiophobia in the NSNP group may have influenced muscle activity, consistent with previous studies showing an association between kinesiophobia and altered muscle activation in painful conditions (Massé-Alarie et al., 2016; Núñez-Cortés et al., 2023).

Muscle activation differences between individuals with neck pain and asymptomatic controls have been previously observed during voluntary movements (Wannaprom et al., 2023; Wolff et al., 2022). The present findings extend this evidence by demonstrating that these differences in muscle activation are also present during neurodynamic test performance, where a priori there is no voluntary contraction on the part of the individual. In addition to sensory responses, individuals with NSNP may exhibit altered neuromuscular responses under neural loading, consistent with compensatory mechanisms and increased muscle activation. Whether these responses extend beyond neurodynamic test performance to functional motor behavior remains unclear. Although potentially protective, altered motor responses in painful conditions have previously been associated with adaptive or maladaptive motor strategies (Hodges and Tucker, 2011). Their identification during neurodynamic testing may nevertheless provide additional insight for clinical assessment.

4.1. Study limitations

This study has several limitations. Firstly, individuals receiving analgesic medication or physical therapy for their pain were excluded, so the individuals included may have higher pain tolerance and lower disability compared to individuals who need medication to manage their pain. Another limitation is that most between-group differences in muscle activation were small in absolute terms (below 1%), potentially limiting their clinical relevance. These low values are partly explained by MVC normalization and the low-intensity, largely involuntary nature of muscle activity during neurodynamic testing. Although relative differences were observed, their small absolute magnitude limits the conclusions regarding motor adaptations or coactivation strategies. Furthermore, sEMG is subject to inherent limitations that may affect the interpretation of low-intensity muscle activity, including inter-individual tissue differences and a low signal-to-noise ratio. In addition, the cross-sectional design precludes causal inference. Finally, generalizability may be limited, as the sample consisted of young individuals with mild to moderate symptoms, potentially limiting extrapolation to populations with different clinical characteristics. Further studies with a larger population and higher levels of neck pain or disability are needed to better understand the association between NSNP and muscular responses during neurodynamic tests.

5. Conclusions

Individuals with NSNP exhibited earlier and higher myoelectric activity compared with asymptomatic individuals during ULNT1 and ULNT2A, with the upper trapezius showing the greatest activity in both groups. The results indicate differences in the activation pattern of the upper trapezius and upper limb muscles between groups, with greater muscle activity observed in individuals with NSNP, suggesting a potential protective neuromuscular pattern within this population. The observed muscle activity during median nerve upper limb neurodynamic tests may be associated with an earlier activation of nociceptive processes in individuals with NSNP, consistent with a compensatory motor strategy. These findings provide descriptive evidence of altered motor control in the studied population of individuals with NSNP and suggest the presence of neuromuscular differences between the NSNP and AS groups during neurodynamic test performance. However, clinical applicability remains preliminary and requires further investigation.

CRediT authorship contribution statement

Jaime Gascón-Jaén: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation, Conceptualization. **Juan-José Carrasco:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Carlos Lozano-Quijada:** Writing – review & editing, Visualization, Methodology, Conceptualization. **Emilio-José Poveda-Pagán:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Sofía Pérez-Alenda:** Writing – review & editing, Writing – original draft, Supervision, Methodology.

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Declaration of competing interest

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

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