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Flexion-relaxation ratio asymmetry and its relation with trunk lateral ROM in individuals with and without chronic non-specific low back pain

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Study Design: A cross-sectional comparative study.

Objective: The present study aimed to investigate the relationship between the flexion-relaxation phenomenon asymmetry of lumbar muscles and trunk lateral Range of Motion (ROM) asymmetry in non-specific chronic low back pain (NSCLBP) patients.

Summary of Background Data: Imbalance in trunk muscle activation between right and left sides can induce pain by loading the spine incorrectly, especially in NSCLBP patients. A previous study reported a greater asymmetry in the flexion-relaxation phenomenon of the erector spinae in NSCLBP patients than in asymptomatic participants (AP). Imbalance of muscle properties, such as trunk ROM, has been suggested as a possible cause of this observed asymmetry.

Methods: Twenty-eight NSCLBP patients and twenty-two AP performed three standing maximal trunk flexions. Surface electromyography were recorded bilaterally for erector spinae longissimus and lumbar multifidus. A flexion-relaxation ratio was calculated for each muscle. The fingertip-to-thigh test was performed to assess trunk lateral ROM. Each parameter's asymmetry was calculated as the absolute difference between right and left sides.

Results: NSCLBP patients present a significantly lower trunk lateral ROM than AP. Flexion-relaxation ratio asymmetry of the erector spinae was significantly greater in NSCLBP patients than in AP ($p<0.05$). Flexion-relaxation ratio asymmetry of the multifidus and trunk lateral ROM asymmetry were not significantly different between groups. Significant correlation ($r = 0.49$) between flexion-relaxation ratio asymmetry of Erector spinae and trunk lateral ROM asymmetry was observed only for NSCLBP patients.

Conclusions: The present findings showed that flexion-relaxation ratio asymmetry of erector spinae longissimus is moderately correlated with trunk lateral ROM asymmetry. In addition, the results confirmed that NSCLBP patients present a reduced trunk lateral ROM, flexion-relaxation ratio asymmetry of the erector spinae which is correlated with trunk rotation. These findings suggested an imbalance spine loading which can contribute to the persistence of pain.

Key words: flexion-relaxation phenomenon; non-specific chronic low back pain; trunk range of motion; electromyography; asymmetry

Level of Evidence: 3

Key points

- Asymmetry of the Flexion-relaxation phenomenon was greater in NSCLBP patients than AP.
- NSCLBP patients had a reduced trunk lateral range of motion
- Asymmetry of the Flexion-relaxation phenomenon was correlate with the asymmetry of the trunk lateral range of motion in NSCLBP patients.

1 Introduction

Since 1990, low back pain (LBP) has been the leading cause of disability worldwide[1], with a lifetime prevalence of 84% in industrialised countries[2]. As the exact cause of pain cannot be ascertained in 85%–90% of cases, patients are classified as having non-specific LBP[3,4]. Among these patients, 10% become chronic sufferers and represent a high socioeconomic burden on the state[5]. Alterations in muscle recruitment patterns have been suggested as one of the factors resulting in chronicity[6].

The flexion–relaxation (FR) phenomenon is defined as reduced activity of lumbar extensor muscles in standing maximum trunk flexion[7]. The FR phenomenon is frequently present in healthy individuals and absent in non-specific chronic LBP (NSCLBP) patients[8]. Quantifying the FR phenomenon using the FR ratio has demonstrated that, at maximum trunk-flexion, NSCLBP patients display greater muscle activity in the erector spinae longissimus (ESL) and superficial lumbar multifidus (LMF) than do asymptomatic participants (APs)[9,10].

Because an imbalance in trunk muscle activation between the right and left sides can induce pain by loading the spine incorrectly, especially in NSCLBP patients[11–14], previous studies have investigated asymmetry in the FR phenomenon[9,15]. No relationship was found between that asymmetry and lumbopelvic rotation in healthy individuals during maximum trunk flexion [15]. However, Kim *et al*. reported that greater asymmetry in the FR ratio of the ESL was associated with lumbopelvic rotation in two subgroups of LBP patients[9]. These authors suggested that this asymmetry could be due to an imbalance in muscle properties, such as the flexibility of the musculotendinous complex and in passive structures. They also reported increased thorax obliquity in NSCLBP patients during maximum flexion. Trunk flexibility was reported to play an important role in trunk muscle recruitment[16]. However, these authors did not investigate the relationships between asymmetrical FR ratios and trunk lateral range-of-motion (ROM). Moreover, despite the important role played by LMF muscles' in maintaining spine stability, to the best of our knowledge, asymmetry in the FR ratios of the LMF muscles in an NSCLBP population has never been investigated.

The present study's main objective was to explore the relationships between asymmetrical FR ratios in the lumbar muscles and asymmetrical restriction of trunk lateral ROM in NSCLBP patients. We hypothesised that asymmetrical trunk lateral ROM would be correlated with asymmetrical FR ratios in NSCLBP patients. First of all, thorax kinematic ROM in the three planes, lumbar muscle FR ratios and trunk lateral ROM, as well as their respective asymmetries, were compared among NSCLBP patients and APs.

2 Materials and Methods

2.1 Study design

This prospective study was approved by the regional ethics committee of a tertiary university hospital, with reference CER: 14-126. The study is part of a broader project on identifying subgroups among NSCLBP patients[17].

2.2 Participants

Twenty-eight NSCLBP patients and 22 APs were enrolled and evaluated in a human movement laboratory. Patients were recruited from the Rheumatology Division and the Orthopaedic Department of a tertiary university hospital. Participants were included in the NSCLBP group if they had had back pain for more than three months and all specific causes (infection, neurological diseases, spinal fractures, axial spondyloarthritis, spinal deformities, tumours or radicular symptoms) had been excluded; they were included in the AP group if they had no history of back pain in the last 6 months. For both groups, additional exclusion criteria were pregnancy, being younger than 18 years old or older than 60 years old, previous back surgery, a body mass index over 30, and pain or injury in any other area of the body.

2.3 Instruments

A twelve-camera motion analysis system (Qualisys Oqus7+, Gothenburg, Sweden), set at a 100 Hz sampling frequency, recorded markers placed on the C7 and T10 spinous processes and on the top and base of the sternum. Electromyography (EMG) signals were measured using active surface electrodes (model Trigno, Delsys Inc., Boston, MA, USA) at a sampling frequency of 1000 Hz. Electrodes were positioned on the right and left sides of the ESL (at the L1 level of the spinous process) and LMF with regard to muscle fibre direction and following the SENIAM recommendations[18], on shaved, abraded and cleaned (with alcohol) skin. Only participants with no visual EMG artefacts on the right and left sides of the same muscles were included in the analysis.

2.4 Experimental procedure

Patients with NSCLBP filled out validated French versions of the Oswestry Disability Index [19] and the Pain Catastrophising Scale[20]. As recommended by the World Health Organization, the Global Physical Activity Questionnaire (GPAQ) was used to quantify weekly physical activity[21]. Pain was characterised by the side (unilateral/bilateral) and duration (in years), and current pain was quantified using a visual analogue scale. To evaluate trunk lateral ROM, participants performed three consecutive fingertip-to-thigh tests[22]. This test was measured with patients standing with their backs against a wall and their feet shoulder-width apart. An initial mark was made where the patient's middle-fingertip rested on the lateral thigh. Then, they were instructed to flex laterally as far as possible while keeping their back and shoulders against the wall. A second mark was made where the middle fingertip had moved down to on the thigh. The distance between the two marks was measured and recorded in centimetres. An average was calculated using three readings per side. Participants were then equipped with EMG electrodes and a sub-maximal voluntary isometric contraction (subMVIC) test against gravity[23] was performed for six seconds in a prone position with the upper edge of their iliac crests aligned along the edge of the table. After 10 minutes rest, participants were equipped with reflective markers and performed three consecutive standing maximal trunk forward bending trials with their legs straight. Each phase of the movement (standing, flexion, full flexion and return to initial standing posture) had a four-second duration, as illustrated in Figure 1. An audible metronome was used to regulate the timing of their movements.

2.5 Data processing

According to Gutierrez et al.[24], the thorax segment was defined from C7, T10, processus xyphoidus, and insisura jugularis markers. The *z* axis (*z*) was defined as the normalised vector from the midpoint of the processus xyphoidus and T10 to midpoint of the insisura jugularis and C7. The *y* axis was orthogonal (to the left) to the plane formed by the four markers and the *x* axis was the result of the cross-product of *y* and *z*. Then, the thorax tilt, obliquity, and rotation were defined with respect to the frame of the laboratory during the trunk forward bending task. The raw EMG signals recorded during the procedure were filtered using a Butterworth (4th order) pass-band filter (20–500 Hz) and were then full-wave rectified and low-pass filtered (2.5 Hz) to produce linear envelopes[25]. To normalise the EMG signals, the mean amplitude of the subMVIC linear envelopes was calculated, and the EMG signal was expressed as a percentage of the subMVIC. The FR ratio was calculated for each muscle, on both sides, as follows[26]:

$$(1) FR\ ratio = \frac{RMS_{fullflexion}}{RMS_{flexion}} \times 100$$

RMS is the maximal root mean square of the linear envelop of one second during the flexion and full flexion phases, respectively. A lower FR ratio indicated a greater state of muscle relaxation. The means of the three trials on each side were used to calculate the FR ratio and trunk lateral ROM. As asymmetry in FR phenomenon means that one side present a higher or lower FR ratio than the other side of a muscle pair, comparing the mean of sides or the sides (FR ratio $\text{Left}_{\text{NSCLBP}}$ vs. Left_{AP} and FR ratio $\text{Right}_{\text{NSCLBP}}$ vs. Right_{AP}) could mask differences. Thus, the "Lower" and the "Higher" values, referred as "*Lower-side* FR ratio" and "*Higher-side* FR ratio" respectively, were determined between the right and the left FR ratio of a muscle pair and used for the statistical analysis[9,27]. Asymmetry in the FR ratio (ΔFR ratio) was calculated as follows: [9]

$$(2)\ \Delta FR\ ratio = \left|\text{FR ratio}_{\text{right−side muscle}} - \text{FR ratio}_{\text{left−side muscle}}\right|$$

The same calculations was used for asymmetry in trunk lateral ROM. Evaluation of the relationships between asymmetries in the FR ratio and trunk lateral ROM used the relative difference between the right and left sides to consider the direction of asymmetry.

2.6 Statistical analysis

The Shapiro–Wilk test was used to evaluate the data distribution's normality. Due to its normal distribution, individual characteristics between groups were compared using unpaired Student t-tests and Pearson's chi-squared test for dichotomous outcomes.

Mann–Whitney tests were used to compare thorax kinematics, EMG signals and flexibility parameters (non-normal distribution) between the two groups. Cohen's effect size and 95% confidence intervals (95% CI) were also reported.

Spearman's coefficient correlation analysis was used to quantify the association between asymmetries in the ΔFR ratio and trunk lateral ROM in the group of NSCLBP patients.

Analyses were performed using R software (version 3.1.3) and the RStudio interface. The significance level was set at $p < 0.05$.

3 Results

Five NSCLBP patients and three APs were excluded from the analysis due to artefacts on at least one EMG signal in each muscle pair. Two additional NSCLBP patients were excluded as they were unable to achieve the maximum trunk forward bending movement required for the study due to pain (> 6/10 on a visual analogue scale). There were no significant differences between the groups' general characteristics (Table 1).

Trunk lateral ROM was reduced in NSCLBP patients compared to APs for both *Lower-side* and *Higher-side* values (Table 2). However, no differences were found with regards to asymmetry in trunk lateral ROM. During maximum trunk forward bending, NSCLBP patients only presented with a significantly lower thorax ROM in the sagittal plane (Table 2). NSCLPB patients showed higher *Higher-side* FR ratios than APs in both the ESL and LMF (Figure 2). Similar higher results were found for *Lower-side* FR $\text{ratio}_{\text{LMF}}$, whereas no significant differences were found between the groups for *Lower-side* FR $\text{ratio}_{\text{ESL}}$ (Figure 2). Asymmetry in the FR $\text{ratio}_{\text{ESL}}$ was greater in the NSCLBP group than among APs, but there was no significant difference between the groups with regard to asymmetry in the FR $\text{ratio}_{\text{LMF}}$. There was no significant difference between *Higher-side* FR ratios among APs (median (IQR) = 0.41 (0.26–0.50)) and *Lower-side* FR ratios among NSCLBP patients (median (IQR) = 0.42 (0.21–0.54)), p-value=1.00. Finally, no significant difference was found in the ΔFR $\text{ratio}_{\text{ESL}}$ between NSCLBP with unilateral pain (n=13; median (IQR) = 0.17 (0.09–0.33)) and those with bilateral pain (n=10; median (IQR) = 0.24 (0.05–0.27)), p-value=0.97.

The FR ratio$_{ESL}$ was significantly and strongly correlated with thorax flexion ROM (Figure 3A). Asymmetry in the FR ratio$_{ESL}$ was significantly and moderately correlated with thorax rotation ROM (Figure 3B) and with asymmetry in trunk lateral ROM (Figure 3C).

4 Discussion

The present study's main objective was to evaluate the relationships between asymmetries in the FR ratios of the lumbar muscles and trunk lateral ROM in NSCLBP patients. Results showed a moderate correlation between asymmetry in the FR ratio$_{ESL}$ and asymmetry of trunk lateral ROM in the NSCLBP group, but not in the AP group. This result supports the hypothesis proposed by Kim *et al*. (2013), who suggested that the asymmetry of the FR ratio$_{ESL}$ could be due to an imbalance in flexibility of the musculotendinous complex and in passive structures. Firstly, we will discuss the findings task by task.

With regard to the FR ratio, our results confirmed that NSCLBP patients exhibited a lower lumbar muscle relaxation pattern during full trunk flexion, as shown by the higher FR ratio$_{ESL}$ and FR ratio$_{LMF}$ in this group. These findings were consistent with those reported in previous studies[28–30]. It has been proposed that the FR phenomenon is the consequence of the stimulation of stretch receptors in posterior discoligamentous tissues during this flexed posture and thus acting to reflexogenically inhibit the ESL[8]. The present study supports this hypothesis through the strong correlation found between thorax flexion ROM and the FR ratio$_{ESL}$ (Figure 3A). The lower thorax flexion ROM in NSCLBP patients than in APs suggests a reduction in the stimulation felt by these receptors and hence a reduced inhibition of lumbar muscle activity. However, it is important to note that other parameters can influence the FR phenomenon, such as muscle spasm, exaggerated stretch reflexes, efforts to protect damaged passive structures or a response to local instability caused by injured spinal structures[31].

With regard to asymmetry in the FR ratio, compared to APs, NSCLBP patients presented a greater ΔFR ratioESL. This result is in line with those previously reported[9] and suggests a higher activity of ESL in one side inducing greater spine loading on one side which may result in pain[11,32]. It is also interesting to note that this greater ΔFR ratioESL showed a moderate correlation (r=0.54) with thorax rotation ROM only in NSCLBP patients. These results are corroborated by Kim et al. (2013). Indeed, considering the movement of unilateral contraction of ESL, higher asymmetry in the FR ratio of ESL could represent a higher activity of one of the ESL which may lead to trunk rotation. However, no such significant difference was observed for the ΔFR $ratio_{LMF}$. One explanation might be that LMF muscles have a bilateral adaptation to pain, which is not the case for ESL muscles. Indeed, a previous study reported bilateral atrophy of the LMF muscles (at level L4–5) in patients with unilateral NSCLBP, whereas ESL atrophy was ipsilateral with the painful side[33]. However, results also showed that the ΔFR $ratio_{ESL}$ was not dependent on the side where the pain was located (unilateral vs bilateral pain). Kim *et al*., (2013) suggested that a greater ΔFR $ratio_{ESL}$ could be due to an imbalance in muscle properties, such as their flexibility, rather than the side where the pain was located.

We also observed lower trunk lateral ROM in the NSCLBP group than in APs, consistent with previous studies[27,34,35]. Nagai *et al*. suggested that lower trunk lateral ROM was a factor associated with chronic LBP, as it generates increased passive tension, which may result in pain[27]. Contrary to previous studies[27,35], we observed no higher asymmetry in trunk lateral ROM among NSCLBP patients compared to APs. The fingertip-to-thigh test does not take into account movement by the pelvis, however, and compensatory pelvic movement mechanisms may reduce asymmetry in trunk lateral ROM, which would explain this contradictory finding. Lower asymmetry could be also related to differences in patients' characteristics. Patients in Nagai *et al*.'s study were helicopter pilots and the authors suggested that the asymmetry in their trunk lateral ROM could be the result of an occupational task-induced adaptation. In another study, the inclusion of patients with specific LBP and a history of surgery could have influenced its findings[35].

Despite the absence of any significant difference in the asymmetry of trunk lateral ROM between our two groups, the results highlighted a significant and moderate correlation between the ΔFR ratio$_{ESL}$ and asymmetry in trunk lateral ROM among NSCLBP patients only. Kuriyama et al., (2005) reported higher activity of the contralateral than ipsilateral ESL during trunk lateral bending[36]. Moreover, ESL have been showed to be the largest contributor to spine stability during lateral bending by increasing muscle stiffness[37]. Thus, ESL may have an important limitation role in trunk lateral ROM. In addition to different tissue elements as fascia tendon etc., asymmetry in trunk lateral ROM could be dependant of the intrinsic characteristics of ESL (stiffness, level activity and/or flexibility). Considering these elements, ESL seem to be involved both in the asymmetry of trunk lateral ROM and in asymmetry of FR phenomenon.

An alternative hypothesis could be derived from the pain adaptation theory proposed by Hodges and Tucker (2011)[38]. These authors proposed that in response to pain, patients modify muscle stiffness and redistribute activity between muscles in protection from further pain or injury. Reduced range of motion and the FR ratio asymmetry highlighted in the present study could be identified as two components of a protective muscle strategy engaged in protecting the spine from pain. In this view, the moderate correlation would suggest the presence of additional components. Indeed, a previous study reported that trunk flexibility in the sagittal plane plays an important role in trunk muscle recruitment[16]. The present results highlight that thorax ROM in the frontal plane could also have an influence on trunk muscle recruitment during trunk flexion. However, the correlation was only moderate, which means that other factors influence these asymmetries. One previous study reported that exercises reduce the asymmetry between the right and left ESL muscle FR phenomenon in APs[39]. It would thus be interesting to investigate whether the improvement in lateral ROM seen during treatment correlates with a decrease in the asymmetry of the FR ratio of lumbar muscles.

This study had some limitations. First, the exclusion of 7 NSCLBP patients and 3 APs, due to EMG signal artefacts or an inability to perform the required tasks, decreased the study's power to detect additional differences. Secondly, using a ruler to measure the fingertip-to-thigh test does not account for movements of the pelvis. Methods using twin inclinometers (on the S2 and T1 spinous processes) or the motion system analysis could be alternatives, as these would remove any pelvis movement from the equation. Finally, NSCLBP patients constitute a heterogeneous population due to the absence of any specific aetiology[40]. Kim *et al*., (2013) found different FR ratio asymmetry responses when NSCLBP patients were put into subgroups according to the O'Sullivan classification[41]. However, a subgroup analysis could not be performed in the present study because of the small number of participants

5 Conclusion

The present study showed that among NSCLBP patients, the asymmetry in the FR ratio of ESL muscles was significantly correlated with asymmetry in trunk lateral ROM. The present study further confirmed the relationship between greater asymmetry in the FR ratio of ESL muscles and thorax rotation ROM. These findings suggested that imbalanced spine loading could contribute to the presence or persistence of pain. Further studies are needed to evaluate whether a decrease in the asymmetry of the flexion–relaxation phenomenon is observed during physical therapy and whether this is associated with improvement in trunk ROM, disability and pain.

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Figure legends

Figure 1: Illustration of the phases of interest during the standing maximum trunk forward bending task.

Figure 2: Comparison of flexion–relaxation (FR) ratio by group, computed during the standing maximum trunk forward bending task for both the erector spinae longissimus (ESL) and lumbar multifidus (LMF) muscles. *Significant difference evaluated at $p < 0.05$ using the Mann–Whitney U test. AP, asymptomatic participants; NSCLBP, non-specific chronic low back pain patients; minima and maxima were determined between the right and left side of muscle pairs; subMVIC, sub-maxim voluntary isometric contraction.

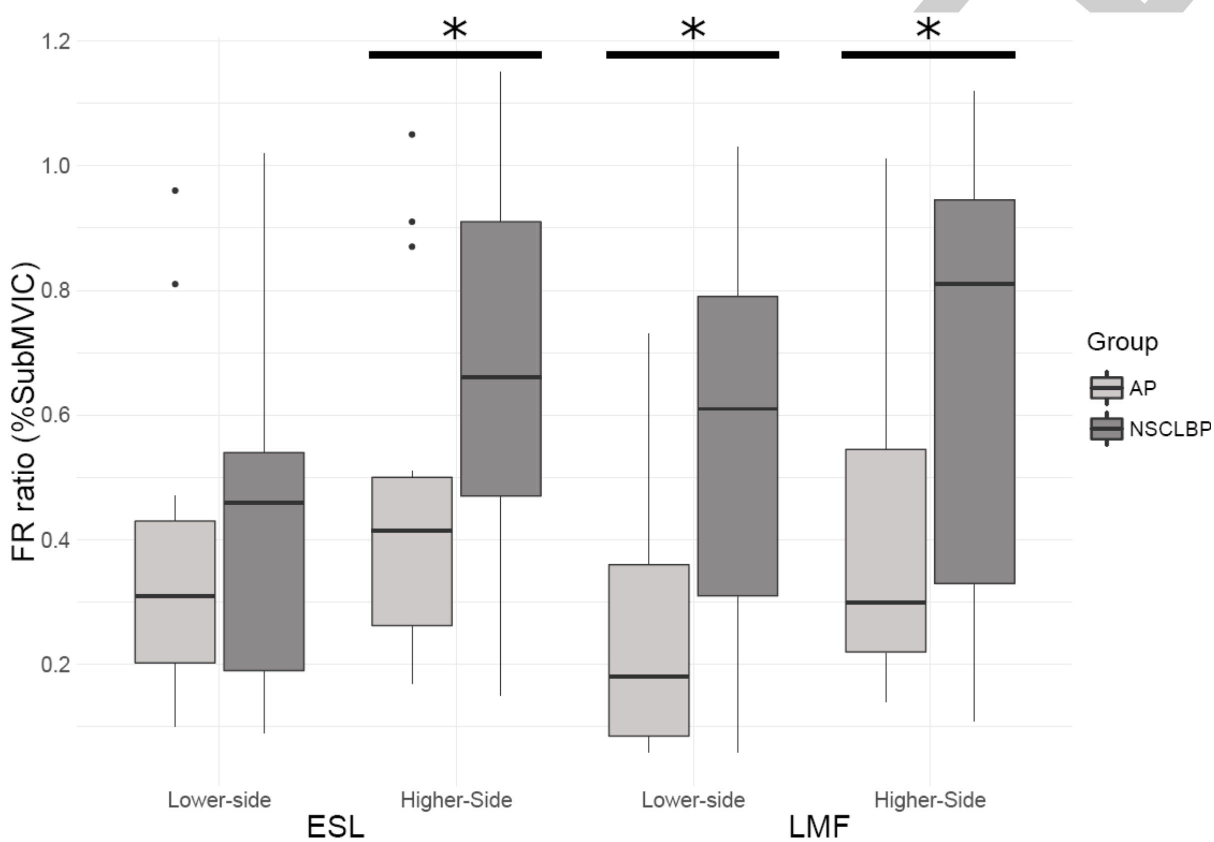

Figure 3: Relationships between flexion–relaxation parameters and thorax flexion (A), thorax rotation (B) and asymmetry in trunk lateral ROM (C) by group. P is the p-value associated with the Spearman coefficient, R. AP, asymptomatic participants; NSCLBP, nonspecific chronic low back pain patients; ROM, range-of-motion; FR, flexion–relaxation; Δ, asymmetry; subMVIC, sub-maximal voluntary isometric contraction.

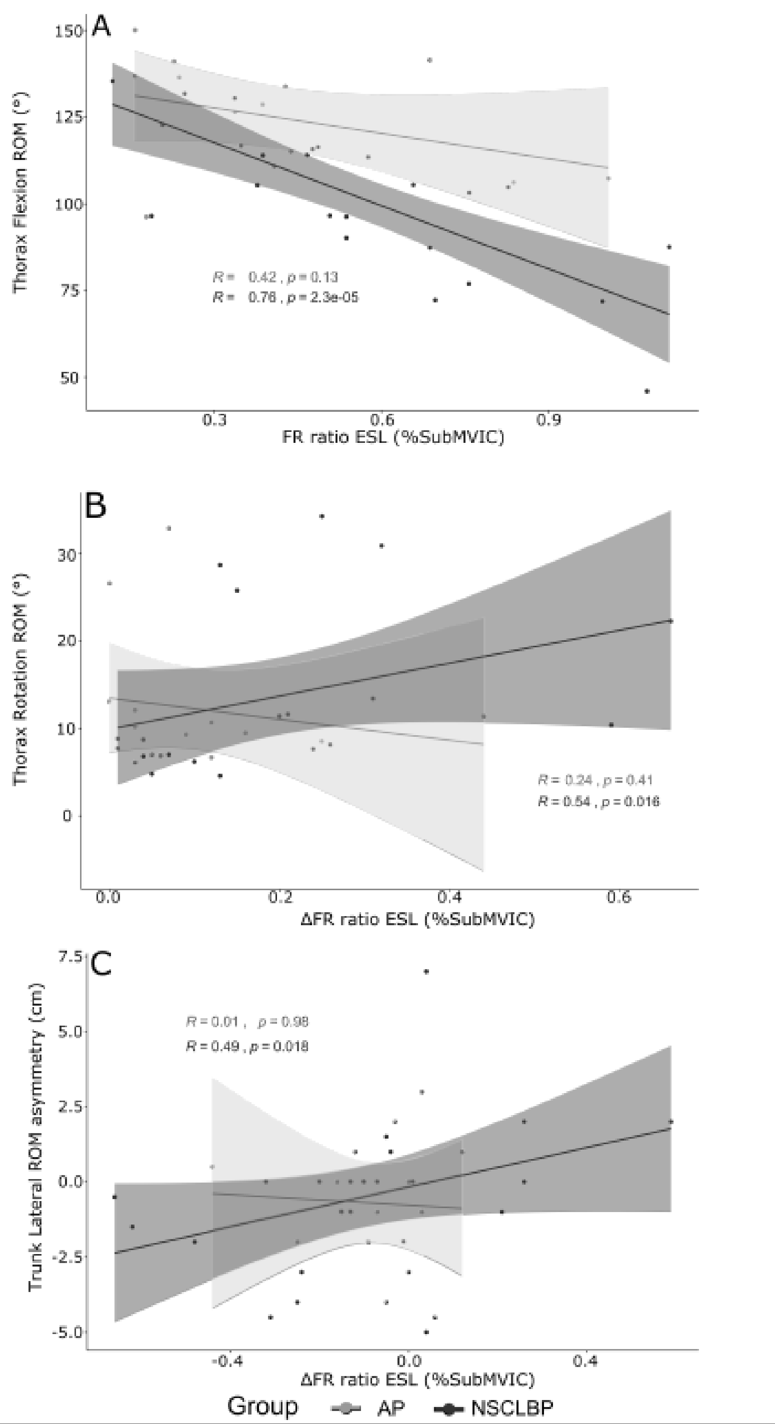

Table 1: Demographic data for both groups.

	Groups		*P*-value	95% CI	Effect size
	NSCLBP patients (n=23)	AP (n=19)			
Individual characteristics					
Female n (%)^k	12 (52%)	9 (47%)	1.000	-32.8 to 39.5	.045
Age (years)^t	39.4 (10.9)	36.0 (10.4)	.273	-2.8 to 9.6	.326
Body weight (kg)^t	69.3 (9.9)	66.5 (10.0)	.330	-3.0 to 9.7	.294
Body height (m)^t	1.72 (0.08)	1.72 (0.09)	.922	-0.05 to 0.05	.030
Body mass index (kg.m^2)^t	23.4 (3.4)	22.2 (2.1)	.142	0.4 to 2.8	.409
Pain-related characteristics					
Current pain (VAS/10)	3.2 (2.1)	-	-	-	-
Unilateral pain (%)	14 (56%)				
Pain duration (years)	9.2 (8.7)	-	-	-	-
Oswestry disability index score (%)	13.7 (6.3)	-	-	-	-
Pain catastrophising scale	16.8 (9.2)	-	-	-	-
GPAQ (MET-minute/week) ^{u}	1560 (840:2786)	2430 (1560:3300)	.149	-1620 to 200	.159
GPAQ *Work* ^{u}	0 (0:0)	0 (0:0)	.438	0 to 0	.023
GPAQ *Leisure* ^{u}	800 (300:13810)	1140 (620:2160)	.222	-960 to 240	.117

Results are presented as mean (standard deviation) for continuous outcomes with normal distribution, as median (interquartile range) for continues outcomes with non-normal distribution and as n (%) for dichotomous outcomes; p-value corresponds to an unpaired Student t-test (^{t}), a Mann-Whitney U test (^{u}) and a Pearson's chi-squared test (^{k}) respectively. Effect size is Cohen's effect size; 95% CI is 95% confidence interval; * Level of significance was set at $p < 0.05$. NSCLBP, non-specific chronic low back pain; APs, asymptomatic participants; VAS, visual analogic scale; GPAQ, Global Physical Activity Questionnaire.

Table 2: Intergroup comparisons between NSCLBP patients and APs for asymmetries in thorax kinematics, trunk lateral ROM, and asymmetry in FR ratios and trunk lateral ROM.

	Groups		*P*-value	95% CI	Effect size
	NSCLBP patients (n=23)	AP (n=19)			
Thorax kinematic ROM (°)					
Flexion	115.0 (99.9–130.4)	134.4 (125.1–147.0)	**.000***	-32.8 to -10.5	.502
Obliquity	7.2 (5.5–8.2)	7.3 (5.6–9.4)	.606	-2.0 to 1.2	.038
Rotation	9.9 (7.3–14.1)]	10.1 (7.5–14.4)	.869	-3.1 to 2.6	.160
Trunk lateral ROM (cm)					
Lower-side	16.0 (15.0–18.5)	21.3 (18.8 – 22.0)	**.000***	-6.0 to -2..0	.498
Higher-side	18.0 (16.0–20.0)	22.3 (21.2–23.6)	**.000***	-6.0 to -2.0	.530
Asymmetry parameters					
ΔFR ratio$_{ESL}$	0.20 (0.07–0.26)	0.06 (0.03–0.11)	**.035***	0.01 to 0.19	.258
ΔFR ratio$_{LMF}$	0.09 (0.04–0.16)	0.09 (0.05–0.21)	.701	-0.09 to 0.05	.075
trunk lateral ROM asymmetry (cm)	1.0 (0.0–2.0)	1.0 (0.5–2.0)	.754	-1.0 to 1.0	.098

Results are presented as median (interquartile range). Effect size is Cohen's effect size; 95% CI is 95% confidence interval; p-value corresponds to Mann–Whitney U test. * Level of significance was set at $p < 0.05$. NSCLBP, non-specific low back pain; AP, asymptomatic participants; FR ratio, flexion–relaxation ratio; ΔFR ratio: asymmetry in flexion–relaxation ratio between right and left sides; ROM, range of motion.