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Research paper

Study of the normal response to the upper limb neurodynamic test 2b and 1 in asymptomatic violin and viola players

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A B S T R A C T

Background: Professional musicians exhibit a high prevalence of work-related musculoskeletal disorders, with nerve entrapment syndromes and dysfunctions of the peripheral nervous system accounting for a significant proportion of these issues. The radial and median nerves of the upper limb are among the most commonly injured nerves due to mechanical and repetitive work. The upper limb neurodynamic test for the radial nerve (ULNT2b) and the upper limb neurodynamic test for the median nerve (ULNT1) are two of the most frequently used tests to assess the mechanosensitivity of these nerves. Currently, there are no studies that describe the normal responses in populations of violinists and violists.
Purpose: Study of the normal response to the ULNT2b and ULNT1 in asymptomatic violin and viola players.
Study Design: A prospective epidemiological study of consecutive cases was designed, characterized as observational, descriptive, comparative, cross-sectional, and double-blind, following the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.
Methods: The normal responses of the ULNT2b and ULNT1 tests were reported in violin and viola musicians. The range of motion (ROM) in degrees was recorded with structural differentiation, along with the location and characteristics of the reported symptom.
Results: The total sample consisted of 56 cases (n=56). In the ULNT2b, the mean range of motion (ROM) was 10.1° ± 16.2, with the most prevalent symptoms being tightness in the dorsal aspect of the forearm. In the ULNT1, the mean ROM was 115.4° ± 39.4, with tightness in the palmar aspect of the forearm being the most commonly reported symptom.
Conclusions: Asymptomatic viola and violin players exhibit greater mechanosensitivity in the radial and median nerves during the ULNT2b and ULNT1 compared to an asymptomatic population. Furthermore, there are no significant differences in the responses of both tests concerning ROM, affected areas, or symptoms, regardless of sex, instrument, or side.

Introduction

In recent years, an increase in studies focusing on the health and ergonomic issues of professional musicians has emerged, driven by the high prevalence of work-related musculoskeletal disorders. Nerve entrapment syndromes and dysfunctions of the peripheral nervous system account for a significant proportion of these disorders.[1-4]

Certain specific injuries may be directly associated with the positioning or technique employed while playing the instrument. Professional or nearly professional dedication typically entails extensive hours of practice, thereby increasing the probability of developing some of these pathologies.[3,5-7]

There is a vast diversity of musical instruments with varying sizes and weights, each requiring different body positions to play. Musculoskeletal injuries are common among musicians; approximately 70% have experienced a musculoskeletal injury at some point

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in their careers, which may include pain and functional limitations.[8,9] Among this population, string players are injured approximately four times more frequently than musicians from other musical families.[1,3] This disparity is related to how the instrument is held, necessitating the maintenance of joint ranges of the upper limb in positions away from the resting joint position, alongside the nature of the movements required by both limbs to produce sound.[2,3,10]

Violinists and violists are particularly prone to developing nerve dysfunctions due to the repetitive movements and asymmetrical postures they must sustain while playing.[5] Issues such as nerve compression and carpal tunnel syndrome are common among string musicians, as they perform precise movements with their upper extremities while holding their instrument between the shoulder and chin.[6,7,11] Approximately 30% of musicians diagnosed with musculoskeletal disorders also suffer from a nerve compression syndrome.[6,7]

Some of the most utilized and relevant tests for detecting peripheral neuropathies during physical examinations are the so-called neurodynamic tests (NDTs).[12-15] NDTs consist of a sequence of body movements designed to mechanically stimulate the neural tissue of the evaluated nerve through sliding and tensioning maneuvers.[14,16,17] The purpose of performing these tests is to elicit a response—such as the manifestation of symptoms, reduced range of motion (ROM), and/or increased resistance—thereby detecting an increase in neural mechanosensitivity and facilitating the clinical diagnosis of pathological conditions present at that tissue level.[14,18-20] When a nerve exhibits increased mechanosensitivity, less stimulus is needed to provoke that response, which is typically more intense; however, all neural structures are mechanosensitive when the appropriate stimulus is applied.[16,21]

To ensure that the response obtained during the test pertains to a neural structure, a structural differentiation is performed to distinguish a neurodynamic response from a musculoskeletal response. This maneuver involves applying or removing tension from the neural structure using joint movements distant from the site of symptom presentation to avoid mobilizing adjacent musculoskeletal structures. If the symptoms change during the structural differentiation maneuver, it confirms that they originate from the nervous system, which is the only structure subject to a change in tension.[14,16,19,20,22]

In the upper limb, the radial, ulnar, and median nerves are typically the most commonly assessed using specific NDTs to evaluate their mechanosensitivity.[16,23] The radial nerve is often among the most described nerves concerning symptoms arising from repetitive mechanical work involving the upper limb.[24-27] The test designed to assess the mechanosensitivity of the radial nerve, in comparison to the ulnar and median nerves, is the upper limb neurodynamic test 2b (ULNT2b).[18,24,28,29] Meanwhile, the median nerve is the peripheral nerve most frequently affected by compressive neuropathies, such as carpal tunnel syndrome and cervical radiculopathy.[30,31] To assess the mechanosensitivity of the median nerve, the upper limb neurodynamic test 1 (ULNT1) is performed,[32,33] which has proven useful in diagnosing carpal tunnel syndrome.[34-36]

Various studies have investigated the normal response of the ULNT2b related to the radial nerve in asymptomatic populations[37,38] and compared it to symptomatic populations or those engaged in occupations that particularly utilize the upper limb.[24,25,27] Similarly, regarding the median nerve, the normal response to the ULNT1 has been described in healthy subjects,[32,37,38] but it remains unclear whether this response is similar in musicians who maintain sustained positions.

Currently, no studies have documented the normal responses for ULNT2b and ULNT1 in asymptomatic violinists and violists. The study hypothesis posits that asymptomatic violinists and violists will exhibit increased neural mechanosensitivity, and that the tests will yield positive results with a reduced ROM during the neurodynamic assessments. The overall objective of this study is to describe the mechanosensitive responses of ULNT2b and ULNT1 in a group of violinists and violists, specifically examining differences between the two instruments, between the upper limbs, and among various anamnesic variables recorded in relation to studies reporting the responses of NDTs in asymptomatic populations.

Materials and methods

A prospective epidemiological study was designed, involving consecutive cases of an observational, descriptive, comparative, cross-sectional, and double-blind nature. The design and development of the study followed the guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology statement for the reporting of observational studies.[39,40] Prior approval was obtained from the Research Ethics Committee of the Autonomous Community of Aragón (registration number PI22/546); furthermore, the study adhered to the ethical principles established in the Declaration of Helsinki.[41]

The study population focused on violin and viola musicians belonging to a conservatory or music school. For the sample size calculation, the statistical software G-Power version 3.1.9.6 (Program written by Franz Faul, Universität Kiel. Germany) was utilized, determining a significance level of $\alpha = 5\%$ and a power of $1 - \beta = 80\%$ with a small to medium effect size "d" (0.35), resulting in a minimum sample size of $n = 52$.[42] For sample selection, a consecutive sampling method was applied to the population of the "Conservatorio Superior de Música de Aragón," the "Conservatorio Profesional de Música de Soria," and the "Escuela Municipal de Música de Zaragoza," including students or teachers of violin and viola.

For the sample selection, the inclusion criteria established—subjects had to meet all of them to be admitted—were individuals over 18 years of age, violinists and violists who dedicated 3 hours or more to the practice of their instrument each day, and who had the capacity for understanding and communication. The exclusion criteria —individuals presenting any of these criteria were excluded—were individuals with painful symptoms in the cervical area or upper extremities in the past week, with central nervous system disorders, neural symptoms in the upper extremity, musculoskeletal injuries in the upper extremity within the previous 6 months, cervical surgery in the past year, diagnosis of cervical hernia, currently receiving neurodynamic treatment for the upper limb, diabetes, thyroid disorders, systemic diseases, oncological processes, and/or presenting yellow flags such as psychiatric pathology or psychosocial problems.

Patients who met the selection criteria were informed about the study and gave their consent to participate before their inclusion. Following the signing of the informed consent, data collection from the clinical history was carried out. The initial anamnesis recorded demographic variables such as "Sex," "Age," "Weight," "Height," and "Dominant Hand," as well as specific study and clinical variables such as "Arc Hand," "Experience" with the violin or viola, and "Dedication" to violin or viola.

After the data collection, the principal investigator performed both NDTs following the sequences described by Shacklock.[16] The sequence for ULNT2b (Fig. 1) included scapular depression, elbow extension, internal rotation of the arm, wrist and finger flexion, and glenohumeral abduction, while for ULNT1 (Fig. 2), it involved scapular fixation, external rotation of the glenohumeral joint, wrist and finger extension, forearm supination, and elbow extension. The starting position was standardized in supine lying, without a pillow, with the arms along the body and the legs extended. There was a minimum time of 5 minutes between the performance of each NDT.

Fig. 1. Neurodynamic test of the radial nerve (ULNT2b). (**A**) Initial test position; (**B**) final test position. ULNT2b = upper limb neurodynamic test 2b.

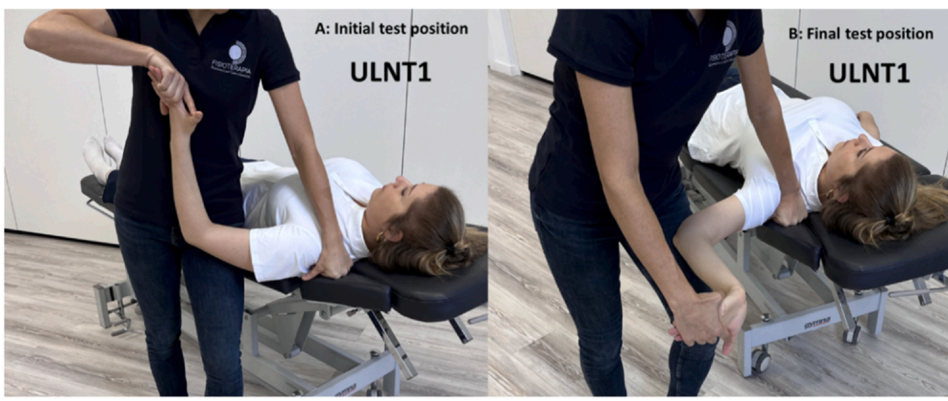

Fig. 2. Neurodynamic test of the median nerve (ULNT1). (**A**) Initial test position; (**B**) final test position. ULNT1 = upper limb neurodynamic test 1.

Patients were instructed to verbalize when they experienced the first onset of symptoms (S1),[43,44] following which structural differentiation was performed by releasing neural tension through a structure as distant as possible from the source of the symptoms to confirm that the symptoms were generated by a neural structure. In the case of proximal symptoms, wrist and finger flexion or extension was decreased according to whether it was ULNT2b or ULNT1, and in the case of distal symptoms, scapular movement was released.[16,18,19] The secondary investigator measured the shoulder abduction angle at S1 for ULNT2b and elbow extension at S1 for ULNT1 using the standard Baseline HiRes 12″ goniometer (Baseline, Elmsford (Nueva York)).

After the completion of each test, participants were asked to mark the location and type of symptoms perceived on a recording sheet. To document the location of the symptoms, a body diagram was used, which divided the upper extremities into eight areas: “palmar surface of fingers,” “dorsal surface of fingers,” “palmar surface of wrist,” “dorsal surface of wrist,” “palmar region of forearm,” “dorsal region of forearm,” “palmar region of arm,” and “dorsal region of arm.”[19,32,44] Additionally, to describe the nature of the symptoms, participants could choose from “tightness,” “pain,” “tingling,” “pinching,” “numbness,” and/or “burning.”[24,43,45] The principal investigator completed the recording sheet by noting the type of response (neurodynamic or musculoskeletal) and the degrees of joint movement at which the test elicited symptoms.

The statistical analysis was conducted using the IBM SPSS Statistics 21 software developed by International Business Machines Corporation (Armonk, NY). The confidence level established for the analysis of the results was 95%. For the descriptive analysis of quantitative variables, measures of central tendency were utilized to summarize the dataset (mean, median, and mode); measures of dispersion that helped characterize the degree of spread or clustering of the variables included standard deviation, variance, range, and minimum and maximum values.[42] For qualitative variables (location and site of symptoms), frequency and percentage analyses were performed.[42] To compare quantitative variables, the non-parametric Mann-Whitney U test was used, as the groups being compared were smaller than 30 cases.[46] For the comparison of qualitative variables, the chi-square statistical test was employed, except when any cell in the contingency table had an expected frequency of less than 5; in those cases, Fisher’s exact test was used.[42]

Results

The total sample size was n = 56, and Figure 3 shows the flow diagram of the sample. Fifty percent of the sample consisted of men and 50% of women; 75% played the violin and 25% played the viola, and in 100% of cases, the dominant hand was the right hand.

The mean age of the total sample was 25.6 ± 9.4 years, with a mean practice duration of 18.6 ± 8.5 years and a mean daily dedication of 4.1 ± 1.3 hours. The variables of height and weight were found to be significantly different between men and women, as well as the years of experience, with the mean being higher in the male group (Table 1).

When comparing between instruments, no demographic variable was found to be significant except for height, which was greater among violists (Table 2).

The mean glenohumeral abduction angle in the ULNT2b was 10.1° ± 16.2, with a significant comparison between the degrees of the sample that exhibited neural response (15° ± 18) vs the degrees of

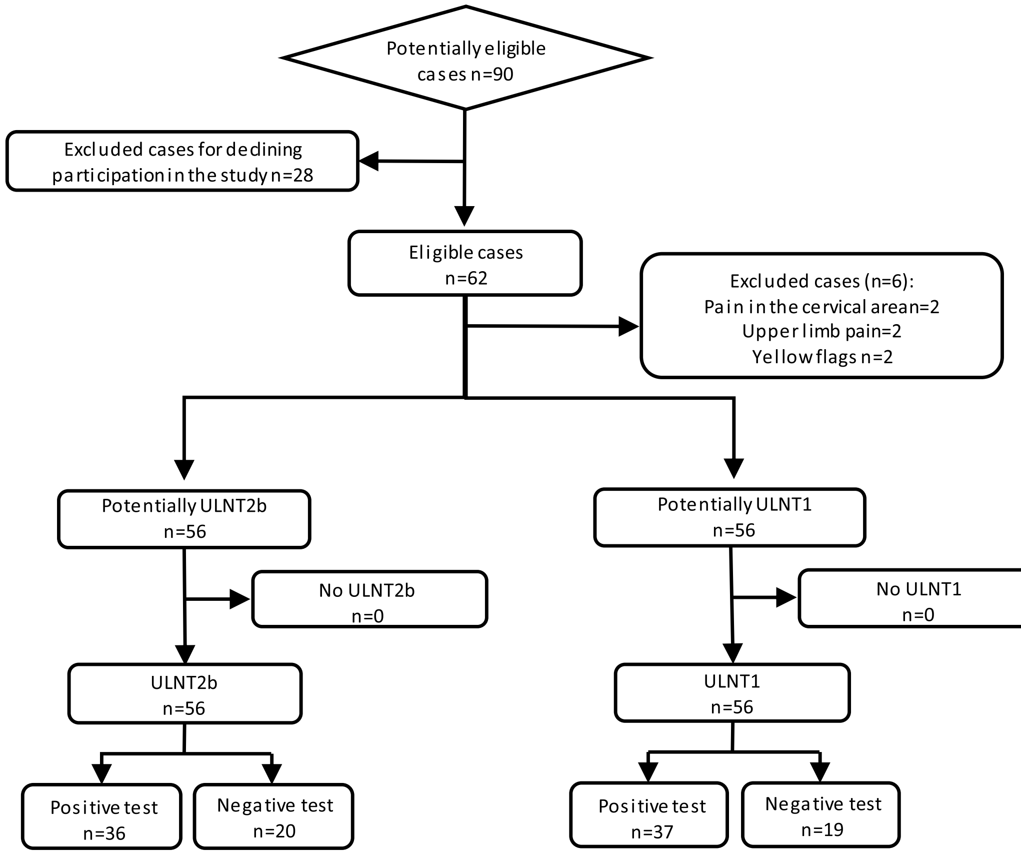

Fig. 3. Recruitment sample flowchart. ULNT1 = upper limb neurodynamic test 1; ULNT2b = upper limb neurodynamic test 2b.

Table 1
Quantitative demographic variables of the entire sample compared by sex

Variables	Total (n = 56)		Men (n = 28)		Women (n = 28)		p value*
	Mean ± SD	CI 95%	Mean ± SD	CI 95%	Mean ± SD	CI 95%	
Age (y)	25.6 ± 9.4	23.1 28.1	28.6 ± 11.8	24.1 33.2	22.6 ± 4.6	20.8 24.4	0.2
Weight (kg)	64.6 ± 9	62.2 67	68.9 ± 8.2	65.8 72.1	60.2 ± 7.7	57.2 63.2	0.0*
Height (cm)	170.7 ± 8.5	168.4 173	174.9 ± 7.7	171.9 177.8	166.5 ± 7.3	163.7 169.3	0.0*
BMI (kg/m²)	22.1 ± 2.4	21.5 22.8	22.5 ± 2.4	21.6 23.5	21.7 ± 2.3	20.8 22.6	0.2
METs PA (mL O_2/kg × min)	2821.1 ± 1750.3	2352.4 3290	2979.8 ± 1887	2248.1 3711.5	2662.5 ± 1621	2033.9 3291	0.6
Experience (y)	18.6 ± 8.5	16.3 20.9	21.7 ± 10.2	17.8 25.7	15.5 ± 4.8	13.7 17.3	0.01*
Dedication (h/d)	4.1 ± 1.3	3.7 4.4	4 ± 1.3	3.5 4.5	4.1 ± 1.3	3.6 4.7	0.8

Statistical test: Mann-Whitney U.
BMI = body mass index; CI = confidence interval; METs PA = METs of physical activity; SD = standard deviation.
* Significant comparison with $p \le 0.1$.

the sample that exhibited muscular response (1.4° ± 5.6). The remaining comparisons of the abduction angles between sex, instrument, or side of the test were not significant (Table 3).

The mean elbow extension angle in the ULNT1 was 115.4° ± 39.4, with a significant comparison between the degrees of the sample that exhibited neural response (124.4° ± 38.2) vs the degrees of the sample that exhibited muscular response (98.1° ± 36.5). The remaining comparisons of the extension angles between sex, instrument, or side of the test were not significant (Table 4).

In the ULNT2b, comparing the ROM degrees of glenohumeral response type—neural or muscular—between the sex of the sample, the side of the test, or the instrument played, none of the comparisons were statistically significant, except for the comparison among violinists regarding response type, where the glenohumeral ROM in the neural response was significantly greater (p = 0.04) compared to the muscular response (Appendices A-C).

In the ULNT1, comparing the elbow extension ROM degrees of test response type—neural or muscular—between the sex of the

Table 2
Quantitative demographic variables of the entire sample compared by instrument

Variables	Total (n = 56)		Violin (n = 42)		Viola (n = 14)		p value*
	Mean ± SD	CI 95%	Mean ± SD	CI 95%	Mean ± SD	CI 95%	
Age (y)	25.6 ± 9.4	23.1 28.1	25.3 ± 8.9	22.5 28.0	26.6 ± 1.2	20.1 33	0.9
Weight (kg)	64.6 ± 9	62.2 67	63.4 ± 9.6	60.4 66.4	68 ± 5.7	64.7 71.3	0.1
Height (cm)	170.7 ± 8.5	168.4 173	168.8 ± 7.5	166.5 171.2	176.3 ± 9.2	171 181.6	0.01*
BMI (kg/m²)	22.1 ± 2.4	21.5 22.8	22.2 ± 2.5	21.4 22.9	22 ± 2.1	20.8 23.1	0.7
METs PA (mL O_2/kg × min)	2821.1 ± 1750.3	2352.4 3290	2911.3 ± 1900.1	2319.2 3503.4	2550.7 ± 1212.3	1850.8 3250.7	0.9
Experience (y)	18.6 ± 8.5	16.3 20.9	18.7 ± 8.5	16.0 21.3	18.4 ± 8.7	13.4 23.5	0.7
Dedication (h/d)	4.1 ± 1.3	3.7 4.4	4.2 ± 1.5	3.7 4.6	3.7 ± 0.7	3.3 4.1	0.1

Statistical test: Mann-Whitney U.
BMI = body mass index; CI = confidence interval; MET = metabolic equivalent of task; METs PA = METs of physical activity; SD = standard deviation.
* Significant comparison with $p \leq 0.1$.

Table 3
ROM in degrees of glenohumeral abduction in the ULNT2b

Variables	Mean ± SD	CI 95%	Mean ± SD	CI 95%	Media ± SD	CI 95%	p value*
	Total (n = 56)		Neural (n = 36)		Muscular (n = 20)		
ROM (°)	10.1 ± 16.2	5.8 14.4	15 ± 18	8.9 21.1	1.4 ± 5.6	−1.3 4	0.1*
			Men (n = 28)		Women (n = 28)		
			8 ± 15.8	1.9 14.1	12.2 ± 16.5	5.8 18.6	0.3
			Violin (n = 42)		Viola (n = 14)		
			8.0 ± 14.3	3.6 12.5	16.4 ± 20.1	4.8 27.9	0.1
			ULNT2b left (n = 28)		ULNT2b right (n = 28)		
			6.2 ± 12.6	1.3 11.1	14 ± 18.4	6.9 21.2	0.1

Statistical test: Mann-Whitney U.
CI = confidence interval; ROM = range of motion; SD = standard deviation; ULNT2b = upper limb neurodynamic test 2b.
* Significant comparison with $p \leq 0.1$.

sample, the side of the test, or the instrument played, none of the comparisons were statistically significant except for the comparison of muscular response ROM, which was significantly greater ($p = 0.04$) in women than in men. Additionally, the comparison of neural response ROM in men was significantly greater ($p = 0.01$) compared to muscular response (Appendices D-F).

None of the comparisons of the dichotomous variables—sex, side of the test, and instrument played—were significant (Pearson chi-

Table 4
ROM in degrees of elbow extension in the ULNT1

Variables	Mean ± SD	CI 95%	Mean ± SD	CI 95%	Media ± SD	CI 95%	p value*
	Total (n = 56)		Neural (n = 37)		Muscular (n = 19)		
ROM (°)	115.4 ± 39.4	104.9 126	124.4 ± 38.2	111.7 137.1	98.1 ± 36.5	80.5 115.7	0.02*
			Men (n = 28)		Women (n = 28)		
			115.1 ± 42.4	98.7 131.6	115.8 ± 36.8	101.5 130.1	0.8
			Violin (n = 42)		Viola (n = 14)		
			114.7 ± 36.9	103.2 126.2	117.8 ± 47.4	90.4 145.1	0.9
			ULNT1 left (n = 28)		ULNT1 right (n = 28)		
			121.9 ± 39.8	106.5 137.3	109.1 ± 38.5	94.1 124	0.2

Statistical test: Mann-Whitney U.
CI = confidence interval; ROM = range of motion; SD = standard deviation; ULNT1 = upper limb neurodynamic test 1.
* Significant comparison with $p \leq 0.1$.

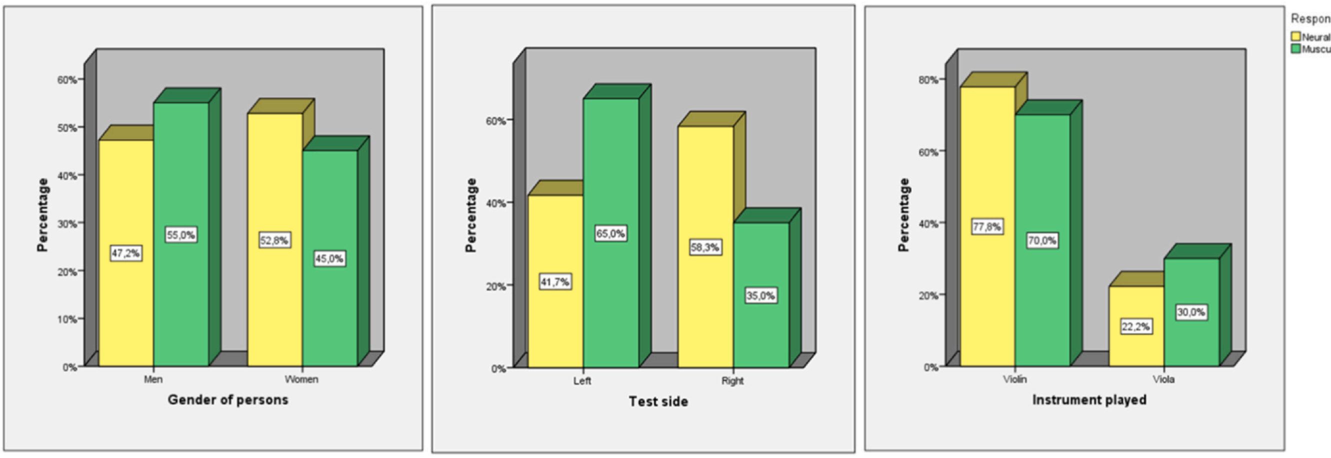

Fig. 4. Comparison of the ULNT2b response between the gender of the sample, side of the test, and instrument played. ULNT2b = upper limb neurodynamic test 2b.

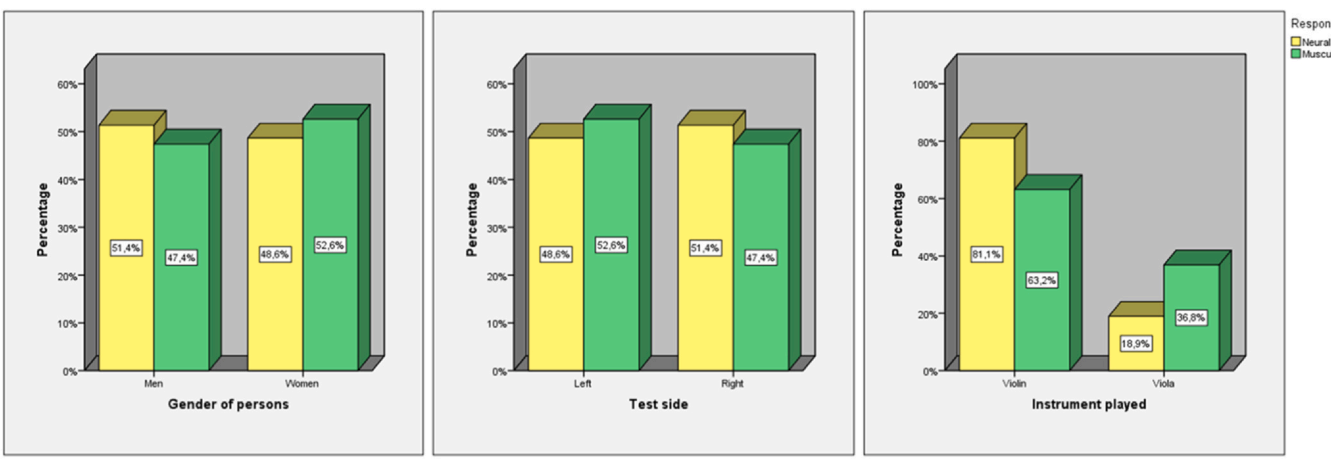

Fig. 5. Comparison of the ULNT1 response between the gender of the sample, side of the test, and instrument played. ULNT1 = upper limb neurodynamic test 1.

square $p \leq 0.1$) with respect to neural or muscular response, neither for ULNT2b (Fig. 4) nor for ULNT1 (Fig. 5).

Regarding the symptoms reported during the ULNT2b, 100% of the sample experienced a sensation of tightness, while the next most frequently reported symptom was pain, observed in 16.1% of the sample. None of the symptoms exhibited a significant comparison between the neural response group and the muscular response group (Table 5).

Regarding the symptoms reported during the ULNT1, 98.2% of the sample experienced a sensation of tightness, while the next most frequently reported symptom was tingling, observed in 14.3% of the sample. None of the symptoms exhibited a significant comparison between the neural response group and the muscular response group (Table 6).

In relation to the area of symptoms reported during the ULNT2b, among those with a muscular response, the most frequently reported area was the dorsal region of the forearm, accounting for 80%; among those with a neural response, the most frequently reported area was also the dorsal forearm, noted by 63.9% (Fig. 6 and Appendix G). None of the areas demonstrated a significant comparison between the neural response group and the muscular response group.

In reference to the area of symptoms reported during the ULNT1, among those with a muscular response, the most frequently reported areas were the palmar region of the forearm and the wrist, both at 52.6%; among those with a neural response, the most frequently reported area was also the palmar region of the forearm, noted by 75.7% (Fig. 7 and Appendix H). None of the areas exhibited a significant comparison between the neural response group and the muscular response group.

Table 5
Comparison of symptoms during the ULNT2b test with the results obtained

Variables		Complete sample (n = 56)	Neural response (n = 36)	Muscular response (n = 20)	p value*
Tightness	Yes	100%	100%	100%	"∅"
	No	0%	0%	0%	
Pain	Yes	16.1%	8.3%	30%	0.1
	No	83.9%	91.7%	70%	
Tingling	Yes	14.3%	19.4%	5.0%	0.2
	No	85.7%	80.6%	95%	
Pricking	Yes	8.9%	13.9%	0%	0.2
	No	91.1%	86.1%	100%	
Numbness	Yes	7.1%	5.6%	10%	0.6
	No	92.9%	94.4%	90%	
Burning	Yes	1.8%	0%	5%	0.4
	No	98.2%	100%	95%	

Statistical test: since more than 20% of the cells had a value less than 5, Fisher's exact test was applied.
ULNT2b = upper limb neurodynamic test 2b.
* Significant comparison with $p \leq 0.1$.

Table 6
Comparison of symptoms during the ULNT1 test with the results obtained

Variables		Complete sample (*n* = 56)	Neural response (*n* = 37)	Muscular response (*n* = 19)	*p* value*
Tightness	Yes	98.2%	100%	94.7%	0.3
	No	1.8%	0%	5.3%	
Pain	Yes	7.1%	10.8%	0%	0.3
	No	92.9%	89.2%	100%	
Tingling	Yes	14.3%	16.2%	10.5%	0.7
	No	85.7%	83.8%	89.5%	
Pricking	Yes	8.9%	10.8%	5.3%	0.7
	No	91.1%	89.2%	94.7%	
Numbness	Yes	3.6%	0%	10.5%	0.1
	No	96.4%	100%	89.5%	
Burning	Yes	8.9%	13.5%	0%	0.2
	No	91.1%	86.5%	100%	

Statistical test: since more than 20% of the cells had a value less than 5, Fisher's exact test was applied.
ULNT1 = upper limb neurodynamic test 1.
* Significant comparison with $p \leq 0.1$.

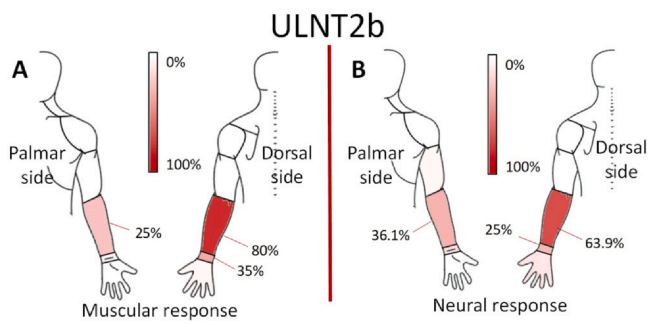

Fig. 6. ULNT2b, prevalence of symptom areas. (**A**) Muscular response group and (**B**) neural response group. ULNT2b = upper limb neurodynamic test 2b.

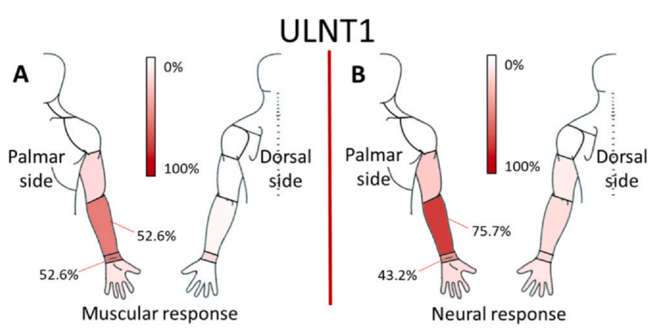

Fig. 7. ULNT1, prevalence of symptom areas. (**A**) Muscular response group and (**B**) neural response group. ULNT1 = upper limb neurodynamic test 1.

Discussion

To the best of our knowledge, this is the first study to describe the normal responses of ULNT1 and ULNT2 in musicians (violinists and violists) and to investigate the influence of demographic variables and the type of instrument played on the responses of both NDTs. The study presented a balanced sample, where demographic variables such as age, BMI, physical activity METs, and commitment did not show significant differences between men and women (Table 1). However, the variables weight, height, and experience demonstrated significant differences favoring the male participants, with a *p* value ≤0.1 (Table 1). It is expected that weight and height would show higher values in the male group, as this reflects typical phylogenetic traits in our species. Notably, the BMI variable, which combines these two factors, did not reveal significant differences between the male and female groups. Regarding the experience variable, the greater number of years favoring the male group may reflect the proportion of male musicians in the studied population.

Regarding the demographic variables of the sample compared by instrument (Table 2), no significant differences were reported except for height, which showed a *p* value ≤0.1 (Table 2). This indicates that the group of violists, although smaller compared to the violinists, was taller on average. The predominant sex of the violists is one factor that may explain this difference in height.

The primary complaints of musicians are often associated with the spine and upper extremities and vary according to the instrument played. Instrumental musicians, for example, have a higher likelihood of experiencing issues in the upper extremities, with a prevalence of 25.7%.[11] For violinists and violists, the most common injuries arise from maintaining static positions in submaximal ranges of the upper cervical spine, shoulder, and left extremity.[2,4,8,10,47] These musicians tend to develop nerve dysfunctions due to repetitive movements and the asymmetric postures required while playing. Specifically, nerve compression and carpal tunnel syndrome are prevalent among string musicians, as they must execute precise movements with their upper extremities while holding their instrument between the shoulder and chin.[6,7,11] Therefore, one of the key aspects of this study was to observe the ROM of both NDTs to determine whether greater mechanosensitivity was present in this population compared to asymptomatic populations, as well as to assess the percentage of tests that elicited a neural response.

ROM ULNT2b

In the ULNT2b, the mean ROM that triggered symptoms (S1) in the total sample was 10.1° ± 16.2, while the mean among those who tested positive was 15° ± 18. These values are significantly lower than the normative data from other studies; for instance, Yaxley and Jull[48] reported a mean ROM for the glenohumeral joint in the ULNT2b of 41.5° ± 4.1 in an asymptomatic population. This same author reported in another study involving a population with lateral epicondylitis[26] a significant difference in ROM between the diagnosed arm with lateral epicondylitis and the asymptomatic arm, with mean ROMs of 24.2° ± 3.1 and 36.6° ± 4.9, respectively. Nevertheless, the mean ROM of the injured subjects would still be greater than that found in our study. Grant et al[25] also investigated the response of the ULNT2b in computer operators working with keyboards compared to a control group, obtaining a mean of 28.9° ± 1.1 in the operator group and 41° ± 1.3 in the control group. In another study[24] aimed at establishing differences in performing the test in symptomatic vs asymptomatic populations, a mean glenohumeral ROM of 37.3° ± 12 was established for the asymptomatic group—although in this asymptomatic group, no maneuvers were performed to determine whether the response to the test was neural or muscular—and for the symptomatic group that tested positive, the mean was 31.1° ± 11.2. Thus, in our study, the population of musicians exhibited greater neural mechanosensitivity than the asymptomatic population and even compared to those engaged in manual labor or symptomatic individuals.

ROM ULNT1

In the ULNT1, the mean ROM that triggered symptoms (S1) in the total sample was 115.4° ± 39.4, while the mean among those who tested positive was 124.4° ± 38.2. These values are significantly lower than the normative data from other studies. In the study by Van Hoof et al,[33] a mean ROM of 156°-157° was obtained for the left or right side in an asymptomatic population; however, this study aimed to establish the maximum tolerable symptom point and did not differentiate structurally. In the study by Boyd[21] involving asymptomatic individuals, the elbow extension ROM was 141.5° ± 18.8 for the dominant extremity and 141.7° ± 20.9 for the non-dominant extremity. The study by Lohkamp and Small[32] conducted the ULNT1, obtaining a mean ROM in S1 of 136.6° ± 11, where the structural differentiation involved a prior tensioning of the nerve with contralateral neck inclination. These data would support the notion that the violist population exhibits greater mechanosensitivity of the median nerve compared to the average population.

Variability between sides and sexes

The main risk factors for string instrumentalists include the maintenance of unnatural postures for prolonged periods due to instrumental practice; levels of repeated and sustained isometric tension while playing, which can lead to overloading in muscles and tendons; lifestyle factors such as sedentary behavior, obesity, and frequent computer use, which increase the risk of musculoskeletal disorders; gender differences—women show a higher tendency to sustain injuries compared to men[9]—; and a poor culture of prevention—many musicians do not engage in warm-up or stretching exercises before and after practice, which raises the risk of injuries.[1] These data may suggest that differences in mechanosensitivity could be observed between sexes or between sides.

However, in our study, no significant comparison of the ROM was found either by extremity or by sex for the ULNT2b or the ULNT1. This result is consistent with the study by Yaxley and Jull[48] which found no differences between sides or sexes, and with the study by Stalioraitis et al[38] which confirmed that there were no significant differences between the dominant and non-dominant limbs for the ULNT2b and ULNT1, noting that a difference of more than 15° and 11°, respectively, would exceed the range of normal asymmetry. However, in the study by Covill and Petersen,[37] it was concluded that it could be normal for an individual to have differences in ROM between extremities in NDTs, although they only found significant differences in the ULNT1—none of the studies utilized structural differentiation maneuvers. The results from some studies suggest that more inclined violin positions, closer to the musician's sagittal plane (with a smaller angle between the instrument's longitudinal axis and the sagittal plane), require greater muscular activation and compensatory efforts in the left arm and shoulder, which may increase the risk of specific health issues related to violin practice.[49] For this reason, it is particularly relevant in our study that no asymmetries were observed between the side holding the violin—the left limb—and the one holding the bow—the right limb—, even though one might initially think that the left would be the more affected area, as indicated by some studies.

Musculoskeletal injuries are very common among musicians in general,[8,9] as an instrumentalist may play an average of 1300 hours annually in non-ergonomic postures.[3,8] Among violists and violas, the prevalence of musculoskeletal injuries is estimated to be between 65% and 90%,[8,50] with tendinitis being the most common pathology, presenting an incidence of 64%.[1] These data are corroborated by the high musculoskeletal response elicited by the tests. In the ULNT2b, 35.7% of the tests showed a muscular response, while in the ULNT1, this figure was 33.9%, both of which are significantly higher than the typical rates of muscular response observed in NDTs, which may be around 5%.[21] In fact, in our study, both the ULNT2b and the ULNT1 exhibited a significantly greater mean ROM when the tests triggered neural responses compared to when they triggered muscular responses, with a p value ≤0.1 (Tables 3 and 4).

Areas and types of symptoms

In the ULNT2b, concerning the types of symptoms, the majority of participants in our study reported a sensation of perceived tension, which was the most frequent symptom, followed by the onset of pain and tingling. We found similar results in the work of Petersen et al[24] where a similar symptom profile was reported in their sample of 60 healthy participants, with perceived tension also being the most common symptom during the execution of the ULNT2b. During the execution of the test, participants in our study reported that their symptoms were distributed in the posterior region of the forearm, which is also the most common distribution in asymptomatic populations.[19]

Regarding the ULNT1, concerning the types of symptoms, the majority of participants in our study reported a sensation of perceived tension, which was the most frequent symptom, followed by the onset of tingling. We found similar results to those of Lohkamp and Small,[32] who identified a similar symptom profile in their sample of 90 healthy participants, where perceived tension was also the most common symptom during the execution of the ULNT1. During the execution of the test, participants in our study reported that their symptoms were distributed in the anterior region of the forearm, which is the most common distribution in asymptomatic populations.[32]

In both the ULNT2b and ULNT1, the most reported sensory response among those who exhibited either a neural or musculoskeletal response was the sensation of perceived tension, rather than predominantly neurogenic symptoms—such as tingling, stabbing sensations, numbness, or burning. This may be attributed to our study sample consisting of asymptomatic violists and violinists who did not report any neural symptoms at the time of the study. Therefore, the mechanosensitivity triggered may not be solely related to neural tissues but could also involve other tissues that induce a stress response, such as musculoskeletal structures and fascial connective tissue, given that this population has been widely studied for muscular overload.[3,8,9,50] A positive response to the test for those who exhibited changes in structural differentiation would not necessarily indicate an underlying pathology, but rather greater mechanosensitivity.[12,20]

In any case, the results of this study would indicate a greater muscular response in both tests, as well as increased mechanosensitivity that does not reflect differences between sides and sexes in the violist population. These circumstances may suggest that this population is ideal for developing prevention programs, training in body care and health, implementing strength and toning exercises, and neural mobilization exercises.

Limitations

Regarding the sample, all participants were right-handed, and although all musicians hold the bow with their right hand regardless of their dominant hand, it would be interesting to investigate whether dominance influences mechanosensitivity, as some studies report differences between dominant and non-dominant sides in asymptomatic populations. Additionally, the majority of cases in the sample were students, and it was not possible to clearly compare the two groups differentiated by years of dedication.

In terms of the conditions in the room where the NDTs were conducted, the study was carried out at each location where the sample was recruited, and there was no control over the room temperature, the timing of measurement, or the prior activity of the subjects.

Concerning the study design, it would have been very interesting to develop a prospective study to determine if this increased mechanosensitivity could lead to chronic neural pathology over the years.

Conclusions

The asymptomatic population of violists and violinists, with an average practice time of 4 hours per day, exhibits greater mechanosensitivity in the radial and median nerves during the ULNT2b and ULNT1, as well as a higher prevalence of muscular responses compared to an asymptomatic population. In the study population, the most common symptom area in the ULNT2b is the dorsal aspect of the forearm, with tightness being the most frequently reported sensation. For the ULNT1, the palmar aspect of the forearm is the most common symptom area, again with tightness as the predominant sensation.

Furthermore, there are no significant differences in the responses of both tests concerning ROM, symptom areas, or symptoms between sexes, sides, or instruments. The only observed significant difference in both tests relates to the joint ROM, which is lower when a muscular response is elicited.

Ethics Committee Approval of the Study Protocol

Ethics Committee of Clinical Research of Aragon - reference number CEICA PI22/546.

Informed Consent Statement

Informed consent was obtained from all subjects involved in this study.

CRediT authorship contribution statement

Isabel Albarova-Corral: Writing – review & editing, Resources. **Gianluca Cuiffreda:** Writing – review & editing, Resources. **Elena Bueno-Gracia:** Writing – original draft, Project administration, Formal analysis. **Alberto Montaner-Cuello:** Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Pilar Pardos-Aguilella:** Writing – review & editing, Resources, Data curation. **Inés Ruíz-Maqueda:** Writing – original draft, Supervision, Methodology, Data curation, Conceptualization.

Data availability

The data presented in this study are available upon request from the corresponding author. The data are not publicly available because permission was obtained solely for their use in this study and not for public dissemination. These are pseudo-anonymized data belonging to the clinical records of each patient in the study.

Declaration of Competing Interest

We confirm that neither the manuscript nor any part of its content is currently under consideration or published in another journal. The authors declare that they have no conflict of interest (or funding sources that might pose a conflict of interest are explicitly declared in the paper).

Appendix A. Comparison of glenohumeral abduction ROM in the ULNT2b by test response type and sex

	Mean ± SD	CI 95%	Mean ± SD	CI 95%	*p* value*
	Women (*n* = 28)		Men (*n* = 28)		
Neural (*n* = 36)	16.6 ± 17.7 (*n*=19)	8.1 25.2	13.1 ± 18.7 (*n* = 17)	3.5 22.8	0.6
Muscular (*n* = 20)	2.9 ± 8.3 (*n* = 9)	−3.5 9.3	0.1 ± 0.3 (*n* = 11)	−0.1 0.3	0.6
p value*	0.1		0.1		

Statistical test: Mann-Whitney U.
CI = confidence interval; ROM = range of motion; SD = standard deviation; ULNT2b = upper limb neurodynamic test 2b.
* Significant comparison with $p \leq 0.1$.

Appendix B. Comparison of glenohumeral abduction ROM in the ULNT2b by test response type and side

	Mean ± SD	CI 95%	Mean ± DS	CI 95%	*p* value*
	ULNT2b left (*n* = 28)		ULNT2b right (*n* = 28)		
Neural (*n* = 36)	9.8 ± 15.4 (*n* = 15)	1.3 18.3	18.7 ± 19.2 (*n* = 21)	9.9 27.4	0.3
Muscular (*n* = 20)	2 ± 6.9 (*n* = 13)	−2.2 6.2	0.1 ± 0.4 (*n* = 7)	−0.2 0.5	0.9
p value*	0.2		0.1		

Statistical test: Mann-Whitney U.
CI = confidence interval; ROM = range of motion; SD = standard deviation; ULNT2b = upper limb neurodynamic test 2b.
* Significant comparison with $p \leq 0.1$.

Appendix C. Comparison of glenohumeral abduction ROM in the ULNT2b by test response type and instrument

	Mean ± SD	CI 95%	Mean ± SD	CI 95%	*p* value*
	Violin (n=42)		Viola (n=14)		
Neural	12 ± 16.2 (*n* = 28)	5.7 18.3	25.4 ± 21.4 (*n* = 8)	7.5 43.2	0.1
Muscular	0.1 ± 0.3 (*n* = 14)	−0.1 0.2	4.3 ± 10.1 (*n* = 6)	−6.3 15	0.4
p value*	0.04*		0.1		

Statistical test: Mann-Whitney U.
CI = confidence interval; ROM = range of motion; SD = standard deviation; ULNT2b = upper limb neurodynamic test 2b.
* Significant comparison with $p \leq 0.1$.

Appendix D. Comparison of elbow extension ROM in degrees in the ULNT1 by test response type between women and men

	Mean ± SD	CI 95%	Mean ± SD	CI 95%	*p* value*
	Women (*n* = 28)		Men (*n* = 28)		
Neural (*n* = 37)	114.3 ± 35.4	96.7	134 ± 39.2	115.1	0.2
	(*n* = 18)	131.9	(*n* = 19)	152.9	
Muscular (*n* = 19)	118.6 ± 41.1	89.2	75.3 ± 0.7	74.8	0.1*
	(n=10)	147.9	(n=9)	75.9	
p value*	1.0		0.01*		

Statistical test: Mann-Whitney U.
CI = confidence interval; ROM = range of motion; SD = standard deviation; ULNT1 = upper limb neurodynamic test 1.
* Significant comparison with $p \le 0.1$.

Appendix E. Comparison of elbow extension ROM in degrees in the ULNT1 by test response type between the left and right sides

	Mean ± SD	CI 95%	Mean ± SD	CI 95%	*p* value*
	ULNT1 left (*n* = 28)		ULNT1 right (*n* = 28)		
Neural (*n* = 37)	130.1 ± 36.2	112.1	119 ± 40.2	99.7	0.3
	(*n* = 18)	148.1	(*n* = 19)	138.4	
Muscular (n=19)	107.1 ± 43.6	75.9	88.1 ± 25.5	68.5	0.5
	(*n* = 10)	138.3	(*n* = 9)	107.7	
p value*	0.1		0.1		

Statistical test: Mann-Whitney U.
CI = confidence interval; ROM = range of motion; SD = standard deviation; ULNT1 = upper limb neurodynamic test 1.
* Significant comparison with $p \le 0.1$.

Appendix F. Comparison of elbow extension ROM in degrees in the ULNT1 by test response type between violin and viola

	Mean ± SD	CI 95%	Mean ± SD	CI 95%	*p* value*
	Violin (*n* = 42)		Viola (*n* = 14)		
Neural (*n* = 37)	121.2 ± 36	107.7	138.3 ± 47	94.8	0.3
	(*n* = 30)	134.6	(*n* = 7)	181.8	
Muscular (*n* = 19)	98.5 ± 35.6	75.9	97.3 ± 40.9	59.4	0.9
	(*n* = 12)	121.2	(*n* = 7)	135.1	
p value*	0.1		0.2		

Statistical test: Mann-Whitney U.
CI = confidence interval; ROM = range of motion; SD = standard deviation; ULNT1 = upper limb neurodynamic test 1.
* Significant comparison with $p \le 0.1$.

Appendix G. Comparison of symptom areas during the test with the ULNT2b results

Variables		Complete sample (*n* = 56)	Neural response (*n* = 36)	Muscular response (*n* = 20)	*p* value*
Dorsal fingers	Yes	8.9%	11.1%	5%	0.4 (F)
	No	91.1%	88.9%	95%	
Palmar wrist	Yes	12.5%	16.7%	5%	0.2 (F)
	No	87.5%	83.3%	95%	
Dorsal wrist	Yes	28.6%	25%	35%	0.4
	No	71.4%	75%	65%	
Palmar forearm	Yes	32.1%	36.1%	25%	0.4
	No	67.9%	63.9%	75%	
Dorsal forearm	Yes	69.6%	63.9%	80%	0.2
	No	30.4%	36.1%	20%	
Palmar arm	Yes	3.6%	5.6%	0%	0.5 (F)
	No	96.4%	94.4%	100%	
Dorsal arm	Yes	10.7%	13.9%	5%	0.4 (F)
	No	89.3%	86.1%	95%	

Statistical test: Pearson chi-square; when more than 20% of the cells had a value less than 5, Fisher's exact test was applied (F).
ULNT2b = upper limb neurodynamic test 2b.
* Significant comparison with $p \le 0.1$.

Appendix H. Comparison of symptom areas during the test with the ULNT1 results

Variables		Complete sample (n = 56)	Neural response (n = 37)	Muscular response (n = 19)	p value*
Dorsal fingers	Yes	12.5%	13.5%	10.5%	1.0 (F)
	No	87.5%	86.5%	89.5%	
Palmar wrist	Yes	7.1%	10.8%	0%	0.3 (F)
	No	92.9%	89.2%	100%	
Dorsal wrist	Yes	46.4%	43.2%	52.6%	0.5
	No	53.6%	56.8%	47.4%	
Palmar forearm	Yes	16.1%	16.2%	15.8%	1.0 (F)
	No	83.9%	83.8%	84.2%	
Dorsal forearm	Yes	67.9%	75.7%	52.6%	0.1
	No	32.1%	24.3%	47.4%	
Palmar arm	Yes	10.7%	13.5%	5.3%	0.7 (F)
	No	89.3%	86.5%	94.7%	
Dorsal arm	Yes	19.6%	21.6%	15.8%	0.7 (F)
	No	80.4%	78.4%	84.2%	
Dorsal fingers	Yes	5.4%	8.1%	0%	0.5 (F)
	No	94.6%	91.9%	100%	

Statistical test: Pearson chi-square; when more than 20% of the cells had a value less than 5, Fisher's exact test was applied (F).
ULNT1 = upper limb neurodynamic test 1.
* Significant comparison with $p \leq 0.1$.

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