Journal of Bodywork & Movement Therapies 39 (2024) 24–31

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Acute effect of dry needling on trunk kinematics and balance of patients with non-specific low back pain

Petros Athanasakis [a], Thomas Nikodelis [a], Vassilios Panoutsakopoulos [a], Vasileios Mylonas [a,*], Theodoros Loizidis [b], Nikolaos A. Koutlianos [c], Iraklis A. Kollias [a]

[a] Biomechanics Laboratory, School of Physical Education and Sport Science at Thessaloniki, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece
[b] Department of Physical and Rehabilitation Medicine, Saint Loukes Hospital, 55236, Panorama, Thessaloniki, Greece
[c] Sports Medicine Laboratory, School of Physical Education and Sport Science at Thessaloniki, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece

ARTICLE INFO

Handling Editor: Dr Jerrilyn Cambron

Keywords:
Inertial measurement units
Torso
Lumbar pain
Rehabilitation
Acupuncture
Biomechanical analysis

ABSTRACT

Background: Limited knowledge exists about the effectiveness of dry needling (DN) concerning the torso kinematics in patients with non-specific low back pain (NS-LBP). Acute effects of DN in NS-LBP patients from a functional perspective were investigated.
Methods: Sixteen NS-LBP patients and 11 healthy individuals (HG) were examined. NS-LBP patients received a single session of DN at the lumbar region. Baseline and immediate post-treatment measurements during flexion-extension and lateral bending of the trunk were conducted for the NS-LBP patients. HG were measured only at baseline to be used as a reference of NS-LBP patients' initial condition. Algometry was applied in NS-LBP patients. Centre of pressure, range of motion of the trunk and its' derivatives were obtained.
Findings: HG performed significantly faster, smoother and with greater mobility in the performed tasks compared to the pre intervention measurements of the NS-LBP patients. For the NS-LBP patients, significant greater angular velocity in frontal plane and significant lower jerk in the sagittal plane were demonstrated post intervention. DN alleviated pain tolerance significantly at the L5 level. Regarding the effectiveness of the DN upon spine kinematics, their derivatives were more sensitive.
Interpretation: It appeared that the pathological type of torso movement was acutely affected by DN. NS-LBP patients showcased smoother movement immediately after the intervention and better control as imprinted in the higher derivative of motion although range of motion did not improve. This quantitative variable may not be subjected to acute effects of DN but rather need additional time and training to be improved.

1. Introduction

Non-specific Low Back Pain (NS-LBP) is defined as pain that arises between the 12th rib and the inferior gluteal, folds with or without leg pain and is not associated with specific underlying pathology (Violante et al., 2015). Sub-acute NS-LBP refers to pain that lasts between six weeks and three months (Krismer and van Tulder 2007). Even though there is not a specific pathological cause, NS-LBP is related to the presence of myofascial trigger points (MTrPs) (Barbero et al., 2019).

MTrPs (Dommerholt and Huijbregts 2011) are defined as "*a hyperirritable spot in skeletal muscle that is associated with a hypersensitive palpable nodule in a taut band*" (Simons et al., 1999). Dysfunction in specific assemblies of the muscle contraction mechanism leads to excessive release of acetylcholine in end plates and to a local energy crisis. The presence of a hyperirritable palpable module contained in the skeletal muscle which is also named as taut band is described as a limited number of fibers with an increased stiffness. Several lines of research suggest that sympathetic activity can strongly modulate the abnormal release of acetylcholine from the nerve's terminal (Hubbard and Berkoff, 1993). Lastly, MTrPs cause pain due to the sensitized nociceptors and release various chemicals who affects the perception of pain. (Dommerholt and Huijbregts 2011). All these effects of the MTrPs have consequences in motor function and pain, be identified by biomechanical and pain measurements (Lucas et al., 2010; Celik and Yeldan, 2011; Ge et al., 2014).

Dry Needling (DN) is a treatment that specifically targets MTrPs by

* Corresponding author.Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
E-mail addresses: Petratha@phed.auth.gr (P. Athanasakis), nikmak@phed.auth.gr (T. Nikodelis), bpanouts@phed.auth.gr (V. Panoutsakopoulos), vmylonas@phed.auth.gr (V. Mylonas), loizidis@yahoo.com (T. Loizidis), koutlian@phed.auth.gr (N.A. Koutlianos), hkollias@phed.auth.gr (I.A. Kollias).

https://doi.org/10.1016/j.jbmt.2024.02.010
Received 12 September 2022; Received in revised form 18 January 2024; Accepted 25 February 2024
Available online 27 February 2024

penetrating the skin, ending up into the muscle belly with a filiform needle. This intervention treats the MTrPs as it releases the taut bands, improves the muscle dysfunction and normalizes the altered chemical environment of the MTrPs. There are studies on diagnosis of MTrPs which have given a large range of results primarily because they could not treat MTrPs, but depending on their location they could have very good to moderate to bad diagnosis (Lucas et al., 2009; Myburgh et al., 2008). In general, DN is effective in alleviating pain and functional disability post-intervention, though the evidence is not robust (Gattie et al., 2017; Hu et al., 2018; Liu et al., 2018).

The center of pressure (CoP) is the point where the average of all pressures applied to the surface through the feet is (Palmieri et al., 2002). The CoP can reflect movements of the upper body (Ruhe et al., 2011), therefore, it is related with the trunk angular displacement. NS-LBP was found to cause instability (Harding et al., 1994) and, at some cases, a more rigid postural control that serves as a motor response strategy (Brumagne et al., 2008; Mazaheri et al., 2013). Nevertheless, acute effects of DN intervention showed that, although the power spectrum of the ground reaction force at the main frequency was increased after the intervention, indicating a smoother movement, the CoP range of motion did not change (Loizidis et al., 2020). Yet, since the researchers examined only the interlimb force distribution there was not any association of their findings with trunk kinematics.

Whereas the range of motion (ROM) of angular displacement expresses the amplitude in a quantitative matter, its derivatives, namely the angular velocity, acceleration, and jerk, describe the quality and smoothness of task executions (Balasubramanian et al., 2015). LBP patients demonstrate limited mobility when compared to normal individuals (Vaisy et al., 2015). Regarding velocity, LBP patients perform slower in spine mobility tasks compared to healthy individuals (Vaisy et al., 2015; Marras and Granata 1997; McGregor et al., 1997). The derivatives of displacement, which indicate movement smoothness (Choi et al., 2014), are suggested to be an effective assessment tool in various cohorts of patients (Mohamed Refai et al., 2021; Schiefelbein et al., 2019; Fukaya et al., 2018). However, there is a contradiction in the literature concerning ROM as a factor that can discriminate LBP patients. For example, ROM was found to show small deviation between subjects with NS-LBP and the normal cohort (McGregor et al., 1997). On the opposite, ROM is different between healthy and LBP for the hip joint (Lee and Kim, 2015) and the lumbar spine (Orakifar et al., 2022).

Traditionally, the methodological approach for understanding the therapeutic mechanism of DN was based on questionnaires, pain assessment, or the quantity of lumbar motion including ROM. However, limited knowledge exists about the DN effectiveness concerning the quality of motion, as expressed by the derivatives of displacement (Mieritz et al., 2014). Thus, it is of interest to examine the possibility to develop effective models that, after the implementation of higher order kinematic measurements, could address the DN treatment modality. Therefore, the purpose of the present study was to investigate the acute effects of DN on sub-acute NS-LBP patients with respect to pain assessment and kinematics measurements of the upper body movement. Firstly, it was hypothesized that healthy participants will perform better than LPB patients and this will prove the LPB group inefficiency due to LBP. Upon that it was hypothesized that LPB patients, after DN treatment will improve at least some of the balance kinetics and kinematics features that express the quality of motion.

2. Materials and methods

The study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee of the School of Physical Education and Sport Science at Thessaloniki, Aristotle University of Thessaloniki, Greece (protocol code EC-14/2020; date of approval: May 27, 2020). Sixteen NS-LBP patients (8 males and 8 females, age: 35–55 yrs) participated in the study. Patient group participants were recruited after attending the medical clinic and reported low back pain. After examination, a subgroup of them was listed as NS-LBP patients and voluntarily participated in the study. A power analysis was conducted to justify the sample size. The power analysis was held with partial η^2 of 0.15, a significance level at 0.05 and desired power of 0.8 using G*Power 3.1 software (Faul et al., 2007). Patients were asked to fill up a pain diagram regarding the anatomical location of their pain and its intensity. It should be located from the lumbar region till the inferior gluteal fold and have a duration of six to twelve weeks. The exclusion criteria were obesity, usage of any anti-inflammatory drug in the past seven days, pain due to sciatica, pregnancy and lumbar surgery. If no exclusion criteria were met, the patients had an essential briefing concerning the assessment and the intervention procedure from the examiner and signed a consent prior to their participation. The tests were performed pre- and post-intervention. Eleven healthy (HG) individuals (5 males and 6 females) aged 25–35 yrs, physically active at least three times per week, also participated and their measurements served as a healthy reference to compare and establish the pathological pattern of the patients. None of them suffered from any injury in the past two months, had surgery in the lumbar region, or felt any pain.

An algometer (Force Dial, Wagner Instruments, Greenwich, CT, USA) was used to measure the Pressure Pain Threshold (PPT). Patients were measured in the prone position. Measurements were taken from the spinous processes from L1 to L5, as well as bilaterally points (25 mm on either side with reference to the spinous process), were palpated and marked by the doctor. Additionally, both sacro-iliac joints were marked. The algometer measured the perpendicular pressure and the maximum pressure applied was 8 kg. The exact moment that the patient felt pain, he/she announced it. The doctor (examiner) applied the test twice and if there was difference between the two values a third measurement was taken. The measurement started from the right side next to the vertebral arch and then went respectively to the left. Next, the spinous processes and the two sacro-iliac joints were measured (Fig. 1a). The process was performed pre- and post-intervention. Healthy individuals were not measured.

Two-force plates (K-Delta, Kinvent, Montpellier, France) were used for recording the vertical Ground Reaction Forces (vGRF) of each leg during the tests. Also, two wireless inertial sensors with 9 degrees of freedom each (K-Sens, Kinvent, Montpellier, France) were used for recording the angular kinematics of the trunk. The inertial sensors were placed at C7 and L5 level. The participants maintained an upright position on the force-plates, with one leg on each force-plate. Then, they were asked to perform a full flexion and extension of the upper body in the sagittal plane and a lateral bending of the upper body in the frontal plane at both sides. The aim was to reach the personal comfort maximum angle. No specific instructions were given about the knee angle, the hands' position and the execution velocity. The measurements were performed pre- and post-DN intervention for the NS-LBP patients and once for the HG. The tests were performed in random order which was the same for pre- and post-measurements regarding the LPB group.

For the treatment of LBP, a DN session was conducted. Fifteen needles were inserted in total ($\varphi = 0.30 \times 50$ mm, Wuxi Jiajian Medical Instrument Co., Ltd, China). Of those, five needles were inserted to the left side next to the pedicles (about 25 mm laterally from the spinous process) from L1 to L5 and five on the right side, respectively. Finally, five needles were inserted between the spinous processes from T12-L1 until L4-L5. All needles were directed into the skin in a perpendicular with the skin surface angle. The DN session lasted 8 min in a steady temperature (approximately 20 °C) (Fig. 1b).

Both the inertia sensors and the force-plates were sampled at 200 Hz. Force and kinematic data of angular velocity were smoothed with a 2nd low pass Butterworth filter with 15 Hz cutoff frequency. Based on the CoP coordinates, the amplitude for the mediolateral (ML) and anteroposterior (AP) axes was calculated. The total range of motion (ROM) was calculated as the summation of the maximum angle values of both directions. The maximum values of the angular velocity of the IMU sensor were calculated concerning the rotational motion of the trunk.

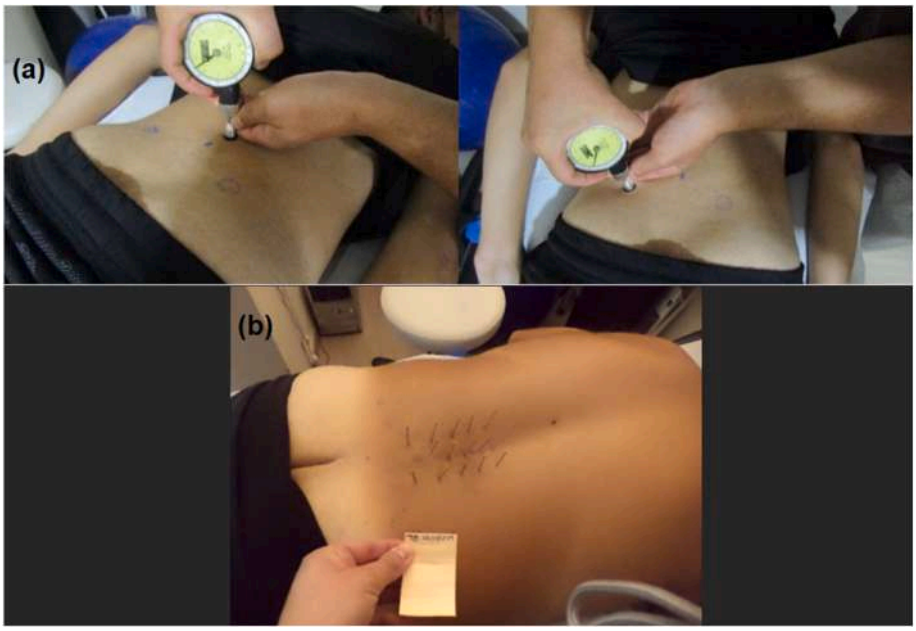

Fig. 1. Pressure pain threshold assessment.
(a) Pressure pain threshold assessment. **(b)** Dry needling applied in patient.

Through angular velocity integration and after drift removal (Averianova et al., 2016), angular displacement was calculated. Moreover, the smoothness of C7 and Pelvis (L5) movement during the performed tests was evaluated using Jerk which was defined as the 2nd derivative of the angular velocity. In specific, the sum of the instances that the value of Jerk changed sign was calculated.

Normal distribution was assessed with the Shapiro-Wilk test. To check the differences in CoP, Angular Displacement and Angular Velocity within the patients' pre- and post-intervention measurements, paired samples *T*-Tests were run. The level of significance was set to $\alpha = 0.05$. The differences between NS-LBP patients' pre-intervention and HG were checked with Independent Samples *T*-Test with Bonferroni adjustment and the level of significance was set to $\alpha = 0.025$. Due to non-normal distribution, non-parametrical tests were applied to check the within NS-LBP patients' differences in PPT and Jerk, namely the Wilcoxon test. The respective between groups differences were examined with Mann-Whitney *U* test, with the level of significance set to $\alpha = 0.05$. The Hedges' *g* was used to check the effect sizes for the *T*-tests (<0.2, <0.5, <0.8 and ≥0.8 indicated trivial, small, medium and large effect sizes, respectively). The respective check was conducted with the Wilcoxon–Mann–Whitney *r* for the Mann Whitney *U* and Wilcoxon test (<0.1, <0.3, <0.5 and ≥0.5 was considered as trivial, small, medium and large effect size, respectively). All statistical analyses were conducted using the IBM SPSS Statistics v.27 software (International Business Machines Corp., Armonk, NY, USA).

3. Results

3.1. Differences in pressure pain threshold

The PPT of the L5 spinous process ($Z = -2{,}448$, $p < 0.05$) and the right L5 transverse process ($Z = -2.201$, $p < 0.05$) were found to be significantly greater after the intervention. There was also a trend for increasing PPT for the right Ilio-lumbar joint ($Z = -1.866$, $p = 0.062$). No statistical differences were found for the rest of the measured points. PPT values are presented in Table 1.

3.2. Differences in CoP

The CoP amplitude in ML axis ($t_{1,25} = -2.44$, $p < 0.025$) during lateral bending of the trunk (Fig. 2b), was found to be significantly higher for HG compared to NS-LBP before the intervention. No other significant difference was found between HG and NS-LBP patients (pre-intervention measure) in CoP amplitude. There was no significant difference ($p > 0.05$) in CoP amplitude within NS-LBP patients before and after the intervention (Fig. 2).

3.3. Differences in angular displacement

The angular displacement of pelvis during flexion in sagittal plane was significantly higher ($t_{1,25} = -2.385$, $p < 0.025$) in HG in comparison with the NS-LBP patients (Fig. 3a) before the intervention, though there were no significant differences during pelvis extension and total ROM of

Table 1
Results (mean ± *SD*) for the Pressure Pain Threshold in the pre- and post-dry needling therapy.

	Left		Right		Center	
	pre	post	pre	post	pre	post
L5 (kg)	7.32 ± 1.18	7.60 ± 0.81	7.27 ± 1.01[a]	7.71 ± 0.53	6.41 ± 1.49[a]	7.29 ± 1.33
L4 (kg)	7.31 ± 1.28	7.55 ± 0.85	7.37 ± 1.09	7.58 ± 0.94	7.11 ± 1.20	7.28 ± 1.56
L3 (kg)	7.67 ± 0.82	7.56 ± 0.87	7.89 ± 0.30	7.68 ± 0.70	7.28 ± 1.19	7.23 ± 1.48
L2 (kg)	7.69 ± 0.60	7.54 ± 0.90	7.84 ± 0.37	7.55 ± 1.07	7.36 ± 1.12	7.52 ± 1.30
L1 (kg)	7.84 ± 0.39	7.60 ± 1.05	7.87 ± 0.38	7.69 ± 0.74	7.50 ± 0.78	7.43 ± 0.92
SI (kg)	6.78 ± 1.80	6.97 ± 1.38	7.04 ± 1.49 ^	7.39 ± 0.97	–	–

[a] Statistically significant, ^: marginal significance.

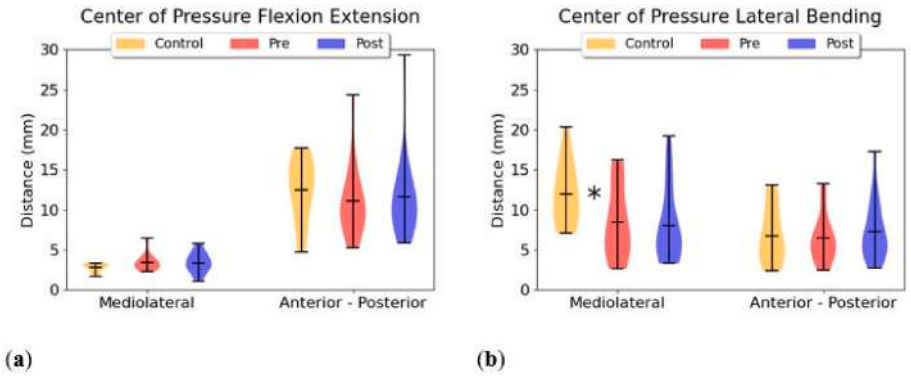

Fig. 2. Results of the Center of Pressure (CoP) amplitude in the mediolateral and anteroposterior axes: (**a**) CoP amplitude in the flexion – extension of the pelvis; (**b**) CoP amplitude in the lateral bending of the pelvis; *: significant difference ($p < 0.05$) between groups.

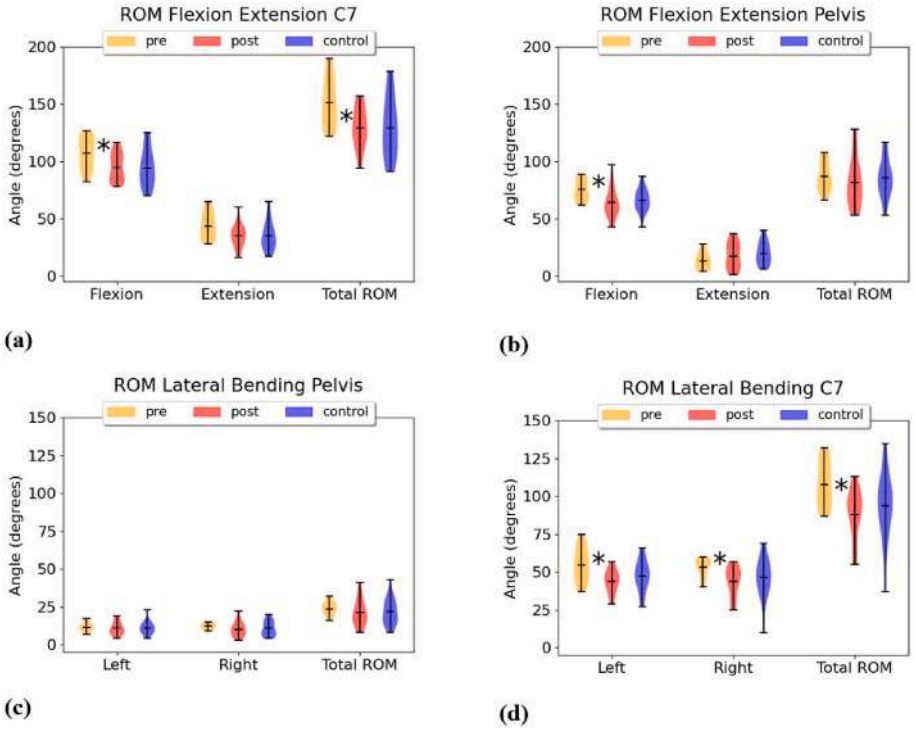

Fig. 3. Results of the Range of Motion (ROM) measurements: (**a**) ROM in the flexion – extension of the pelvis; (**b**) ROM in the flexion – extension of C7; (**c**) ROM in the lateral bending of the pelvis; (**d**) ROM in the lateral bending of C7; *: significant difference ($p < 0.05$) between groups.

the pelvis between HG and NS-LBP patients before the intervention. The angular displacement of C7 was significantly higher during the flexion of the trunk ($t_{1,25} = -2.400$, $p < 0.025$) in HG compared to NS-LBP pre-intervention. The same was observed for the total ROM in the sagittal plane ($t_{1,25} = -2.739$, $p < 0.025$; Fig. 3b) in HG compared to NS-LBP pre-intervention. No significant differences were indicated during extension of C7 between the HG and NS-LBP pre-intervention measurement.

The angular displacement of C7 in the frontal plane was found to be significantly higher in HG when compared to NS-LBP patients' pre-intervention measurement. In specific, the C7 left ($t_{1,25} = -2.890$, $p < 0.025$) and right ($t_{1,25} = -2.660$, $p < 0.025$) bending was significantly higher in HG than NS-LBP patients. Consequently, the total ROM of C7 was found to be significantly higher ($t_{1,25} = -3.130$, $p < 0.025$; Fig. 3d). There were no significant differences ($p > 0.05$) for all the parameters concerning the angular displacement of pelvis in frontal plane between HG and NS-LBP patients' pre-intervention measurements.

No significance differences ($p > 0.05$) were shown in angular displacement within NS-LBP patients for all the performed tests (Fig. 3).

3.4. Differences in angular velocity

The maximum angular velocity of pelvis ($t_{1,25} = -5.85$, $p < 0.025$) during trunk flexion in the sagittal plane was significantly higher in healthy participants when compared to patients before the intervention. The maximum angular velocity of pelvis ($t_{1,25} = -3.08$, $p < 0.025$) during trunk extension in the sagittal plane was significantly higher as well (Fig. 4a). Moreover, the maximum angular velocity of C7 ($t_{1,25} = -3.57$, $p < 0.025$) was significantly higher in HG than the NS-LBP patients' pre-intervention measurements during trunk flexion. Concerning the C7 maximum extension angular velocity ($t_{1,25} = -2.59$, $p < 0.025$), it was significantly higher for the HG compared to NS-LBP during pre-intervention measurement as well (Fig. 4b).

Significant ($t_{1,25} = -4.24$, $p < 0.025$) higher maximum angular velocities of C7 in HG were indicated during left lateral bending of the trunk in the frontal plane when compared with the NS-LBP patients' pre-

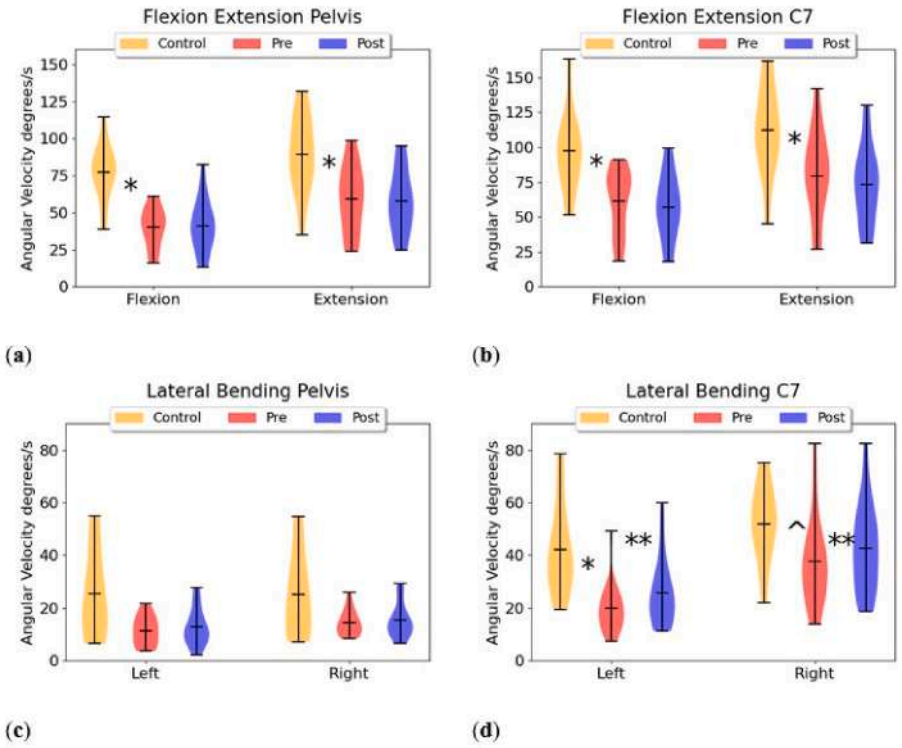

Fig. 4. Results of the maximum angular velocity measurements: (**a**) peak angular velocity in the flexion – extension of the pelvis; (**b**) peak angular velocity in the flexion – extension of C7; (**c**) peak angular velocity in the lateral bending of the pelvis; (d) peak angular velocity in the lateral bending of C7; *: significant difference ($p < 0.05$) between groups; **: significant difference ($p < 0.05$) within groups, ^: marginal difference.

intervention measurement. The C7 maximum angular velocity during the right bending was found to be marginally, yet not significantl, higher (Fig. 4d).

No significant differences ($p > 00.05$) were found concerning the pelvis and C7 maximum angular velocity during trunk flexion-extension in the sagittal plane within NS-LBP patients in the pre- and the post-intervention measurement. The maximum angular velocity in left ($t_{1,15} = -3.22$, $p < 0.05$) and right ($t_{1,15} = -2.19$, $p < 0.05$) bending were significantly higher after the intervention (Fig. 4d) for the NS-LBP group.

3.5. Differences in jerk

The jerk of the pelvis was found to be significant greater ($Z = -3.08$, $p < 0.05$) in NS-LBP patients' pre-intervention measurement during trunk flexion-extension in the sagittal plane compared to HG (Fig. 5a). The jerk of the C7 region was significantly higher in NS-LBP patients' pre-intervention measurement during trunk flexion-extension ($Z = -3.11$, $p < 0.05$) in the sagittal plane (Fig. 5a) compared to HG. No significant differences in jerk of the C7 were revealed between NS-LBP patients and HG during the trunk lateral bending in the frontal plane, although there was a trend ($p = 0.68$) derived from the NS-LBP patients increased jerk value (Fig. 5b).

Jerk of C7 within NS-LBP was found to be significantly lower ($Z = -2.04$, $p < 0.05$) during trunk flexion-extension in the sagittal plane after the intervention (Fig. 5a). The differences in jerk of the C7 during trunk lateral bending in frontal plane were not significant ($p > 0.05$) between groups. No significant within NS-LBP patient differences ($p > 0.05$) were indicated concerning the jerk of the pelvis during the trunk flexion-extension in the sagittal plane and the trunk lateral bending in the frontal plane between pre- and post-intervention measurements.

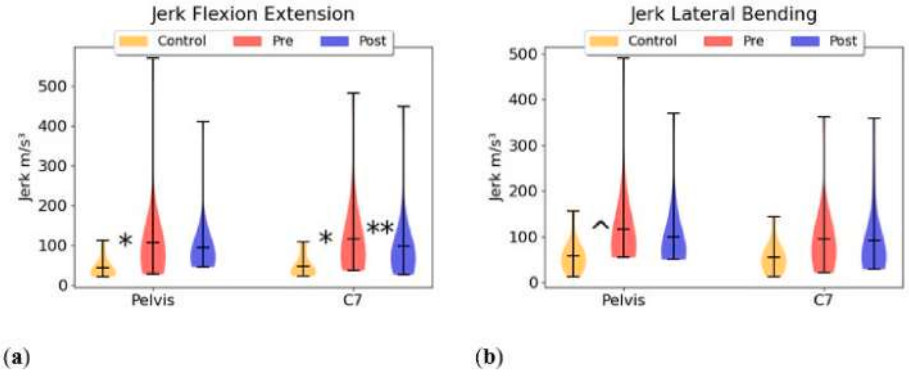

Fig. 5. Results of the jerk measurements: (**a**) jerk in the flexion – extension of the pelvis; (**b**) jerk in the lateral bending of the pelvis; *: significant difference ($p < 0.05$) between groups; **: significant difference ($p < 0.05$) within groups, ^: marginal difference.

4. Discussion

The first hypothesis of the research that healthy participants will perform better than LPB patients was confirmed for all levels of comparison. This finding was a prerequisite for formulating the next step at the logical tree of the current study since it proved that LPB group performance was inefficient as a result of the low back pain that they experienced. Therefore, the necessity of an intervention was justified and based on the existing literature DN intervention was contacted.

The most important symptom for the patients, pain was improved after the intervention. More specifically, PPT of the L5 spinous process and the L5 right side of the spinal process were significantly higher in post-intervention measurements, indicating pain reduction for the specific points.

This finding is in general agreement with a recent systematic review with meta-analysis (Hu et al., 2018). However, the review indicated low to moderate levels of evidence and analyzed different protocols while most of them included Asian population. Others have also reported increased PPTs tolerance of lumbar region after DN (Loizidis et al., 2020; Castro-Sánchez et al., 2017).

The DN session had a middle needle that affected the supraspinal and interspinal ligaments. The loads of the spinal column are accumulated to the lower and bigger vertebra L5. It may be assumed that the increase of motion of the whole column and the release of the ligaments improved the pain in L5. The L5 vertebrae dimensions are larger than the previous vertebras (Zhou et al., 2000). This construction implies the need of higher support to progressively increasing loads (Panjabi and White, 1980). The L5 vertebrae is the inferior point of the vertebral column, so it has to support all the mass that lies superiorly (Kapandji, 1987). Moreover, the L5-S1 junction demonstrates the greatest occurrence of degenerative conditions, about 20% of the total spine (Sparrey et al., 2014). These may be some of the reasons for the sensitivity found at L5 level.

The application of algometry in different points may lead to different PPT scores. In a recent study (Loizidis et al., 2020) in the lumbar region, the anatomical points of algometry and intervention were the same as in the present study yet, PPT values for measured points were not presented individually, but as a total mean difference and as a result, it was not possible to observe which points were affected the most. A general conclusion for the literature is that the DN immediate or post effects in pain were investigated by choosing the most symptomatic side or the most sensitive point (Farasyn and Meeusen, 2005; Koppenhaver et al., 2020; Wang-Price et al., 2020), in contrast with the present study which applied algometry evaluation for the both sides and spinous processes also.

Another question that emerged is "why a bonny structure –the L5 spinous process– indicated higher tolerance in post intervention PPT measurements", while the DN was performed on soft tissues, mainly muscles and ligaments. At pre-intervention, due to general sensitization of the area, any pressure stimuli applied on a bonny structure could result to pain despite the undamaged bony tissue. A possible explanation could be the effect of DN on supraspinous and interspinous ligaments and interspinales lumborum muscle. These two ligaments and the lumbar muscle are penetrated from the needle inserted between two spinous processes. Pain can arise from several structures like muscles and ligaments or by the release of local nociceptors (Arendt-Nielsen et al., 2011). In this case, both of these structures mentioned before had been penetrated.

Kinematic analysis revealed that smoothness (as imprinted through jerk variable), but not range of motion improved as an acute effect of DN. Also, the maximum velocity in the ML plane was improved.

In general, human movement can be judged as successful, smoother or skillful when the higher derivatives are minimum (Choi et al., 2014). Concerning the higher derivatives of angular displacement, the jerk was found to be significantly higher in patients regarding the pelvis and the C7 during flexion/extension of the trunk and for C7 during lateral bending. Although the literature is scarce regarding the jerk (smoothness of motion), that compare healthy individuals and LBP patients; as an indicator of successful movement (Choi et al., 2014), jerk is expected to be less for the healthy group.

There were not any studies concerning the effects of DN upon higher order kinematics of the spine. While this field is not fully explored, it is known from the integrated hypotheses (Dommerholt and Huijbregts, 2011), that from a mechanical perspective the effects of DN may breakdown the contraction knots, amend the alignment of sarcomeres as well as the overlap between actin and myosin. Also, DN changes the biochemical environment by modifying the release of acetylcholine and ameliorate the function of acetylcholinesterase in the endplate of the muscle similarly to the normal muscle regeneration process (Dommerholt & Fernández-de-las-Peñas, 2018). Dar and Hicks (2016) concluded that DN has acute effects on multifidus by improving the muscle activation for the L4-L5 level in healthy individuals (Dar and Hicks, 2016). These effects may provide better muscle functionality instantly after the treatment.

Regarding the angular velocity of the patients after the intervention, no significant differences were found in AP. It seems that DN didn't affect the execution velocity in the AP plane, in contrast with the ML, where lateral bending of the C7 was significantly faster.

From a mechanical perspective, flexion/extension is more demanding in comparison with lateral bending. While the ROM of the lumbar region is equal for sagittal and frontal planes in the mid-age (Kapandji, 1987), the contribution of pelvis during rotation, makes the whole body able to cover a greater range in sagittal plane than in frontal. The role of the fascia stiffness should not be neglected (Schleip et al., 2007). Research indicates that the stiffness of various layers within the thoracolumbar fascia affects the stability of the spine during movements like bending backwards or forwards (Barker et al., 2006). Flexion severely increases the loading in the back muscles and passive tissues (Marras and Wongsam, 1986). The moments developed in L5/S1 during flexion/extension are almost the double than lateral bending (Larivière et al., 2000). These factors may explain why DN affected the angular velocity only in ML.

Yet, lateral bending of the trunk is a more complex motion, as more muscles are involved and co-activate in comparison with flexion/extension of the trunk and the motion of the vertebra is more complex. (Kapandji, 1987; Behnke, 2006). For example, when trunk bends laterally, the ipsilateral portion of erector spinae seems to contract, while the contra-lateral portion seems to work eccentric. Moreover, two large muscles, the contra-lateral portions of latissimus dorsi and internal oblique are recruited to act eccentrically too.

On the contrary, the jerk was improved in the AP plane. The initial value of Jerk in the AP was higher (115) in comparison with the equivalent value in ML (94) in patient group, while the healthy demonstrated almost equal jerk values in all planes of motion. Possibly the impairment in patients regarding jerk, is more pronounced in the AP than in ML plane, due to the activation of paraspinal muscles as the main extensors (Larivière et al., 2000). By penetrating these muscles, DN seems to be effective by improving the smoothness of motion. There was a small improvement also in the ML plane, yet not significant. The initial jerk values which are lower in the ML plane as well as the restricted contribution of the paraspinal muscles in lateral bending and the co-activation of various muscle groups, may be some reasons why the jerk index did not change. The amplitude of displacement, as expressed by the ROM and the COP, didn't meet any significant alterations. The current study could not investigate if the patients' significant poorer mobility was caused by the LBP or not, due to the lack of a control patients' group.

However, if it is hypothesized that the differences in the range of the motion are caused by pathological restrictions, then possibly a single session of DN is not effective enough to treat the restrictions and immediately regain the altered mobility, at least in the short-term. The study of Castro-Sánchez et al. (2017) found a negligible to small effect

size for spinal mobility in a 4 once-weekly DN sessions. The etiology and pathophysiology of MTrPs are not yet fully understood, thus possible causes for restrictions in mobility are still not apparent. We must also consider the alterations that happened on muscles coordination as an adaptation on the presence of MTrPs. Also, therapeutic exercise as an addition to DN could be effective. Strong evidence suggests that exercise improves post-treatment pain intensity and long-term functions (van Middelkoop et al., 2010). Yet, a methodology design regarding the effectiveness of various interventions upon function consists a challenging attempt.

Moreover, it is possible that acute and chronic LBP patients demonstrate an altered type of locomotion, as a defensive mechanism. Such conclusion can be drawn from the results of the present study but has also been suggested in previous research (Mieritz et al., 2014; Thomas et al., 2008).

The strength of the findings of the present study is confined by several limitations. Firstly, there were no algometer measures for the HG to compare them with the patients' group pre-intervention values. Although the HG were not in pain, such measures could reflect the sensitivity of each participant, which could partially bias the results. Nevertheless, the algometer measures were compared using repeated measures statistical model and this limitation was partially resolved. Also, the fact that no specific instructions were given to the participants about the knee angle may have led to the different execution of the LBP group at the post-intervention assessment. Although it was assumed that the technique, at least in terms of ROM of an unaffected joint (i.e., the knee) will remain the same, since the effect was acute and new intersegmental coordination patterns could not be established.

Despite the aforementioned limitations, this study can drive the research logical tree to some new theoretical implications. The mid- and long-term effect of DN should be measured to provide evidence about how the improvement in the quality of motion is preserved and what occurs to the rotational kinematics in terms of ROM which is critical for daily living. Such steps will provide evidence and bases for the practical implications in rehabilitation and the restoration of a healthy movement pattern. At this point, practical implications are limited to the fact that acute pain relief and improvement on displacement derivatives of motion provides a training base for the therapists to work on restoring mobility. The effectiveness of different manners of implementing this is also another field of future research.

Conclusively, it seems that displacement derivatives are more sensitive regarding the effectiveness of the DN upon spine kinematics than parameters which express the amplitude of displacement. DN has acute effects on lumbar functionality by providing faster execution during lateral bending in ML and smoother locomotion during flexion/extension in AP plane. From the present evidence, it is concluded that a pathological type of locomotion tends to return to normality by initially affecting its quality components. It appears that range of motion may need more time and training to be improved, such speculation however, must be proved experimentally.

Funding

This research received no external funding.

Institutional review board statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the ethics committee of the Faculty of Physical Education and Sport Sciences at Thessaloniki, Aristotle University of Thessaloniki, Greece (protocol code EC-14/2020; date of approval: May 27, 2020).

Informed consent statement

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

Data availability statement

Not applicable.

Clinical relevance

- Dry needling for low back pain treatment alleviated pressure pain threshold in L5.
- Dry needling acutely affects the quality of motion but not the range of motion.
- This effect could provide a window for retraining the movement's range of motion.

CRediT authorship contribution statement

Petros Athanasakis: Writing – original draft, Data curation. **Thomas Nikodelis:** Writing – review & editing, Visualization, Validation, Project administration, Methodology, Conceptualization. **Vassilios Panoutsakopoulos:** Writing – review & editing, Investigation, Formal analysis. **Vasileios Mylonas:** Writing – review & editing. **Theodoros Loizidis:** Writing – review & editing, Validation, Resources, Project administration, Methodology. **Nikolaos A. Koutlianos:** Writing – review & editing, Supervision. **Iraklis A. Kollias:** Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare no conflict of interest.

References

Arendt-Nielsen, L., Fernández-de-las-Peñas, C., Graven-Nielsen, T., 2011. Basic aspects of musculoskeletal pain: from acute to chronic pain. J. Man. Manip. Ther. 19 (4), 186–193. https://doi.org/10.1179/106698111X13129729551903.

Averianova, A., Nikodelis, T., Konstantakos, V., Kollias, I., 2016. Rotational kinematics of pelvis and upper trunk at butterfly stroke: can fins affect the dynamics of the system? J. Biomech. 49 (3), 423–428. https://doi.org/10.1016/j.jbiomech.2016.01.004.

Balasubramanian, S., Melendez-Calderon, A., Roby-Brami, A., Burdet, E., 2015. On the analysis of movement smoothness. J. NeuroEng. Rehabil. 12 (1), 1–11. https://doi.org/10.1186/s12984-015-0090-9.

Barbero, M., Schneebeli, A., Koetsier, E., Maino, P., 2019. Myofascial pain syndrome and trigger points: evaluation and treatment in patients with musculoskeletal pain. Curr. Opin. Support. Palliat. Care 13 (3), 270–276. https://doi.org/10.1097/SPC.0000000000000445.

Barker, P.J., Guggenheimer, K.T., Grkovic, I., Briggs, C.A., Jones, D.C., Thomas, C.D., Hodges, P.W., 2006. Effects of tensioning the lumbar fasciae on segmental stiffness during flexion and extension: Young Investigator Award winner. Spine 31 (4), 397–405. https://doi.org/10.1097/01.brs.0000195869.18844.56.

Behnke, R.S., 2006. Kinetic anatomy. In: Human Kinetics Champaign IL, second ed.

Brumagne, S., Janssens, L., Knapen, S., Claeys, K., Suuden-Johanson, E., 2008. Persons with recurrent low back pain exhibit a rigid postural control strategy. Eur. Spine J. 17 (9), 1177–1184. https://doi.org/10.1007/s00586-008-0709-7.

Castro-Sánchez, A.M., García-López, H., Matarán-Peñarrocha, G.A., Fernández-Sánchez, M., Fernández-Sola, C., Granero-Molina, J., Aguilar-Ferrándiz, M.E., 2017. Effects of dry needling on spinal mobility and trigger points in patients with fibromyalgia syndrome. Pain Physician 20 (2), 37–52.

Celik, D., Yeldan, I., 2011. The relationship between latent trigger point and muscle strength in healthy subjects: a double-blind study. J. Back Musculoskelet. Rehabil. 24 (4), 251–256. https://doi.org/10.3233/BMR-2011-0302.

Choi, A., Joo, S.B., Oh, E., Mun, J.H., 2014. Kinematic evaluation of movement smoothness in golf: relationship between the normalized jerk cost of body joints and the clubhead. Biomed. Eng. Online 13 (1), 20. https://doi.org/10.1186/1475-925X-13-20.

Dar, G., Hicks, G.E., 2016. The immediate effect of dry needling on multifidus muscles' function in healthy individuals. J. Back Musculoskelet. Rehabil. 29 (2), 273–278. https://doi.org/10.3233/BMR-150624.

Dommerholt, J., Fernández-de-las-Peñas, C., 2018. Trigger Point Dry Needling: an Evidenced and Clinical-Based Approach, second ed. Elsevier.

Dommerholt, J., Huijbregts, P., 2011. Myofascial Trigger Points: Patophysiology and Evidence-Informed Diagnosis and Management, third ed. Jones and Bartlett Publishers, Burlington, MA, USA.

Farasyn, A., Meeusen, R., 2005. The influence of non-specific low back pain on pressure pain thresholds and disability. Eur. J. Pain 9 (4), 375–381. https://doi.org/10.1016/j.ejpain.2004.09.005.

Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39 (2), 175–191. https://doi.org/10.3758/bf03193146.

Fukaya, T., Mutsuzaki, H., Nakano, W., Mori, K., 2018. Smoothness of the knee joint movement during the stance phase in patients with severe knee osteoarthritis. Asia-Pac. J. Sports Med. Arthrosc. Rehabil. Technol. 14, 1–5. https://doi.org/10.1016/j.asmart.2018.08.002.

Gattie, E., Cleland, J.A., Snodgrass, S., 2017. The effectiveness of trigger point dry needling for musculoskeletal conditions by physical therapists: a systematic review and meta-analysis. J. Orthop. Sports Phys. Ther. 47 (3), 133–149. https://doi.org/10.2519/jospt.2017.7096.

Ge, H.Y., Monterde, S., Graven-Nielsen, T., Arendt-Nielsen, L., 2014. Latent myofascial trigger points are associated with an increased intramuscular electromyographic activity during synergistic muscle activation. J. Pain 15 (2), 181–187. https://doi.org/10.1016/j.jpain.2013.10.009.

Harding, V.R., Williams, AC. de C., Richardson, P.H., Nicholas, M.K., Jackson, J.L., Richardson, I.H., Pither, C.E., 1994. The development of a battery of measures for assessing physical functioning of chronic pain patients. Pain 58 (3), 367–378. https://doi.org/10.1016/0304-3959(94)90131-7.

Hu, H.T., Gao, H., Ma, R.J., Zhao, X.F., Tian, H.F., Li, L., 2018. Is dry needling effective for low back pain? Medicine 97 (26), e11225. https://doi.org/10.1097/MD.0000000000011225.

Hubbard, D.R., Berkoff, G.M., 1993. Myofascial trigger points show spontaneous needle EMG activity. Spine 18 (13), 1803–1807. https://doi.org/10.1097/00007632-199310000-00015.

Kapandji, I.A., 1987. The Physiology of the Joints. In: The Spinal Column, Pelvic Girdle and Head, Vol. 3. Churchill Livingstone, New York, NY, USA.

Koppenhaver, S., Gaffney, E., Oates, A., Eberle, L., Young, B., Hebert, J., Proulx, L., Shinohara, M., 2020. Lumbar muscle stiffness is different in individuals with low back pain than asymptomatic controls and is associated with pain and disability, but not common physical examination findings. Musculoskelet. Sci. Pract. 45, 102078 https://doi.org/10.1016/j.msksp.2019.102078.

Krismer, M., van Tulder, M., 2007. Strategies for prevention and management of musculoskeletal conditions. Low back pain (non-specific). Best Pract. Res. Clin. Rheumatol. 21 (1), 77–91. https://doi.org/10.1016/j.berh.2006.08.004.

Larivière, C., Gagnon, D., Loisel, P., 2000. The comparison of trunk muscles EMG activation between subjects with and without chronic low back pain during flexion–extension and lateral bending tasks. J. Electromyogr. Kinesiol. 10 (2), 79–91. https://doi.org/10.1016/s1050-6411(99)00027-9.

Lee, S.W., Kim, S.Y., 2015. Comparison of chronic low-back pain patients hip range of motion with lumbar instability. J. Phys. Ther. Sci. 27 (2), 349–351. https://doi.org/10.1589/jpts.27.349.

Liu, L., Huang, Q.M., Liu, Q.G., Thitham, N., Li, L.H., Ma, Y.T., Zhao, J.M., 2018. Evidence for dry needling in the management of myofascial trigger points associated with low back pain: a systematic review and meta-analysis. Arch. Phys. Med. Rehabil. 99 (1), 144–152. https://doi.org/10.1016/j.apmr.2017.06.008.

Loizidis, T., Nikodelis, T., Bakas, E., Kollias, I., 2020. The effects of dry needling on pain relief and functional balance in patients with sub-chronic low back pain. J. Back Musculoskelet. Rehabil. 1, 1–7. https://doi.org/10.3233/bmr-181265.

Lucas, K.R., Rich, P.A., Polus, B.I., 2010. Muscle activation patterns in the scapular positioning muscles during loaded scapular plane elevation: the effects of Latent Myofascial Trigger Points. Clin. Biomech. 25 (8), 765–770. https://doi.org/10.1016/j.clinbiomech.2010.05.006.

Lucas, N., Macaskill, P., Irwig, L., Moran, R., Bogduk, N., 2009. Reliability of physical examination for diagnosis of myofascial trigger points: a systematic review of the literature. Clin. J. Pain 25 (1), 80–89. https://doi.org/10.1097/AJP.0b013e31817e13b6.

Marras, W.S., Granata, K.P., 1997. Spine loading during trunk lateral bending motions. J. Biomech. 30 (7), 697–703. https://doi.org/10.1016/S0021-9290(97)00010-9.

Marras, W.S., Wongsam, P.E., 1986. Flexibility and velocity of the normal and impaired lumbar spine. Arch. Phys. Med. Rehabil. 67 (4), 213–217. https://doi.org/10.5555/uri:pii:0003999386903655.

Mazaheri, M., Coenen, P., Parnianpour, M., Kiers, H., van Dieën, J.H., 2013. Low back pain and postural sway during quiet standing with and without sensory manipulation: a systematic review. Gait Posture 37 (1), 12–22. https://doi.org/10.1016/j.gaitpost.2012.06.013.

McGregor, A.H., McCarthy, D., Doré, C.J., Dore, C.J., Hughes, S.P., 1997. Quantitative assessment of the motion of the lumbar spine in the low back pain population and the effect of different spinal pathologies on this motion. Eur. Spine J. 6, 308–315. https://doi.org/10.1007/BF01142676.

Mieritz, R.M., Hartvigsen, J., Boyle, E., Jakobsen, M.D., Aagaard, P., Bronfort, G., 2014. Lumbar motion changes in chronic low back pain patients: a secondary analysis of data from a randomized clinical trial. Spine J. 14 (11), 2618–2627. https://doi.org/10.1016/j.spinee.2014.02.038.

Mohamed Refai, M.I., Saes, M., Scheltinga, B.L., van Kordelaar, J., Bussmann, J.B.J., Veltink, P.H., Buurke, J.H., Meskers, C.G.M., van Wegen, E.E.H., Kwakkel, G., van Beijnum, B.F., 2021. Smoothness metrics for reaching performance after stroke. Part 1: which one to choose? J. NeuroEng. Rehabil. 18 (1), 154. https://doi.org/10.1186/s12984-021-00949-.

Myburgh, C., Larsen, A.H., Hartvigsen, J., 2008. A systematic, critical review of manual palpation for identifying myofascial trigger points: evidence and clinical significance. Arch. Phys. Med. Rehabil. 89 (6), 1169–1176. https://doi.org/10.1016/j.apmr.2007.12.033.

Orakifar, N., Shaterzadeh-Yazdi, M.J., Salehi, R., Mehravar, M., Namnik, N., Haghpanah, S.A., 2022. Comparison of kinematic movement patterns between 2 subgroups of females with low back pain and healthy women during sit-to-stand and stand-to-sit. J. Appl. Biomech. 38 (5), 346–354. https://doi.org/10.1123/jab.2022-0064.

Palmieri, R.M., Ingersoll, C.D., Stone, M.B., Krause, B.A., 2002. Center-of-pressure parameters used in the assessment of postural control. J. Sport Rehabil. 11 (1), 51–66. https://doi.org/10.1123/jsr.11.1.51.

Panjabi, M.M., White, A.A., 1980. Basic biomechanics of the spine. Neurosergery 7 (1), 76–93. https://doi.org/10.1227/00006123-198007000-00014.

Ruhe, A., Fejer, R., Walker, B., 2011. Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls: a systematic review of the literature. Eur. Spine J. 20 (3), 358–368. https://doi.org/10.1007/s00586-010-1543-2.

Schiefelbein, M.L., Salazar, A.P., Marchese, R.R., Rech, K.D., Schifino, G.P., Figueiredo, C.S., Cimolin, V., Pagnussat, A.S., 2019. Upper-limb movement smoothness after stroke and its relationship with measures of body function/structure and activity - a cross-sectional study. J. Neurol. Sci. 401, 75–78. https://doi.org/10.1016/j.jns.2019.04.017.

Schleip, R., Vleeming, A., Lehmann-Horn, F., Klingler, W., 2007. Letter to the Editor concerning "A hypothesis of chronic back pain: ligament subfailure injuries lead to muscle control dysfunction" (M Panjabi). Eur. Spine J. 16 (10), 1733–1735. https://doi.org/10.1007/s00586-006-0298-2.

Simons, D.G., Travell, J.G., Simons, L.S., 1999. Myofascial Pain and Dysfunction: Upper Half of Body. Lippincott Williams & Wilkins, Philadelphia, PE, USA.

Sparrey, C.J., Bailey, J.F., Safaee, M., Clark, A.J., Lafage, V., Schwab, F., Smith, J.S., Ames, C.P., 2014. Etiology of lumbar lordosis and its pathophysiology: a review of the evolution of lumbar lordosis, and the mechanics and biology of lumbar degeneration. Neurosurg. Focus 36 (5), E1. https://doi.org/10.3171/2014.1.FOCUS13551.

Thomas, J.S., France, C.R., Lavender, S.A., Johnson, M.R., 2008. Effects of fear of movement on spine velocity and acceleration after recovery from low back pain. Spine 33 (5), 564–570. https://doi.org/10.1097/BRS.0b013e3181657f1a.

Vaisy, M., Gizzi, L., Petzke, F., Pfingsten, M., Falla, D., 2015. Measurement of lumbar spine functional movement in low back pain. Clin. J. Pain 31 (10), 876–885. https://doi.org/10.1097/AJP.0000000000000190.

van Middelkoop, M., Rubinstein, S.M., Verhagen, A.P., Ostelo, R.W., Koes, B.W., van Tulder, M.W., 2010. Exercise therapy for chronic nonspecific low-back pain. Best Pract. Res. Clin. Rheumatol. 24 (2), 193–204. https://doi.org/10.1016/j.berh.2010.01.002.

Violante, F.S., Mattioli, S., Bonfiglioli, R., 2015. Low-back pain. Handb. Clin. Neurol. 131, 397–410. https://doi.org/10.1016/B978-0-444-62627-1.00020-2.

Wang-Price, S., Zafereo, J., Couch, Z., Brizzolara, K., Heins, T., Smith, L., 2020. Short-term effects of two deep dry needling techniques on pressure pain thresholds and electromyographic amplitude of the lumbosacral multifidus in patients with low back pain - a randomized clinical trial. J. Man. Manip. Ther. 28 (5), 254–265. https://doi.org/10.1080/10669817.2020.1714165.

Zhou, S.H., McCarthy, I.D., McGregor, A.H., Coombs, R.R.H., Hughes, S.P.F., 2000. Geometrical dimensions of the lumbar vertebrae - analysis of data from digitised CT images. Eur. Spine J. 9 (3), 242–248. https://doi.org/10.1007/s005860000140.