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Effects of neural mobilization of sciatic nerve and its branches in plantar foot pressures and stabilometry

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Benefits of neural mobilization (NM) have been described in musculoskeletal patients. The effects of NM on balance appear to be unclear in research, and no studies have tested the possible effects of NM on plantar pressures. Eighteen subjects were evaluated pre and post bilateral gliding of the sciatic nerve and its branches posterior tibial nerve, lateral dorsocutaneous, medial and intermediate dorsocutaneous nerves. Static variables of the plantar footprint and stabilometric variables were measured in a pre-post study. We found no differences in plantar pressure variables, Rearfoot maximum pressure ($p=0.376$), Rearfoot medium pressure ($p=0.106$), Rearfoot surface ($p=0.896$), Midfoot maximum pressure ($p=0.975$), Midfoot medium pressure ($p=0.950$), Midfoot surface ($p=0.470$) Forefoot maximum pressure ($p=0.559$), Forefoot medium pressure($p=0.481$), Forefoot surface ($p=0.234$), and stabilometric variables either, X-Displacement eyes-open ($p=0.086$), Y-Displacement eyes-open ($p=0.544$), Surface eyes-open ($p=0.411$), Medium speed latero-lateral displacement eyes-open ($p=0.613$), Medium speed anteroposterior displacement eyes-open ($p=0.442$), X Displacement eyes-closed ($p=0.126$), Y-Displacement eyes-closed ($p=0.077$), Surface eyes-closed ($p=0.502$), Medium speed latero-lateral displacement eyes-closed ($p=0.956$), Medium speed anteroposterior displacement eyes-closed ($p=0.349$). All variables don´t have significant differences however the measurements had a high reliability with at least an ICC of 0.769. NM doesn´t change plantar pressures or improve balance in healthy non-athletes subjects. NCT05190900.

Keywords Foot, Sciatic nerve, Peripheral nerves, Physical therapy modalities, Rehabilitation

Abbreviation
NM Neural mobilization

In the peripheral nervous system (PNS), involvement has been observed in each musculoskeletal injury investigated. These include areas of pain in the arm, related to the neck, and leg, associated with the lumbar area[1,2]. Other common conditions where the PNS plays a role are entrapment neuropathies such as sciatica[3], heel pain, carpal tunnel syndrome, and epicondylalgia[4].

Neural mobilization, also known as neurodynamics, is a movement-based intervention aimed at restoring homeostasis in and around the nervous system[4]. This principle maintains that the nervous system should tension and relax properly to maintain normal muscle tension and ensure range of motion. This technique is utilized for the recovery of soft tissue mobility[4,5].

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Building on Shacklock's idea, the argument posits that treating the nervous system with manual therapy may be a compelling pain management strategy [Shacklock]. This therapy focuses on neural tissues and the structures surrounding the nervous system, including muscles, fascia, and connective tissues[6].

Neural mobilization (NM) techniques are utilized for the diagnosis and treatment of the mechanical and physiological properties of the PNS[6]. NM techniques are centered on manual manipulations and exercises to restore homeostasis within and around the nervous system[7].

Two variants of NM have been described. Neurodynamic sliding is defined as the mobilization of the nerve, alternating the movement of at least two joints that tense the PNS. In contrast, a separate joint movement occurs that reduces nerve tension. The neurodynamic tensioning variant is described as the simultaneous movement of two joints, where one movement loads the nervous system while the other joint's movement further increases the load tension on the nervous system[6,8].

The research developed in animal and human models has found several benefits of NM. These benefits include a decrease in pain and hyperalgesia[9] intraneural edema of the median nerve in subjects with carpal tunnel syndromes[10]. Other benefits include an increase of glial cells and neural growth factor responses[11], as well as a decrease in electromyographic activity in the biceps brachii of stroke patients with spasticity[12]. NM also facilitates nerve regeneration, involving nerve growth factor and myelin protein zero in individuals after they have sustained a sciatic nerve injury[13].

The effects of mobilization treatment have been demonstrated to enhance pain relief and functionality. In the context of low back pain, it has been found that combining Butler's NM with Mulligan's bent leg raise helps ameliorate pain and enhance the joint range of straight leg raising (SLR) immediately following the treatment[14].

The use of isolated NM has been shown to improve straight leg elevation (SLR) after its application in both sliding and neural tensioning techniques[15,16]. However, no differences have been found in improving the cervical range of motion when comparing the application of NM to the use of ibuprofen for cervicobrachial pain[17]. Both femoral NM and sciatica have demonstrated effectiveness in immediately increasing vertical jumps in adults[15]. Attempting to improve joint range may be essential in foot pathologies such as ulcers, metatarsalgia, and the functional equinus condition[18,19]. However, no study in the literature proves this effect of NM therapy.

The maintenance of postural balance necessitates the detection of body movements, integration of sensory information within the central nervous system, and an appropriate motor response[20]. The position of the body in space is determined by visual, vestibular, and somatosensory functions[20].

Motor control and the dynamic maintenance of balance involve the coordinated activity of muscular kinetic chains[20]. After the technique was implemented, no differences in pain perceived by A-delta fibers were found. However, significant hypoalgesia was observed in subjects who underwent NM, a sensitivity mediated by C fibers. Hence, the relationship between NB and balance captures the interest of several authors. Nunes did not find any differences in dynamic balance. In contrast, other studies indicate that NM of the sciatic nerve can improve static balance on one leg[21]. Furthermore, the dynamic balance improves with sliding and tensioning NM, resulting in enhanced dynamic postural control and hop testing in football players[22].

No study has been conducted on static equilibrium with eyes closed. Further research is required to examine the impact of NM of the lateral, intermediate, and medial dorsocutaneous, posterior tibial, and deep peroneal nerves on sensory-motor impairments, postural control, and functional performance. This is needed to determine whether the effects of balance improvement can be achieved through the mobilization of anterior and posterior nerves.

Other therapies, such as ankle stretching, myofascial induction therapy in the plantar fascia, and dry needling in the Flexor digitorum Brevis muscle[23], have been shown to alter the balance by changing plantar pressures[24,25]. As a result, it is necessary to investigate whether NM can also modify plantar pressures.

Our hypothesis posits that, after the application of NM, plantar pressures decrease across all footprints and that stabilometric variables and static balance will also improve. Our study aimed to illustrate the immediate effects of NM on the foot to enhance post-treatment recommendations. As it stands now, there are no established recommendations for NM.

Methods

Sample size calculation

We used the G*Power® 3.1.9.7 software to calculate the sample size needed to fulfill the study's objective. Aimed at observing differences in plantar pressures, range of motion (ROM), and balance before and after NM, we noted a similar methodology study conducted by researchers who investigated the acute effects of intermittent stretching on plantar pressures during standing. These authors found a decrease in maximum pressure (KPa) of the rear foot from 106.24 ± 20.89 to 87.45 ± 22.28 ($P = 0.004$) after the stretching 23,26. Thus, for our sample size calculation, we used the test of related sample differences (same group before and after an intervention), assuming a two-tailed hypothesis with a statistical confidence of 95%, an alpha error probability of 0.05, and a power of 0.80. This calculation yielded a sample size of 18 subjects. The study was registered on clinicaltrials.gov under the identifier NCT05190900.

Subjects

We selected 18 participants (ten females and eight males) aged 18–37 years. Sociodemographic characteristics are displayed in Table 1.

The inclusion criteria comprised healthy individuals devoid of pain, in line with observing the effects of NM on healthy tissues[20].

The exclusion criteria for the study included: (1) diagnosis of any lower limb injury, such as tendinopathy, bursitis, ligament involvement, or fasciitis[26]; (2) history of lower limb surgery[24]; (3) the requirement that

Variable total ($n = 18$)	Female Mean ± SD CI 95%	Male Mean ± SD CI 95%	Total group Mean ± SD CI 95%	*P*
Age (years)	29.36 ± 7.25 (23.36–35.36)	28.85 ± 6.89 (27.39–30.35)	28.80 ± 6.91 (25.56–32.03)	0.096[b]
Body mass (Kg)	58.09 ± 5.83 (53.26–62.91)	69.75 ± 10.26 (67.54–71.23)	62.55 ± 9.69 (58.01–67.08)	0.013[b]
Height (cm)	162.81 ± 5.11 (158.58- 167.04)	171.62 ± 12.71 (168.89- 174.35)	166.35 ± 9.63 (161.83- 170.86)	0.097[b]
BMI (Kg/m^2)	21.90 ± 1.95 (20.29–23.54)	23.64 ± 1.94 (23.22–24.06)	22.52 ± 2.10 (21.54–23.50)	0.029[b]
Size of shoe	37.90 ± 1.44 (36.71–39.10)	41.25 ± 3.32 (40.53–41.96)	39.30 ± 2.81 (37.98–40.61)	0.052[a]

Table 1. Socio-demographic characteristics of the sample population. Abbreviation: Kg (Kilograms); cm (centimeters), BMI (Body Mass Index), SD (standard deviation), CI 95% (confidence interval 95%).[a] non-normal distribution (U Mann Withney) [b]normal distribution (T-Student).

Fig. 1. Initial and ending sliding position of NM.

participants should not have undergone ankle stretching or any other treatment[23]; (4) diabetes, due to potential alterations in distal arterial circulation[27]; and (5) toe deformities, like hammer toes and hallux valgus.

All subjects signed an informed consent form before participating in the study. Concerning the ethics committee, the principles of the Helsinki Declaration were followed. The ethics committee of Rey Juan Carlos University approved the study with number 3,010,201,915,819. The registration protocol was made at ClinicalTrials.gov NCT05190900 on 13/01/2022.

Neural mobilization therapy

A type of NM technique, neurodynamic glide, was executed where the nerve glides between at least two joints. In this instance, the glide was performed between the cervical area and the distal part of the foot, involving dorsal flexion and plantar flexion. Specifically, the posterior tibial nerve and the lateral dorsocutaneous nerve were glided during dorsal flexion while the dorsal, medial dorsocutaneous and medial dorsal nerves were glided during plantar flexion.

The primary investigator, possessing over 10 years of experience in performing the NM technique, implemented the treatment. We followed the established guidelines for conducting gliding type NM, as cited in various studies, applying them to all distal branches of the sciatic nerve. The procedure involved extending the knee and flexing the hip in one plane, taking the leg to a point where neural symptoms such as paraesthesia were reproduced[28,29]. In this situation, a passive dorsal ankle flexion was conducted. This is because nerve gliding involves utilizing two joints; in this instance, plantar ankle flexion coincides with cervical retropulsion, and they engage in distinct movements. These are executed in such a manner that one joint's movement results in the elongation of neural structures at one end and shortening on the other end simultaneously[28,30,31]. This was repeated a minimum of five times[21]. All procedures were performed in a lateral decubitus position to ensure the maintenance of the degrees of hip flexion during the technique's execution (Fig. 1). The technique was applied bilaterally to both lower limbs.

Measurement

The protocol conducted was as follows: (1) Pre-evaluation. Stabilometric variables and pressures were measured in a randomized manner using the platform. Plantar pressures and stabilometric tests were also randomized, with separate conditions implemented for both open and closed eyes. Three recordings were taken with open eyes and three with closed eyes; (2) Implementation of the NM gliding technique on the distal branches of the posterior sciatic nerve tibial nerve, as well as the lateral, medial, and intermediate dorsocutaneous nerves; (3) Immediate post-evaluation. Stabilometric variables and pressures were randomly measured again using the platform. Plantar pressures and stabilometric tests were also randomized again, with separate conditions sustained for both open and closed eyes.

Specification description	
Size (length x width x height)	530 × 600 × 45 mm
Thickness	4 mm
Active surface	400 × 400 mm
Weight	6.8 kg
Sensors Calibrated	resistive
Sensor	8 × 8 mm
Sensor thickness	0.15 mm
No. of sensors	2304 (48 × 48)
Permissible temperature	From 40 grade C to 85 grade C
Sensor pressure	0.4 N/m2 (0.0004 kPa)/
(minimum/maximum)	100 N/m^2 (0.1 kPa)

Table 2. Technical specifications of the pressure platform. Abbreviation: Kg (Kilograms); cm (centimeters), mm (millimeters), C (centigrade); KPa (Kilopascales), N/m^2 (Newton/ Meters^2).

In all evaluations, subjects were instructed to stand barefoot on platform[18], their feet at a 30° angle to the midline[32], maintaining an upright posture with their upper limbs alongside their bodies[18]. For the recording of stabilometry, subjects were asked to remain upright for 30 s, attempting to maintain this position without movement, while focusing on a point on the wall at eye level and 2 m away[33]. As for the recording of the static plantar footprint and its pressures, three trials were conducted. The foot area was divided into three bilateral regions: (1) the bilateral hindfoot, (2) the bilateral midfoot, and (3) the bilateral forefoot[21,25].

Instrumentation

Ground reaction forces and moments were recorded and digitized using Podoprint (Medicapteurs; Balma, France). The platform features an active area of 400 × 400 mm, equipped with 2304 sensors. Each sensor consists of conductive foam, with a PCB electrode size of 10 × 10 mm. The system operates at an acquisition frequency of 200 Hz for dynamic sampling (200 images per second), making it suitable for studies involving static and dynamic plantar pressures[24,34] and stabilometry[35].

The platform features a self-calibration mode (ACM: Auto Calibration Mode), eliminating the need for any balancing system throughout its service life. All platform characteristics can be found in Table 2.

The manufacturer provides the software used to analyze the data. This software allows for the extraction of variable data at various points during the stance phase of the gait ([19]Supplementary Material).

Variables

Statistical analysis

All data were examined for normality using the Shapiro-Wilk test[18] because the sample size was < 30 subjects[36]. Data were deemed to be normally distributed if $p > 0.05$. Descriptive statistical analysis was carried out using the mean ± standard deviation (SD) along with a 95% confidence interval (CI).

In our reliability study, we explored two types of reliability: (1) relative, which refers to the extent to which individuals maintain their position or value; and (2) absolute reliability, which relates to the degree of association between different measures about different individuals. For absolute reliability, we utilized the intra-class correlation coefficient (ICC), and for the standard errors of the mean (SEM), as recommended by Bruton, Conway, and Holgate[37], in addition to Landis and Koch[38] in their studies. These methods have also been used in other studies aiming to examine reliability analysis[18,25].

Thus, the ICC was used to assess the reliability of each parameter for each intra-session trial. To interpret ICC values, we utilized benchmarks proposed by Landis and Koch[38]: (1) ≤ 0.20, indicating slight agreement; (2) 0.21–0.40, suggesting fair agreement; (3) 0.41–0.60, denoting moderate agreement; (4) 0.61–0.80, marking substantial agreement; and (5) ≥ 0.81, signifying almost perfect agreement.

SEM values were calculated to estimate the range of error for each parameter. The SEM was derived from the ICCs and SDs between sessions. SEM = s_x.√(1- r_xx), where s_x was the SD of the observed test scores set, and r_xx was the reliability coefficient for these data; in this case, the ICC was used as a measure of reliability.

With the obtained records, we examined three instances of each variable for every circumstance, both pre-evaluation and re-evaluation. This evaluation included each stabilometric variable with eyes open and closed, along with pressures in different foot sectors: plantar, forefoot, midfoot, and rearfoot. Podoprint software lets make divisions and calculates accuable variables of these areas.

Finally, the values of normality (VN) for all variables from the ultrasound and cadaveric dissection samples were determined. These were derived from the formula VN = Mean ± 1.96 * SD. The resultant VN of each variable was used to calculate the 95% CI. A p-value of less than 0.05 with a 95% CI was deemed statistically significant for all tests (SPSS for Windows, version 26.0; SPSS Inc., Chicago, Illinois).

The intra-session reliability study of plantar pressure variables and the normality values for the total population are displayed in Tables 3 and 4.

Variable	Pre-test ($n=18$)			Post-test ($n=18$)		
	ICC (95% CI)	SEM	Values of Normality 95% CI	ICC (95% CI)	SEM	Values of Normality 95% CI
Rearfoot maximum pressure (kPa)	0.912 (0.761–0.967)	5.99	2483.56-2565.95	0.849 (0.598–0.943)	6.84	1925.33-2001.45
Rearfoot medium pressure (kPa)	0.851 (0.611–0.944)	1.06	243.77-257.41	0.946 (0.856–0.980)	0.96	231.00-253.97
Rearfoot surface (cm^2)	0.966 (0.911–0.987)	2.23	1040.37-1087.84	0.925 (0.804–0.972)	3.05	943.44-987.11
Midfoot maximum pressure (kPa)	0.985 (0.960–0.994)	1.99	190.68-254.46	0.953 (0.878–0.982)	3.70	261.17-328.08
Midfoot medium pressure (kPa)	0.999 (0.997-1.00)	0.22	19.66-428.46	0.868 (0.643–0.952)	3.13	36.97–70.84
Midfoot surface (cm^2)	0.996 (0.990–0.999)	1.46	337.67-428.46	0.955 (0.880–0.983)	4.59	317.39-402.38
Forefoot maximum pressure (kPa)	0.848 (0.583–0.944)	4.53	806.42-852.01	0.975 (0.933–0.991)	1.46	664.51-700.93
Forefoot medium pressure (kPa)	0.977 (0.939–0.991)	1.41	202.92-239.38	0.962 (0.897–0.986)	0.65	84.83–98.08
Forefoot surface(cm^2)	0.873 (0.658–0.953)	3.41	1904.79-1993.03	0.976 (0.936–0.991)	3.41	1998.21-2084.73

Table 3. Analysis of intrasession reliability of the plantar pressures variables studied and values of normality in total population. Abbreviation: Kg (Kilograms); cm (centimeters), cm^2 (centimeters^2), SD (standard deviation), CI 95% (confidence interval 95%).

Variable	Pre-test ($n=18$)			Post-test ($n=18$)		
	ICC (95% CI)	SEM	Values of normality 95% CI	ICC (95% CI)	SEM	Values of normality 95% CI
X Displacement eyes open (mm)	0.901 (0.791–0.958)	1.32	0.66–17.16	0.979 (0.956–0.991)	0.83	-4.15-18.41
Y Displacement eyes open (mm)	0.950 (0.875–0.980)	2.46	6.1-49.36	0.992 (0.982–0.996)	0.79	-1.57-55.03
Surface eyes open (mm2)	0.943 (0.881–0.976)	1.69	-0.57-27.25	0.983 (0.963–0.993)	1.15	-6.04-28.76
Medium speed of the latero-lateral displacement eyes open (mm/s)	0.812 (0.604–0.920)	5.66	-24.44-26.62	0.953 (0.902–0.980)	0.05	0.57–1.55
Medium speed of the anteroposterior Displacement eyes open (mm/s)	0.908 (0.807–0.961)	0.060	0.47–1.25	0.974 (0.945–0.989)	0.03	0.31–1.49
X Displacement eyes closed (mm)	0.840 (0.663–0.932)	1.7	0.03–16.69	0.975 (0.948–0.989)	0.62	-2.19-15.91
Y Displacement eyes closed (mm)	0.980 (0.959–0.992)	1.62	3.15–48.19	0.995 (0.990–0.998)	1.08	-5.41-54.51
Surface eyes closed (mm^2)	0.899 (0.787–0.957)	5.87	-14.94-57.54	0.860 (0.706–0.940)	7.13	-14.82-59.96
Medium speed of the latero-lateral Displacement eyes closed (mm/s)	0.769 (0.514–0.902)	0.12	0.72–1.72	0.937 (0.867–0.973)	0.06	0.71–1.71
Medium speed of the anteroposterior Displacement eyes closed (mm/s)	0.873 (0.731–0.946)	0.13	0.44–1.96	0.976 (0.936–0.991)	0.41	-3.41-6.97

Table 4. Analysis of intrasession reliability of the stabilometric variables studied and values of normality in total population. Abbreviation: Kg (Kilograms); cm (centimeters), cm^2 (centimeters^2), SD (standard deviation), CI 95% (confidence interval 95%), Kpa (Kilopascals).

Results

Sociodemographic characteristics are displayed in Table 1.

All platform characteristics can be found in Table 2.

The reliability analysis can be observed in Table 3 for Plantar Pressure variables and Table 4 for Stabilometric Variables. All variables yielded a value of ≥ 0.81. SEM and ICC values have confirmed the reliability of these variables.

Five Plantar Pressures Variables and four Stabilometric variables showed a non-normal distribution ($P<0.05$): (1) rear foot surface, (2) midfoot maximum pressure, (3) midfoot medium pressure, (4) midfoot surface, (5) forefoot medium pressure (Table 4); (1)X displacement with eyes open, (2) surface eyes open, (3) surface eyes closed (4), anteroposterior displacement eyes closed (Table 5).

Variable	PRETEST ($n=20$)		POSTTEST ($n=20$)		
	Mean ± SD (CI 95%)	Median (RI)	Mean ± SD (CI 95%)	Median (RI)	*P*
Rearfoot maximum pressure (kPa)	110.32 ± 21.52 (100.25–120.40)	101.90 (35.16)	107.66 ± 22.62 (97.07-118.25)	105.05 (41.51)	0.376[b*]
Rearfoot medium pressure (kPa)	40.20 ± 5.64 (37.56–42.84)	38.55 (7.00)	38.82 ± 5.16 (36.41–41.24)	39.30 (8.90)	0.106[b]
Rearfoot surface (cm^2)	86.28 ± 7.10 (82.95–89.61)	86.10 (8.30)	86.57 ± 9.18 (82.27–90.87)	82.75 (15.40)	0.896[a]
Midfoot maximum pressure (kPa)	13.02 ± 13.06 (6.90-19.13)	12.45 (19.08)	12.03 ± 9.48 (7.59–16.47)	14.12 (18.35)	0.975[a]
Midfoot medium pressure (kPa)	6.53 ± 5.63 (3.89–9.17)	7.90 (9.82)	5.98 ± 4.58 (3.84–8.13)	8.40 (9.28)	0.950[a]
Midfoot surface (cm^2)	14.95 ± 15.70 (7.62–22.32)	11.50 (27.40)	12.15 ± 12.21 (6.43–17.86)	11.75 (23.4)	0.470[a]
Forefoot maximum pressure (kPa)	64.14 ± 12.90 (58.10-70.17)	65.75 (19.48)	65.40 ± 13.29 (59.17–71.62)	69.70 (23.85)	0.559[b]
Forefoot medium pressure (kPa)	27.38 ± 11.31 (22.09–32.68)	25.80 (5.25)	25.60 ± 3.59 (23.92–27.28)	25.62 (5.32)	0.481[a]
Forefoot surface(cm^2)	90.22 ± 12.42 (84.40-96.04)	87.00 (17.00)	92.47 ± 10.66 (87.48–97.46)	93.00 (12.50)	0.234[b]

Table 5. Static footprints variables before and after neural mobilization. Abbreviations: SD, Standard Deviation; CI 95%, Confidence interval 95%; RI, Range interquartile; cm^2 (centimeters^2), Kpa (Kilopascals); [a]P value in from Wilcoxon Signed-Rank Test; [b]P value from paired t-test; A p value < 0.05 with a confidence interval of 95% was considered statistically significant, *statistical significance.

Variable	PRETEST ($n=18$)		POSTTEST ($n=18$)		
	Mean ± SD (CI 95%)	Median (RI)	Mean ± SD (CI 95%)	Median (RI)	*P*
X Displacement eyes open (mm)	8.91 ± 4.21 (6.93–10.88)	9.15 (4.75)	7.13 ± 5.76 (4.43–9.83)	6.82 (8.37)	0.086[a]
Y Displacement eyes open (mm)	27.73 ± 11.04 (22.56–32.90)	28.67 (18.53)	26.73 ± 14.44 (19.97–33.48)	26.40 (26.46)	0.544[b]
Surface eyes open (mm^2)	13.34 ± 7.10 (7.62–19.05)	9.50 (11.85)	11.36 ± 8.88 (7.20-15.51)	8.80 (10.42)	0.411[a]
Medium speed of the latero-lateral displacement eyes open (mm/s)	1.09 ± 13.06 (0.99–1.19)	1.07 (0.39)	1.06 ± 0.25 (0.94–1.18)	1.05 (0.41)	0.613[b]
Medium speed of the anteroposterior Displacement eyes open (mm/s)	0.86 ± 0.20 (0.76–0.96)	0.87 (0.30)	0.90 ± 0.29 (0.76–1.04)	0.82 (0.40)	0.442[b*]
X Displacement eyes closed (mm)	8.36 ± 4.25 (6.36–10.35)	7.62 (6.48)	6.86 ± 4.62 (4.69–9.02)	5.87 (5.97)	0.126[b]
Y Displacement eyes closed (mm)	25.67 ± 11.49 (20.29–31.04)	26.95 (13.18)	24.55 ± 15.29 (17.39–31.70)	23.22 (26.07)	0.077[b]
Surface eyes closed (mm^2)	21.30 ± 18.49 (12.65–29.96)	14.27 (14.72)	22.57 ± 19.08 (13.64–31.50)	17.97 (20.92)	0.502[a]
Medium speed of the latero-lateral Displacement eyes closed (mm/s)	1.22 ± 0.26 (1.09–1.34)	1.20 (0.49)	1.21 ± 0.26 (1.09–1.34)	1.17 (0.31)	0.956[b*]
Medium speed of the anteroposterior Displacement eyes closed (mm/s)	1.20 ± 0.39 (1.01–1.38)	1.07 (0.55)	1.78 ± 2.65 (0.54–3.02)	1.15 (0.58)	0.349[a]

Table 6. Stabilometry variables before and after neural mobilization. Abbreviation: mm (millimeters), mm^2 (millimeters^2); mm/s (millimeters per second), cm^2 (centimeters^2), SD (standard deviation), CI 95% (confidence interval 95%), RI, Range interquartile, [a]P value in from Wilcoxon Signed-Rank Test; [b]P value from paired t-test; A p value < 0.05 with a confidence interval of 95% was considered statistically significant, *statistical significance.

Discussion

The results of our study did not yield improvements in static balance or changes in plantar pressure variables, thereby compelling us to reject our initial hypothesis. According to the reliability study, all the measurements were found to be reliable.

The NM technique in healthy subjects has proven to result in and improvement of the SLR range[14] and increased tissue elasticity[3]. Nerve tensile, shear, and compressive stresses, as well as excursion or traction, are necessary during the movements and postures we perform[6,39]. NM enhances this excursion and traction, thus improving the mechanical and neurophysiological integrity of peripheral nerves[14]. Until now, no study has measured the potential changes in plantar pressures following NM. Techniques like the calf stretch have demonstrated changes in stabilometry and plantar pressures[24,40]. The ROM in different unhealthy conditions, such as cervical radiculopathy patients' pain[41], lymphedema[42], and lumbar spine fusion[43], has appeared to improve after NM. In healthy subjects, calf muscle stretches have been shown to improve plantar pressures after stretching[18,40]. However, the results of the current study failed to confirm a change in plantar pressures after the NM technique, suggesting that NM can be used to increase ROM and tissue elasticity without affecting plantar pressures (Table 6).

This is the initial study on plantar pressures, and thus we are unable to compare its results with existing research. Subsequent studies may reveal whether these effects differ among other pathologies, such as diabetics with less tibial nerve excursion compared to healthy individuals[44], or in those experiencing lumbosacral pain, which could demonstrate improved posterior muscle contraction following NM application[45].

Regarding balance and static postural control, Ferreira et al.[46], evaluated 36 football players after using a pressure platform to measure balance. They compared improvements in two groups, the sliding and tensioning groups, and found enhanced balance persisting for 30 min after the session in both groups. Football players represent a population with a high prevalence of radiculopathies and cervical alterations. In this population, 53% presented narrowed cervical canals due to development, while 87% displayed evidence of disc disease as demonstrated by MRI[47].

On the other hand, Kurt et al.[48] compared the electrotherapy treatment with NM in patients with low back pain in a slumped posture (semi-flexion of body and neck), which involved simultaneous ankle plantar flexion with knee and head flexion for ten repetitions in 1 min. The treatment was implemented as a home-based exercise program over a 3-week intervention period, 5 days a week. They found no significant differences or improvements in balance after the program.

The impact on the NM balance may be immediate, and the effects may not be long-lasting even if an extended program is implemented in unhealthy individuals.

In dynamic postural control, Park et al.[21] found a decrease in the x-center of pressure velocity variable using the sliding technique in a slump position, paired with head movement and lengthy sliding, for five repetitions among healthy adults aged from 20 to 30 years old. Dynamic equilibrium is an increasingly demanding process, which could explain why improvements may have been more readily observed in healthy subjects. Additionally, the application and test were conducted and verified in a one-leg position.

The immediate application of NM, particularly in higher doses, often causes a sensation of paraesthesia in the treated area. This feeling tends to last longer at higher doses and in cases of pathology. However, according to the findings of our study, this does not seem to affect the balance of healthy subjects, even if applied bilaterally, as we have done in our research. This establishes a level of performance reliability that other physiotherapy techniques, like dry needling applied to the foot, do not typically exhibit[23].

Limitations of the Study: One of the limitations of this study is the inability to compare long-term effects and segregate results by gender. Future studies with a control group may yield more evidence about the NM effect on plantar pressures and balance. However, pretest post-studies could also exhibit the efficacy of these treatments[49]. Furthermore, we perceive this study as significant as the NM technique is applied bilaterally in healthy individuals daily, with it being increasingly recommended for musculoskeletal disorders[50,51]. We are now able to advocate the safe usage of the bilateral application.

Conclusions

Our study demonstrates that NM does not modify plantar pressures. Static postural control remains unchanged in healthy non-athletic subjects post-NM, even under bilateral application. Apparently, NM does not influence plantar pressures. This could have clinical applicability when aiming to enhance tissue flexibility without altering the plantar footprint, such as in the case of healthy individuals for instance. Further studies are necessary to compare the impacts of intrameningeal mobilization in diverse populations.

Data availability

"Data are obtanaible for a reasonable reason by request at first author Eva María Martínez Jiménez (evamam03@ucm.es)".

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Declarations

Competing interests
The authors declare no competing interests.

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