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ORIGINAL ARTICLE

Asymmetry of lumbar muscles fatigability with non-specific chronic low back pain patients

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Abstract

Purpose Non-specific chronic low back pain (NSCLBP) patients present with reduced back extensor muscle endurance which could be explained by the higher fatigability of their lumbar muscles. However, studies investigating lumbar muscle fatigability have shown contradictory findings. Furthermore, none investigated potential asymmetry in lumbar muscle fatigability, despite neuromuscular asymmetry being reported as a risk factor for NSCLBP. The present study's primary purpose was to determine whether NSCLBP patients presented with higher lumbar muscle fatigability and fatigability asymmetry than asymptomatic participants.

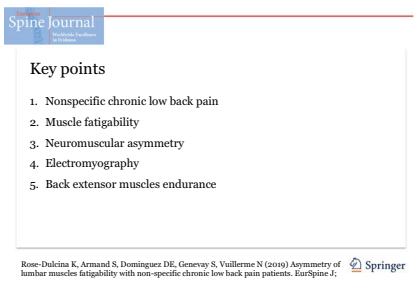
Methods Thirty NSCLBP patients and 23 asymptomatic participants performed the Sorensen test. The median frequencies from the electromyographs of the right and left erector spinae longissimus (ESL) and lumbar multifidus (LMF) were measured during the test. A linear regression was performed on the median frequencies on each muscle. Slope and initial median frequency were extracted to characterize fatigability. Asymmetry was quantified by the absolute differences between right-side and left-side muscle pairs.

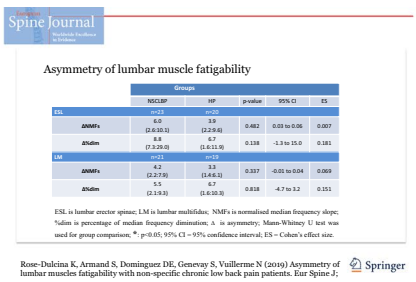
Results NSCLBP patients presented significantly poorer back extensor muscle endurance than asymptomatic participants. No differences were found between NSCLBP patients and asymptomatic participants in terms of fatigability or fatigability asymmetry for either the ESL or LMF. The initial median frequency in both muscles was significantly lower among NSCLBP patients.

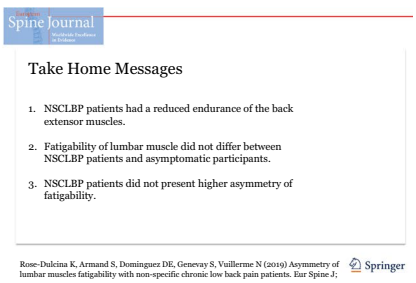
Conclusions The present study showed that NSCLBP patients did not present higher fatigability or higher fatigability asymmetry in lumbar muscles than asymptomatic participants. The heterogeneity of the NSCLBP population, due to the absence of any specific etiology, may explain these findings.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







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Keywords Non-specific chronic low back pain · Muscle fatigability · Neuromuscular asymmetry · Electromyography · Back extensor muscles endurance

Background

Low back pain (LBP) has been the leading cause of disability worldwide since 1990 [1], with an increase in years lived with disability of over 50% since then [2]. Most LBP is classified as non-specific because the pain's source cannot be precisely established in 85–90% of cases [3]. With pain lasting for more than 3 months [3], about 10% of these cases will become chronic and be identified as non-specific chronic low back pain (NSCLBP). This represents a major, global, socioeconomic challenge [4].

Deconditioned lumbar extensor muscles have been identified as one risk factor of NSCLBP [5]. It is difficult to establish whether the characteristics of muscle deconditioning are due to or result from the growing pain as lumbar muscles atrophy. At the lumbar spine level, several studies have reported a strong positive correlation between pain and muscle atrophy location [6–8]. However, contradictory results have been reported in patients presenting unilateral pain: the presence of either bilateral [8] or ipsilateral muscle atrophy [7]. Exploring structural modifications, Mannion et al. [9] suggested that fiber-type transformations, rather than size transformations, were the predominant changes in NSCLBP. These authors observed a higher proportion of type IIx (fast-twitch or glycolytic) fibers than type I (slow-twitch oxidative) fibers in patients with chronic LBP, in comparison with asymptomatic individuals. Subsequent studies supported Mannion's results, reporting a lower level of back extensor muscle endurance [10, 11] and a higher level of back extensor muscle fatigability in NSCLBP patients [12, 13]. Severijns et al. [14] defined fatigability as "the magnitude or rate of change of motor performance on an objectively measured reference criterion after any type of voluntary activity or exercise." Lower endurance and higher fatigability also characterize the deconditioned lumbar extensor muscles in NSCLBP patients. Indeed, reduced back extensor endurance has been shown to be one of the muscle deconditioning characteristics leading to the development of NSCLBP [15]. However, the characteristics of lumbar muscle fatigability in NSCLBP patients remain unclear because many studies did not observe higher fatigability [16, 17].

It has also been suggested that asymmetry in spine muscles could contribute to chronicity [18]. Some studies have found that muscle contraction patterns are closely associated with spine loading [19, 20]. NSCLBP patients have asymmetrical lumbar erector spinae longissimus (ESL) contraction patterns during lifting tasks [21], leading to an imbalance in spinal loading and potential spinal injuries [18]. NSCLBP patients also present with an asymmetrical ESL flexion–relaxation phenomenon associated with spinal rotation [22]. These asymmetrical patterns may cause cumulative stress and pain in the lumbar region [23]. In this context, it is possible that asymmetric lumbar muscle fatigability could contribute to asymmetric back movements and consequently to pain during daily life activities [18]. More than 20 years ago, Tsuboi et al. [24] reported significant differences in the degrees of fatigability asymmetry between the left and right lumbar multifidus (LMF) in both asymptomatic participants (APs) and NSCLBP patients. However, that study reported no direct comparison between those two populations. What is more, the study was never replicated. The present study aimed to clarify previous findings on lumbar muscle fatigability in NSCLBP patients, as this could have an impact on rehabilitation techniques for this population. We hypothesized that during the performance of a trunk extensor endurance test, NSCLBP patients would demonstrate greater lumbar muscle fatigability (hypothesis 1) and a higher degree of asymmetry in this fatigability than APs (hypothesis 2).

Methods

Study design

This prospective study was approved by the local ethics commission, with reference CER: 14–126. This study is part of a larger project on the identification of NSCLBP subgroups whose protocol was recently published [25].

Participants

Patients were recruited from the rheumatology and orthopedic divisions of a tertiary university hospital in Switzerland (Geneva University Hospitals). They were included in the NSCLBP group if they had presented with NSCLBP (absence of infection, rheumatologic or neurologic diseases, spinal fractures, any known spinal deformities, tumors or radicular symptoms) for more than 3 months. Participants 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, age below 18 or above 60 years, previous back surgery, a body mass index over 30, and pain or injury in any other body parts. Thirty chronic NSCLBP patients and 23 APs were enrolled and then evaluated in a human movement laboratory.

Pain-related outcomes

In order to characterize pain-related variables, pain duration and intensity were assessed using a 10-cm visual analogical scale (VAS). Assessment of functional disability and pain catastrophizing were quantified using the French versions of the Oswestry Disability Index (ODI) [26] and the Pain Catastrophizing Scale (PCS) [27], respectively. As recommended by the World Health Organization, the Global Physical Activity Questionnaire (GPAQ) was used to quantify weekly physical activity [28].

Experimental procedure

Experimental procedures were described to participants on arrival, and they signed a written informed consent form. They performed a trunk extensor endurance test known as the Sorensen test (Fig. 1) [29]. Participants were placed in a prone position on an examination couch so that the upper edges of their iliac crests were aligned with the couch's edge. Both lower limbs were attached to the couch using three straps at the levels of the pelvis, knees, and ankles [29]. With their arms folded across their chest, participants were asked to maintain a horizontal position (ankles, knees, and shoulders aligned) for as long as possible. The investigator gave verbal feedback and standardized encouragement during the test. Endurance performance was quantified by the maximum holding time; the investigator stopped the test if participants reached 240 s [30]. During the test, participants were asked to quantify their perceived exertion every 15 s (including at the end of the test) on the Borg CR-10 scale as suggested in a previous study [31].

Instruments and data processing

Electromyograph (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 bilaterally on the ESL (at the level of the L1 spinous process) and LMF muscles with regard to muscle fiber direction following the recommendations of the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) project, on shaved, abraded, and cleaned (with an alcoholic solution) skin [32]. All data processing was performed using MATLAB R2012a (MathWorks, Inc., Natick, MA, USA). Raw EMG signals were passband filtered (20–500 Hz) using a 4th order Butterworth filter [12].

Median frequency (MF) has been shown to be a reliable parameter with which to evaluate the fatigue of paraspinal muscles in both APs and LBP patients [33]. The MF of the surface EMG power spectrum was calculated at each 1 s interval using a fast Fourier transform. A linear regression analysis was performed on the MFs calculated as a function of time. As MF evolution is linear during fatigue tasks [34], participants with an MF linear regression coefficient of $r < 0.70$ were excluded from further analysis. The MF slope was used to evaluate muscle fatigability and was determined from the linear regression's slope [34]. The initial MF (MFi) was defined as the intercept of the regression line. To avoid subcutaneous bias, the slope was normalized to the MFi, as in Eq. 1 [35]. The MF at the end of the endurance task (MFend) was calculated using the normalized linear regression equation at the performance time (Eq. 2). Two variables were used to quantify the reduction in MF: the normalized median frequency slope (NMFs) and the MF percentage of diminution (%dim). The %dim was calculated as shown in Eq. 3. These two variables were calculated to facilitate

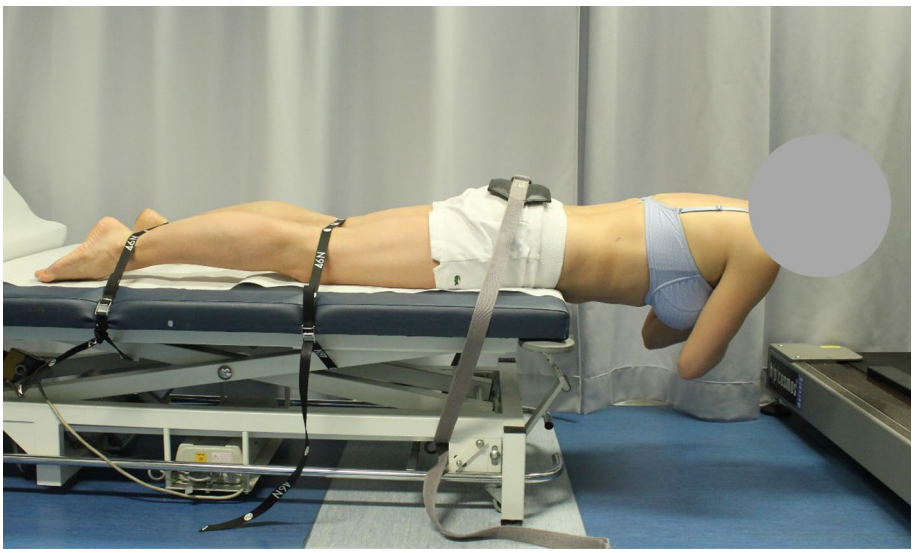

Fig. 1 Illustration of the testing position for the Sorensen test

comparisons with the literature [10]. For all variables, the mean value of the right and left sides of each muscle was used for statistical analysis. The asymmetry between the right and left of the NMFs and %dim for each muscle pair were calculated using the relative difference between the right (*R*) and left (*L*) sides (Eq. 4) [22]

$$\mathrm{NMFs}_{\mathrm{muscle}} = \left(\mathrm{MF\ slope}_{\mathrm{muscle}}/\mathrm{MFi}_{\mathrm{muscle}}\right) \times 100 \quad (1)$$

$$\mathrm{MFend}_{\mathrm{muscle}} = \left(\mathrm{performance} \times \mathrm{NMFs}_{\mathrm{muscle}}\right) + \mathrm{MFi}_{\mathrm{muscle}} \quad (2)$$

$$\%\,\mathrm{dim}_{\mathrm{muscle}} = \left(\mathrm{MFi}_{\mathrm{muscle}} - \mathrm{MFend}_{\mathrm{muscle}}\right)/\mathrm{MFi}_{\mathrm{muscle}} \quad (3)$$

$$\Delta X = \left|X_{\mathrm{R}} - X_{\mathrm{L}}\right| (\text{where } X \text{ are the fatigability variables : NMFs or \% dim}) \quad (4)$$

(where *X* are the fatigability variables: NMFs or %dim)

Statistical analysis

Analyses were performed using R v.3.1.3 software and the RStudio interface, with a level of significance set at $p < 0.05$. The Shapiro–Wilk test was used to evaluate the normality of the data distribution. Comparisons between groups were made using unpaired Student's t tests for outcomes with normal distributions, unpaired Mann–Whitney *U* tests for non-normal distributions, and Pearson's chi-squared test for dichotomous outcomes. Intragroup comparisons were performed using the Wilcoxon test. Cohen's effect size (ES) and the 95% confidence interval (95% CI) were also reported.

Results

Four NSCLBP patients and three APs were excluded due to MF linear regression coefficients (*r*) inferior to 0.70. Two NSCLBP patients could not perform the test because of pain. Finally, 24 NSCLBP patients and 20 APs were included. Participants' characteristics are presented in Table 1. Intergroup comparisons showed that the NSCLBP group had a significantly shorter endurance performance than the AP group, with a median (interquartile range) of 124 (87–175) seconds and 182 (133–222) seconds, respectively (p value = 0.013; ES = 0.369; 95% CI = −95 to −8). Results showed that five APs and two NSCLBP patients reached the limit of 240 s. Six out of the seven participants (four APs and two NSCLBP patients) also reached the maximum value of the Borg scale at the time of the 240 s. Concerning fatigue parameters, no significant differences were found between the groups for either the NMFs or %dim (Table 2). NSCLBP patients had significantly lower MFi than APs for all muscles, whereas no differences were found in MFend for any muscles (Table 2). Concerning asymmetry parameters, no significant differences between groups were found for either the ΔNMFs or Δ%dim for any muscles (Table 3).

Table 1 General characteristics of the study sample

	Groups		*p* value	95% CI	ES
	NSCLBP patients ($n = 24$)	Asymptomatic Participants ($n = 20$)			
Individual characteristics					
Female (%)[a]	9 (38%)	9 (45%)	0.845	− 32.8 to 53.8	0.045
Age (year)[b]	40.8 (9.1)	36.2 (10.0)	0.157	− 1.9 to 11.1	0.490
Body mass (kg)[b]	68.6 (8.8)	66.4 (10.3)	0.480	− 4.2 to 8.7	0.243
Body height (m)[b]	1.72 (0.08)	1.72 (0.09)	0.890	− 6.3 to 5.6	0.044
Body mass index ($kg.m^{-2}$)[c]	22.4 (21.6:24.2)	22.5 (20.7:23.1)	0.703	− 0.9 to 2.0	0.090
Pain-related characteristics					
Current pain (VAS /10)[b]	3.2 (1.4)	–	–	–	–
Pain duration (years)[b]	10.6 (9.8)	–	–	–	–
ODI (%)[b]	14.2 (7.6)	–	–	–	–
PCS[b]	17.2 (10.6)	–	–	–	–
GPAQ (MET-minute/week)[c]	2280 (1440:3120)	2520 (1670:3320)	0.595	− 1320 to 740	0.040

ES Cohen's effect size, *95% CI* 95% confidence interval, *VAS* visual analogue scale, *GPAQ* global physical activity questionnaire

*$p < 0.05$

[a]Values are *n* (%) and Pearson's chi-squared test was used

[b]Values are mean (standard deviation) and unpaired Student's *t*-test was used

[c]Values are median (interquartile range) and Mann–Whitney *U* test was used

Table 2 Fatigue parameters

	Groups		*p* value	95% CI	ES
	NSCLBP patients	Asymptomatic Participants			
ESL	*n* = 24	*n* = 20			
MFi	75.5 (65.1:87.3)	85.8 (79.5:95.0)	0.048*	− 22.0 to − 0.1	0.245
MFend	52.5 (46.3:65.0)	51.7 (46.4:61.5)	0.844	− 7.0 to 9.2	0.148
NMFs (%)	− 21.7 (− 29.5:− 16.5)	− 19.5 (− 26.5:− 15.6)	0.471	− 0.08 to 0.04	0.012
%dim	34.9 (25.4:40.7)	42.8 (28.7:50.1)	0.207	− 4.5 to 16.7	0.135
LMF	*n* = 23	*n* = 19			
MFi	101.1 (89.0:105.5)	109.1 (105.3:122.5)	0.027*	− 22.5 to − 1.5	0.283
MFend	63.3 (51.3:89.0)	62.1 (50.8:72.3)	0.423	− 8.5 to 18.0	0.029
NMFs (%)	− 27 (− 30:− 20)	− 25 (− 31:− 20)	0.851	− 0.07 to 0.06	0.178
%dim	31.1 (25.8:44.1)	40.7 (33.1:49.9)	0.133	− 2.7 to 17.9	0.185

%dim is percentage of median frequency diminution; Mann–Whitney *U* test was used for group comparison

ESL lumbar erector spinae, *LMF* lumbar multifidus, *MFi* initial median frequency, *MFend* last median frequency, *NMFs* normalized median frequency slope, *95% CI* 95% confidence interval, *ES* Cohen's effect size

*$p < 0.05$

Table 3 Asymmetry parameters

	Groups		*p* value	95% CI	ES
	NSCLBP patients	Asymptomatic Participants			
ESL	*n* = 23	*n* = 20			
ΔNMFs	6.0 (2.6:10.1)	3.9 (2.2:9.6)	0.482	0.03 to 0.06	0.007
Δ%dim	8.8 (7.3:29.0)	6.7 (1.6:11.9)	0.138	− 1.3 to 15.0	0.181
LMF	*n* = 21	*n* = 19			
ΔNMFs	4.2 (2.2:7.9)	3.3 (1.4:6.1)	0.337	− 0.01 to 0.04	0.069
Δ%dim	5.5 (2.1:9.3)	6.7 (1.6:10.3)	0.818	− 4.7 to 3.2	0.151

%dim is percentage of median frequency diminution; Δ is asymmetry; Mann–Whitney *U* test was used for group comparison

ESL lumbar erector spinae, *LMF* lumbar multifidus, *NMFs* normalized median frequency slope, *95% CI* 95% confidence interval, *ES* Cohen's effect size

*$p < 0.05$

Discussion

The present study aimed to clarify the characteristics of fatigability in NSCLBP patients. Although observed back extensor muscle endurance during the Sorensen test was lower in NSCLBP patients than in APs, measurements of lumbar muscle fatigability were not significantly different between the groups (rejecting hypothesis 1) and showed no patterns of asymmetrical fatigability (rejecting hypothesis 2).

Previous findings on lumbar muscle fatigability revealed several inconsistencies with studies that reported higher NSCLBP fatigability [12, 13], and other studies showed NSCLBP patient fatigability similar to that of APs [16, 17]. The absence of significant differences between NSCLBP patients and APs in terms of their fatigability parameters (NMFs and %dim), observed in the present study, was previously reported by Kankaanpää et al. [16]. Indeed, these authors found no significant difference in the $NMFs_{ESL}$ between NSCLBP patients and APs when using a 90-second seated back extension against a dynamometer as a fatigue task. A study by Johanson et al. reported $\%dim_{LMF}$ (NSCLBP patients = 36%; APs = 47%) results similar to ours (NSCLBP patients = 31%; APs = 41%), but they did not provide any statistical analyses [10]. Other studies that reported increased fatigability in NSCLBP populations also had relevant differences in their protocols from the present study. Although MFi in the present study was computed using the intercept of

the regression line, two other studies chose to compute MFi using the mean of the first or the first five seconds [12, 13]. These methods are more sensitive to extreme values or EMG artefacts than using the regression line's intercept, and this could significantly affect the results. In addition, the studies by Larivière et al. [17, 36] used a dynamometer rather than the Sorensen test to induce trunk muscle fatigue. It is known that maximum voluntary isometric contraction is difficult to perform on a pathological population and it may alter their results [37]. It is also worth noting that these studies were only able to demonstrate increased fatigue in subgroups of patients. In the first study [36], only the male NSCLBP patients were found to have greater absolute ESL and LMF MF slopes, whereas in the second [17], a significant difference in MF slope was only reported for patients with a high level of pain catastrophizing. No significant difference in fatigability was found for NSCLBP patients with PCS scores below 21. The present study's results are consistent with this finding, as our NSCLBP patients also had a mean PCS below 21 (Table 1). It has been suggested that patients with a low level of pain catastrophizing tended to finish all activities despite pain leading to more physical activity and better endurance [38]. Overall, it appears that there was no difference in lumbar muscle fatigability between NSCLBP patients and APs, although it might be the case in specific subgroups of NSCLBP patients.

The present study's results for MFi were partially consistent with those found by Kankaanpää et al. [16]. Indeed, those authors found lower MFi in NSCLBP patients than in APs but only for the right ESL. It is important to note that the present study computed MFi using the intercept of the regression line, whereas Kankaanpää et al. used the mean of the first five seconds to obtain their MFi value. As well as Kolur et al. [12] and Suuden et al. [39] found, in opposition, no significant differences in initial MF between groups for lumbar muscles. Suuden et al. [39] suggested that a lower MFi was an indicator of greater pre-fatigue loading. The measurement of MFi showed good reproducibility [40] but was not validated as a measure of the state of muscle fatigue. However, it was reported that initial MF was related to such different muscle parameters as conduction velocity, composition, and cross-sectional area (force) of the muscle fibers [41–43]. The lower MFi observed in the NSCLBP patients could be related to these parameters. However, it is important to note that the MF value can be influenced by several factors, such as electrode location or soft tissue (low-pass effect on EMG) [43]. Further investigations will be needed to verify this hypothesis.

Finally, regarding asymmetry, no significant differences were found in lumbar muscle fatigability asymmetry, for either muscle, between NSCLBP patients and APs. This result does not confirm our second hypothesis. The present study's NSCLBP patients presented with low levels of disability and pain (see Table 1), which may not have been severe enough to highlight any asymmetry between groups. Only Tsuboi et al. [24] have investigated the side-to-side difference of lumbar muscle fatigability in NSCLBP patients. They found that the right MF slope was significantly different from the left MF slope, both in LBP patients and in APs. However, comparing the right side to the left side does not reflect asymmetry. Indeed, the difference can be hidden depending on which side is higher or lower. This absence of higher LMF fatigability asymmetry in NSCLBP patients is consistent with the bilateral atrophy of LMF present in NSCLBP patients and reported by Beneck and Kulig [8]. It could now be interesting to couple imagery analysis (e.g., magnetic resonance imaging) with EMG analysis to verify whether there are subgroups among NSCLBP patients. One NSCLBP patient subgroup could have a symmetrical muscle adaptation, whereas another may not, which could explain the inconsistencies in lumbar deconditioning observed among NSCLBP patients.

The present study had certain limitations. First, nine participants were excluded because their linear regression coefficient was below 0.7. Of these, three NSCLBP patients showed an insufficient endurance performance time and consequently an insufficient number of MF values to calculate a linear regression. Two other NSCLBP patients could not perform the test due to the intensity of their pain. One NSCLBP patient and three APs were excluded because EMG artefacts on their signals altered their MF linear regression. Secondly, the end of the Sorensen test at of 240 s could have been a limit. However, only one AP was stopped at 240 s without reaching the maximal value on the Borg scale, suggesting that participants were close to their maximum capacity. Hence, it is unlikely that this time limit has significantly affected the results. Thirdly, Müller et al. [44] showed that hip extensors could also play a significant role in the Sorensen test, despite it being considered the gold standard of back extensor endurance tests [44]. The contribution of hip extensors was not included in the analysis and interpretation of the present results. Furthermore, psychological factors [45] and anthropometric characteristics [39] have been found to influence the Sorensen test's performance. The present study did not include these factors in its analysis. In addition, the use of surface EMG electrodes for the assessment of LMF activity remains contentious considering the contradictory findings of different studies [46, 47]. The results of LMF activity must therefore be considered with caution. Finally, the NSCLBP population was heterogeneous due to the absence of a specific etiology. A previous study found that only analyses based on NSCLBP subgroups revealed significant differences in lumbar muscle activity compared to APs during usual sitting posture [48]. The fact that no significant differences were observed in the present study

may be due to the analysis of pooled NSCLBP patients, but the overall low number of participants prevented us from performing any additional subgroup analysis.

Conclusion

This study showed that NSCLBP patients did not present higher fatigability or higher fatigability asymmetry between the right and left lumbar muscles than asymptomatic participants. These findings could be explained by the heterogeneity of our NSCLBP population due to the absence of any specific etiology. However, the initial median frequencies of the lumbar muscles were lower in NSCLBP patients and further investigations are needed to understand these findings.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Vos T, Abajobir AA, Abbafati C et al (2017) Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: a systematic analysis for the global burden of disease study 2016. Lancet 390:1211–1259. https://doi.org/10.1016/S0140-6736(17)32154-2
2. Hartvigsen J, Hancock MJ, Kongsted A et al (2018) What low back pain is and why we need to pay attention. Lancet. https://doi.org/10.1016/S0140-6736(18)30480-X
3. Balagué F, Mannion AF, Pellisé F, Cedraschi C (2012) Non-specific low back pain. Lancet 379:482–491. https://doi.org/10.1016/S0140-6736(11)60610-7
4. Clark S, Horton R (2018) Low back pain: a major global challenge. Lancet. https://doi.org/10.1016/S0140-6736(18)30725-6
5. Steele J, Bruce-Low S, Smith D (2014) A reappraisal of the deconditioning hypothesis in low back pain: review of evidence from a triumvirate of research methods on specific lumbar extensor deconditioning. Curr Med Res Opin 30:1–47. https://doi.org/10.1185/03007995.2013.875465
6. Hides J, Gilmore C, Stanton W, Bohlscheid E (2008) Multifidus size and symmetry among chronic LBP and healthy asymptomatic subjects. Man Ther 13:43–49. https://doi.org/10.1016/j.math.2006.07.017
7. Barker KL, Shamley DR, Jackson D (2004) Changes in the cross-sectional area of multifidus and psoas in patients with unilateral back pain. Spine (Phila Pa 1976) 29:E515–E519. https://doi.org/10.1097/01.brs.0000144405.11661.eb
8. Beneck GJ, Kulig K (2012) Multifidus atrophy is localized and bilateral in active persons with chronic unilateral low back pain. Arch Phys Med Rehabil 93:300–306. https://doi.org/10.1016/j.apmr.2011.09.017
9. Mannion AF, Käser L, Weber E et al (2000) Influence of age and duration of symptoms on fibre type distribution and size of the back muscles in chronic low back pain patients. Eur Spine J 9:273–281. https://doi.org/10.1007/s005860000189
10. Johanson E, Brumagne S, Janssens L et al (2011) The effect of acute back muscle fatigue on postural control strategy in people with and without recurrent low back pain. Eur Spine J 20:2152–2159. https://doi.org/10.1007/s00586-011-1825-3
11. Rossi DM, Morcelli MH, Cardozo AC et al (2015) Discriminant analysis of neuromuscular variables in chronic low back pain. J Back Musculoskelet Rehabil 28:239–246. https://doi.org/10.3233/BMR-140509
12. Kolur MK, Norasteh AA, Daneshmandi H (2011) Electromyographic fatigue evaluation of back and hip extensor muscles and its relationship with anthropometric characteristic of athletes with chronic low back pain. Med Dello Sport 64:435–448
13. McKeon MD, Albert WJ, Neary JP (2006) Assessment of neuromuscular and haemodynamic activity in individuals with and without chronic low back pain. Dyn Med 5:6. https://doi.org/10.1186/1476-5918-5-6
14. Severijns D, Zijdewind I, Dalgas U et al (2017) The assessment of motor fatigability in persons with multiple sclerosis: a systematic review. Neurorehabil Neural Repair 31:413–431
15. Biering-Sørensen F (1984) Physical measurements as risk indicators for low-back trouble over a one-year period. Spine 9:106–119
16. Kankaanpää M, Colier WN, Taimela S et al (2005) Back extensor muscle oxygenation and fatigability in healthy subjects and low back pain patients during dynamic back extension exertion. Pathophysiology 12:267–273. https://doi.org/10.1016/j.pathophys.2005.09.013
17. Larivière C, Bilodeau M, Forget R et al (2010) Poor back muscle endurance is related to pain catastrophizing in patients with chronic low back pain. Spine (Phila Pa 1976) 35:E1178–E1186. https://doi.org/10.1097/BRS.0b013e3181e53334
18. Renkawitz T, Boluki D, Grifka J (2006) The association of low back pain, neuromuscular imbalance, and trunk extension strength in athletes. Spine J 6:673–683. https://doi.org/10.1016/j.spine.2006.03.012
19. Solomonow M, Zhou BH, Harris M et al (1998) The ligamento-muscular stabilizing system of the spine. Spine (Phila Pa 1976) 23:2552–2562
20. Magnusson ML, Aleksiev A, Wilder DG et al (1996) European Spine society–the acromed prize for spinal research 1995. Unexpected load and asymmetric posture as etiologic factors in low back pain. Eur Spine J 5:23–35
21. Lu WW, Luk KDK, Cheung KMC et al (2001) Back muscle contraction patterns of patients with low back pain before and after rehabilitation treatment: an electromyographic evaluation. J Spinal Disord 14:277–282. https://doi.org/10.1097/00002517-200108000-00001
22. Kim M, Yoo W, Choi B, (2013) Differences between two subgroups of low back pain patients in lumbopelvic rotation and symmetry in the erector spinae and hamstring muscles during trunk flexion when standing. J Electromyogr Kinesiol 23:387–393. https://doi.org/10.1016/j.jelekin.2012.11.010
23. Van Dillen LR, Sahrmann SA, Norton BJ et al (2003) Movement system impairment-based categories for low back pain: stage 1 validation. J Orthop Sport Phys Ther 33:126–142. https://doi.org/10.2519/jospt.2003.33.3.126
24. Tsuboi T, Satou T, Egawa K et al (1994) Spectral analysis of electromyogram in lumbar muscles: fatigue induced endurance contraction. Eur J Appl Physiol 69:361–366
25. Rose-Dulcina K, Vuillerme N, Tabard-Fougère A et al (2018) Identifying subgroups of patients with chronic nonspecific low back pain based on a multifactorial approach: protocol

for a prospective study. JMIR Res Protoc 7:e104. https://doi.org/10.2196/resprot.9224
26. Vogler D, Paillex R, Norberg M et al (2008) Validation transculturelle de l'Oswestry disability index en français. Ann Readapt Med Phys 51:379–385. https://doi.org/10.1016/j.annrmp.2008.03.006
27. French DJ, Noël M, Vigneau F et al (2005) L'Échelle de dramatisation face à la douleur PCS-CF Adaptation canadienne en langue française de l'échelle «Pain Catastrophizing Scale». Can J Behav Sci 37:181–192. https://doi.org/10.1037/h0087255
28. Bull FC, Maslin TS, Armstrong T (2009) Global physical activity questionnaire (GPAQ): nine country reliability and validity study. J Phys Act Health 6:790–804
29. Latimer J, Maher CG, Refshauge K, Colaco I (1999) The reliability and validity of the Biering-Sorensen test in asymptomatic subjects and subjects reporting current or previous nonspecific low back pain. Spine (Phila Pa 1976) 24:2085–2089. https://doi.org/10.1097/00007632-199910150-00004
30. Kankaanpää M, Laaksonen D, Taimela S et al (1998) Age, sex, and body mass index as determinants of back and hip extensor fatigue in the isometric Sorensen back endurance test. Arch Phys Med Rehabil 79:1069–1075. https://doi.org/10.1016/S0003-9993(98)90173-3
31. Dedering Å, Németh G, Harms-Ringdahl K (1999) Correlation between electromyographic spectral changes and subjective assessment of lumbar muscle fatigue in subjects without pain from the lower back. Clin Biomech 14:103–111. https://doi.org/10.1016/S0268-0033(98)00053-9
32. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G (2000) Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 10:361–374. https://doi.org/10.1016/S1050-6411(00)00027-4
33. Bandpei MAM, Rahmani N, Majdoleslam B et al (2014) Reliability of surface electromyography in the assessment of paraspinal muscle fatigue: an updated systematic review. J Manipulative Physiol Ther 37:510–521
34. Moffroid MT (1997) Endurance of trunk muscles in persons with chronic low back pain: assessment, performance, training. J Rehabil Res Dev 34:440–447
35. Coorevits P, Danneels L, Cambier D et al (2008) Assessment of the validity of the Biering-Sørensen test for measuring back muscle fatigue based on EMG median frequency characteristics of back and hip muscles. J Electromyogr Kinesiol 18:997–1005. https://doi.org/10.1016/j.jelekin.2007.10.012
36. Larivière C, Arsenault AB, Gravel D et al (2003) Surface electromyography assessment of back muscle intrinsic properties. J Electromyogr Kinesiol 13:305–318. https://doi.org/10.1016/S1050-6411(03)00039-7
37. Burden A (2010) How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25years of research. J Electromyogr Kinesiol 20:1023–1035. https://doi.org/10.1016/j.jelekin.2010.07.004
38. Hasenbring MI, Plaas H, Fischbein B, Willburger R (2006) The relationship between activity and pain in patients 6 months after lumbar disc surgery: do pain-related coping modes act as moderator variables? Eur J Pain 10:701–709. https://doi.org/10.1016/j.ejpain.2005.11.004
39. Süüden E, Ereline J, Gapeyeva H, Pääsuke M (2008) Low back muscle fatigue during Sørensen endurance test in patients with chronic low back pain: relationship between electromyographic spectral compression and anthropometric characteristics. Electromyogr Clin Neurophysiol 48:185–192
40. Oliver CW, Tillotson KM, Jones APC et al (1996) Reproducibility of lumbar paraspinal surface electromyogram power spectra. Clin Biomech 11:317–321. https://doi.org/10.1016/0268-0033(96)00020-4
41. Kupa EJ, Roy SH, Kandarian SC, De Luca CJ (2017) Effects of muscle fiber type and size on EMG median frequency and conduction velocity. J Appl Physiol 79:23–32. https://doi.org/10.1152/jappl.1995.79.1.23
42. Stolen FB, De Luca CJ (1981) Frequency Parameters of the Myoelectric Signal as a Measure of Muscle Conduction Velocity. IEEE Trans Biomed Eng BME-28:515–523. https://doi.org/10.1109/TBME.1981.324738
43. De Luca CJ, Sabbahi MA, Roy SH (1986) Median frequency of the myoelectric signal–effects of hand dominance. Eur J Appl Physiol Occup Physiol 55:457–464. https://doi.org/10.1007/BF00421637
44. Müller R, Strässle K, Wirth B (2010) Isometric back muscle endurance: An EMG study on the criterion validity of the Ito test. J Electromyogr Kinesiol 20:845–850. https://doi.org/10.1016/j.jelekin.2010.04.004
45. Mannion AF, O'Riordan D, Dvorak J, Masharawi Y (2011) The relationship between psychological factors and performance on the Biering-Sørensen back muscle endurance test. Spine J 11:849–857. https://doi.org/10.1016/j.spinee.2011.08.004
46. Stokes IAF, Henry SM, Single RM (2003) Surface EMG electrodes do not accurately record from lumbar multifidus muscles. Clin Biomech 18:9–13. https://doi.org/10.1016/S0268-0033(02)00140-7
47. Arokoski JPA, Kankaanpää M, Valta T et al (1999) Back and hip extensor muscle function during therapeutic exercises. Arch Phys Med Rehabil 80:842–850. https://doi.org/10.1016/S0003-9993(99)90237-X
48. Dankaerts W, O'Sullivan P, Burnett A et al (2006) Differences in sitting postures are associated with nonspecific chronic low back pain disorders when patients are subclassified. Spine (Phila Pa 1976) 31:698–704. https://doi.org/10.1097/01.brs.0000202532.76925.d2

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