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Trunk muscles' characteristics in adolescent gymnasts with low back pain: a pilot study on the effects of a physiotherapy intervention including a postural reeducation program

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ABSTRACT

Background: Trunk muscles' function and characteristics are of great importance for both static and dynamic tasks in different sports, and abnormalities of trunk flexors and extensors might be associated with low back pain (LBP). The aim of this study was to provide a comprehensive evaluation of the functional, morphological and contractile properties in trunk flexors and extensors of young gymnasts with and without LBP.

Methods: Young gymnasts (14/25 females, 14–18 y) were screened for the presence of chronic LBP. Abdominal and lumbar muscles were tested for function (McGill's endurance tests), thickness (ultrasound), and contractile responses (tensiomyography). An 8-sessions physiotherapy intervention including postural reeducation was performed by a subsample of 10 subjects with LBP.

Results: LBP was found to be associated to higher flexors-to-extensors endurance ratio (OR 11.250, 95% CI: 1.647–76.849, $p = 0.014$), reduced mean lumbar multifidus thickness (OR 16.500, 95% CI: 2.246–121.228, $p = 0.006$), and reduced mean erector spinae radial displacement (OR 16.500, 95% CI: 2.246–121.228, $p = 0.006$). The physiotherapy intervention was found to reduce LBP symptoms and it was associated with a significant improvement in the flexors-to-extensors ratio ($p < 0.001$).

Conclusions: This study provides preliminary evidence of functional, morphological, and contractile trunk muscles' alterations associated with chronic LBP in young gymnasts, and presents the effects of a postural reeducation program on symptoms and muscles' functional properties.

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Gymnastics; tensiomyography; low back pain; ultrasound; exercise; rehabilitation

1. Introduction

The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) indicated that low back pain (LBP) is one of the five causes of DALYs rate (disability-adjusted life-years) in the 25–49-year age, being prevalent also for ages 10–24 years. In fact, LBP is a common musculoskeletal disorder present in both sexes and for all age groups, and it might be associated with sedentary occupations as well as with some sport activities [1,2]. LBP can be common in young athletes from different sports, and especially in adolescents, it might be caused by extreme hyperextension positions, and by repetitive high-velocity movements such as bending, twisting, or jumping [3,4]. In particular, despite some conflicting results exist about the increased prevalence of LBP in gymnastics compared to other sports [5–7], the specific sport characteristics might suggest that gymnasts might be at a higher risk of low back injuries due to the excessive forces placed on the spine during some of the movements [8]. Moreover, it seems that some physical and individual characteristics could be linked to LBP in gymnasts, such as the imbalance among the core muscles that could lead to dysfunction in the coordination among muscles and, consequently, to a lack of control and stabilization of the lumbar spine [3,9].

Core muscle imaging, as paraspinal and trunk muscles, is of growing interest to better understand common spinal disorders, although further studies are recommended in relation to other physiological and pathophysiological responses of muscles when related to spinal health [2,10]. Tensiomyography (TMG) is a mechanomyographic method that has been used in several studies and represents a promising tool to assess in vivo skeletal muscle mechanical contractile properties (i.e. a time-displacement curve of radial muscle belly displacement) [11–14], and especially in athletes, providing information about muscle asymmetries, stiffness, and fatigue [12,15,16]. TMG assessment of trunk muscles has been proposed, including rectus

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abdominis and erector spinae [17–19], and the assessment of muscle groups imbalances and/or side-to-side asymmetries might be useful to evaluate muscle mechanical properties in LBP [20].

As such, this pilot study aimed to investigate abdominal and lumbar muscles' characteristics, including endurance performance, muscle thickness, and TMG parameters, in a sample of young male and female gymnasts, and their association with sport-related chronic LBP. In addition, those who presented with chronic LBP were invited to participate in a physiotherapy intervention, which included a postural reeducation program, and assessments were repeated to evaluate the effects on the clinical outcomes and trunk muscle characteristics.

2. Materials and methods

This manuscript presents the findings from two studies that were conducted in the same period and with the same participants. A prospective cross-sectional observational study was performed on a population of young gymnasts of both sexes to compare the trunk muscles' characteristics between those with and without LBP. In addition, the participants from the cross-sectional study with a history of chronic LBP were invited to participate in a single-arm physiotherapy intervention, and outcomes were compared before and after the whole exercise program. Chronic LBP symptoms were investigated by asking the participants to subjectively report if they suffered from chronic low back pain in the past 12 months and if the pain influenced their sports activity or not, according to previous studies [21,22]. They were also asked to rate the common LBP intensity with a numeric rating scale (NRS) from 0 (no pain) to 10 (not possible to tolerate) and to indicate on a body map where pain usually occurred (Figure 1).

All the procedures were performed according to the Declaration of Helsinki, all the participants (or their legal guardians) signed informed consent, and the study was approved by the local institutional review board and ethics committee (122/2022). The participants were recruited among gymnasts from local gymnastics clubs, aged between 13 and 18 years. Twenty-five young gymnasts (median age 16, 25th-75th percentile 14–18 y, 56% females) volunteered and were included in the study and performed all the measurements. The included participants had to be training in gymnastics for not less than 3 years. Participants were excluded if presented with any recent or current health complaint, except low back pain, or if low back pain manifested with sciatica. Then, the participants were instructed to refrain from: (i) performing strenuous exercise in the 48-h preceding testing; (ii) consuming caffeine or alcohol in the 24 h preceding testing; and (iii) consuming food in the 3 h preceding testing. In addition to this, the participants had to be pain-free during the measurements and did not take any analgesic for at least 72 h before, including manual or other therapies.

A survey was designed to collect data about demographic and medical history information for each participant, including age, ethnicity, body mass, height, as well as training characteristics, such as duration of gymnastics participation (years), level of gymnastics (recreational or national/international), training frequency (times/wk) and volume (h/wk), and if they performed resistance training and stretching (also specific for the spine). Then, skinfolds were collected to estimate body density for each participant, using the Jackson & Pollock 7-skinfolds formula for males [23]

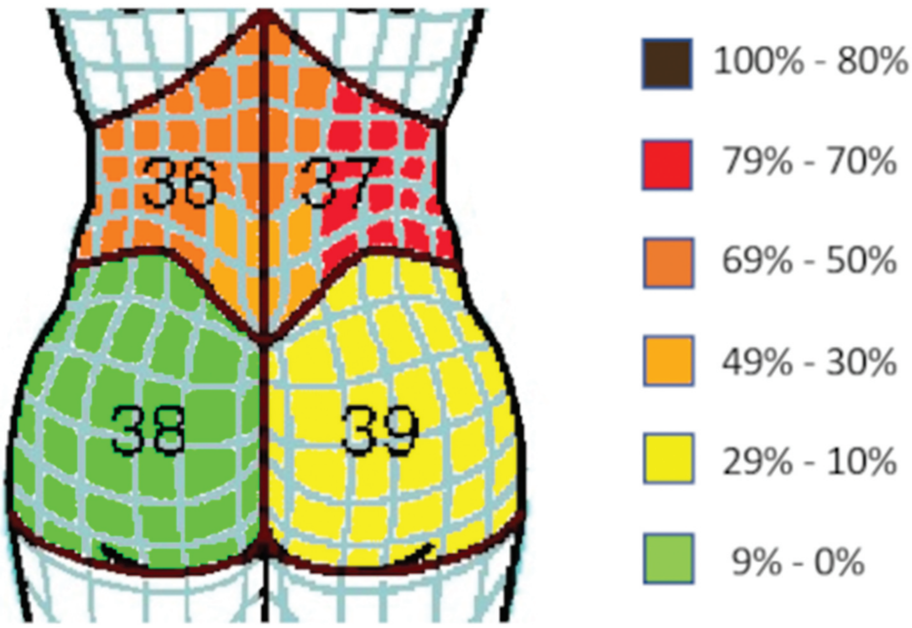

Figure 1. Body map density of low back pain (LBP) in the included sample ($n = 12$).

Figure 2. Postural reeducation exercises: A) lying posture with legs extension progression, and B) standing posture with trunk flexion progression.

and 4-skinfolds formula for females [24] fat mass (FAT, %) was then calculated with the Siri equation [25]. Finally, the Prone Instability Test (PIT) was performed, which identifies lumbar shear instability with adequate interrater reliability; patients were asked to lie prone while the examiner applied a passive manual force over each lumbar vertebra [26]. Two trained physiotherapists independently reviewed each medical history information and determined the criteria for sport-related chronic LBP [27]. In case of disagreement, a third researcher was asked to decide.

2.1 *Physiotherapy intervention*

Extensive research recommends an integrated treatment in the management of low back pain [28–30]. For this reason, we choose a combination of approaches from the most used in the literature for low back pain, such as myofascial release [31,32], spinal mobilization [33,34] and global postural reeducation [35,36].

The participants with LBPs were invited to participate in a dedicated physiotherapy program, which consisted of 8 sessions, 2/wk for 45 min, over a 1-month period. Each session was conducted by a physiotherapist in a one-to-one fashion and was designed as follows: i) myofascial release techniques, ii) spine mobilization exercises, iii) postural reeducation exercises.

The myofascial release techniques were primarily focused on the sacroiliac joint and on the paravertebral muscles [31,37]. To promote spine mobilization, Maitland's spinal mobilization was adopted [38–40]. Participants were first put prone on the treatment table with a pillow under the abdomen. The physiotherapist applied posterior-to-anterior pressure to the spinous process of each lumbar vertebra using small amplitude movements (grade I). The pressure should reproduce the discomfort experienced while bending backward in standing. If no pain was reproduced with grade 1 of mobilization then further higher grades were used (grades II – IV). Once the vertebral level where discomfort similar to bending backward in standing was identified, a session of mobilization was initiated. Initially, the most painful lumbar segment was treated with graded posterior-to-anterior oscillations. Three bouts of 40-second oscillations were applied to this segment at a frequency of 1 to 2 Hz and at the amplitude tolerated by the patient. Following mobilization of the most painful segment, 2 bouts of 40-second oscillations (up to grade IV but short of symptom reproduction) were administered to each of the remaining lumbar vertebral levels. Finally, postural reeducation exercises included the two postural exercises most used for low back pain: i) lying posture with legs extension progression and ii) standing posture with trunk flexion progression (Figure 2) [41].

2.2 *Trunk muscles' function testing*

Trunk muscles' endurance evaluation has been recommended for LBP assessment, as lack of endurance or imbalances of the trunk muscles can be important factors contributing or characterizing the condition [42–44]. According to validated protocols, the flexor and extensor muscles of the trunk were tested to assess torso stabilization and endurance (Figure 3) [45,46]. The flexor endurance test required the participant to sit on the test bench and place the upper body against a support with an angle of 60° from the test bed. Both the knees and hips were flexed to 90°. The arms were folded across the chest with the hands placed on the opposite shoulder and toes were placed under toe straps. The participants were instructed to maintain the body position while the supporting wedge was pulled back 10 cm to begin the test. The test ended when the upper body fell below the 60° angle. The side bridge test consisted of participants laying on an exercise mat (thickness, 2.5 cm) on their sides with their legs extended. The top foot was placed in front of the lower foot on the mat for support. The participants were instructed to support themselves by lifting their hips off the mat to maintain a straight line over their full-body length and support themselves on one elbow and their feet. The uninvolved arm was held across the chest with the hand placed on the opposite shoulder. The test ended when the hips returned to the exercise mat. During the extensor endurance test, the participants laid prone with the lower body fixed to the test bed at the ankles, knees, and hips and the upper body extended in a cantilevered fashion over the edge of the test bench. The test bench surface was approximately 25 cm above the surface of the floor. The participants rested their upper bodies on the floor before the exertion. At the beginning of the exertion, the upper limbs were held across the chest with the hands resting on the opposite shoulders, and the upper body was lifted off the floor until the upper torso was horizontal to the floor. The participants were instructed to maintain the horizontal position as long as possible. The endurance time was manually recorded in seconds with a stopwatch from the point at which the subject assumed the horizontal position until the upper body came in contact with the floor. The front plank was performed in the prone position with the elbows flexed to 90° and knees fully extended, only with the forearms and toes in contact with the ground [47]. In the dynamic endurance test time to exhaustion was determined when performing a cyclic hiking movement (1 Hz) within a hip range of motion of 36–60° [48]. During all tests, the participants were reminded to maintain their position as long as possible and were not provided with any clues to their scores until the conclusion of the test. A flexor/extensor (FlexExt) ratio was calculated by dividing the flexor endurance test time by the extensor endurance test time, which has been usually reported to be around one in healthy women athletes [49].

2.3 Ultrasound

Ultrasound assessment of trunk muscles has been suggested to provide useful information regarding possible factors associated with LBP in athletes [50]. Ultrasound evaluation was performed by an experienced researcher [51–54], with a portable imaging unit set in B mode (Vscan Extend, General Electric Co., USA) with a 3–12 MHz linear array transducer. Abundant gel was used, and the transducer was gently applied to the skin to reduce mechanical alterations [54]. Muscles' thicknesses (mm) were measured at rest on both the right and left sides. For abdominal muscles, the participants were positioned in supine crook-lying while pillows were placed under their head and knees [55]. The angle of the knees was checked by a hand goniometer, and the position of the lumbar spine was assessed visually. The abdominal wall was exposed, and the inferior border of the rib cage and the iliac crest were marked as reference points. All images were captured directly at the end of the expiration, as determined by the visual inspection of the

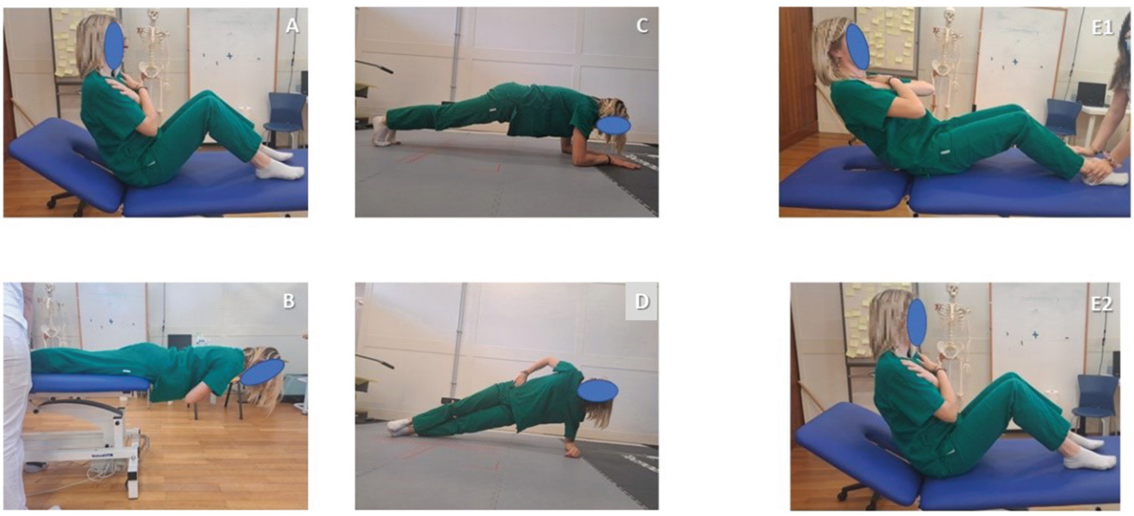

Figure 3. Trunk muscles' endurance evaluation: A) flexors, B) extensors, C) plank, D) side plank, E) dynamic test (36–60°, 1 Hz).

abdominal content. The following muscles were selected: rectus abdominis (RA) (2–3 cm above the umbilicus, 2–3 cm from the midline), external oblique (EO), internal oblique (IO), and transversus abdominis (TrA) (transducer was transversely located across the right side of the abdominal wall over the anterior axillary line, midway between the 12th rib and the iliac crest). Clear images of the muscles were collected, and thickness was measured according to defined landmarks [55]. For lumbar muscles, each participant lay in a prone position with a pillow beneath their abdomen (lower side of the pillow positioned to the anterior superior iliac spine) to minimize lumbar lordosis. The examiner palpated caudally to identify the superior iliac posterior spine (SIPS), L5 and S1 spinal levels. First, the probe was placed with gel longitudinally along the spine to identify the spinous process of L5 and S1. Second, the probe was turned horizontally to the spine at the L5-S1 level. Third, the probe was moved laterally and stopped when SIPS was identified as an anatomical landmark. Fourth, the probe was turned over in the transversal plane to create an angle (between the probe and low back) that resulted in an optimal image of the lumbar multifidus (LM) at the level L5-S1 with the anatomical landmarks SIPS and lamina. LM thickness (mm) was measured in the area between the lamina of the vertebrae to the superficial border of the LM [56]. For both abdominal and lumbar muscles, two images of each muscle were taken and imported on ImageJ (NIH, USA) for thickness measurements, and the mean of the two measurements was used in the statistical analyses. In a pilot study on eight healthy participants, all selected muscles were assessed twice 30 min apart, with test-retest reliability ranging from 0.864 (MF) to 0.933 (RA).

2.4 Tensiomyography

TMG offers a noninvasive tool to measure contractile properties and mechanical responses based on radial muscle belly displacement after an electrical stimulation, therefore presenting an 'active' response of the muscle compared to other 'passive' measures of stiffness as shear wave elastography or myotonometry [20,57,58]. It has been recently suggested as a possible assessment method to detect muscle contractile characteristics of the trunk in athletes with LBP [20]. Participants were in the same supine and prone positions assumed for the US evaluation. TMG measurements were performed during electrically evoked maximal isometric contractions on both RA and erector spinae (ES) muscles, bilaterally, according to previously described procedures [17,54]. A single, 1 ms maximal monophasic electrical impulse was used to elicit a twitch contraction that caused the muscle belly to oscillate. These oscillations were recorded using a sensitive digital displacement sensor (TMG-BMC Ltd., Ljubljana, Slovenia) placed on the skin's surface at the measuring site of the muscle of interest. Initially, the stimulation amplitude was set just above the threshold and then gradually increased until the amplitude of the radial twitch Dm (in millimeters) increased no further. Electrical pulses ranged between 85 and 110 mA at constant 30 V. An inter-stimulation time interval of 10–15 s was used. From two maximal responses all contractile parameters were estimated and average values were taken for further consideration. The TMG parameters were: Dm [the maximal displacement (mm)], Td [delay time; the time from electrical pulse to 10% of Dm (ms)], Tc [contraction time; the time between 10 % and 90 % of Dm (ms)], Ts [sustain time; the time when the response was above 50% of Dm (ms)] and Tr [half-relaxation time; the time from 90% to 50% of Dm during muscle relaxation (ms)] were extracted by TMG software (Version 3.6.16) and used for offline analysis [59–61]. Dm is the absolute spatial transverse deformation of the muscle and reduced Dm is interpreted as an increase in muscle stiffness, whereas larger Dm implies lower muscle stiffness; Td provides a measure of muscle responsiveness; Tc reflects the speed of twitch force generation, and might reflect muscle fiber type or tendon stiffness; Ts providing a theoretical assessment of muscle fiber fatigue status; Tr is actually considered the least reliable parameter across studies and should be further investigated [11,12,62].

2.5 Statistical analyses

All statistical analyses were performed with SPSS v.23 (IBM Inc.). Shapiro-Wilk test for normality of distribution was performed, and most outcomes were not normally distributed. As such, non-parametric analyses were chosen. Data are reported as the medians and 25th-75th percentile, or counts and proportions (%) as appropriate. Continuous variables were compared between athletes with and without LBP, with the Mann-Whitney U-test, while for proportions Fisher's exact test was performed. To account for any side effects, a mixed-factors analysis of variance (ANOVA) was performed (within-subjects: side, between subjects: LBP) for the outcomes assessed on the right and left side, which resulted significant from the between-groups comparison. Partial eta-squared (η [2]$_{p}$) was used for effect size. Receiver operating characteristic (ROC) curves were performed for LBP indicating as variables FlexExt, the mean bilateral LM thickness, and mean bilateral ES Dm. Based on the identified cutoff values, a binary logistic regression was performed to assess such outcomes as risk factors for LBP. To assess the effects of the physiotherapy program on a single arm of subjects with LBP, the Wilcoxon signed-rank test was used to compare clinical outcomes, muscles' endurance, thickness and TMG parameters. The effect size was determined as proposed by Rosenthal (1994) [63]. Significance was set at $p < 0.05$.

3. Results

Participants' demographics and training characteristics are presented in Table 1. All gymnasts were right-handed. According to the reported symptoms, 12 subjects were included in the LBP group. Pain intensity on a scale from 0 to 10 was rated as 5 (4–6), and PIT was absent in 60% e, negative in 4%, and positive in 36% of the overall sample. No significant differences were found between gymnasts with and without LBP, except for smaller training frequency and volume ($p = 0.002$ and $p = 0.002$, respectively). In addition, none of the participants with LBP reported performing spine strengthening exercises, while 38.4% of the healthy subjects performed such training exercises ($p = 0.039$) (Table 2).

3.1 Trunk muscles' function

Gymnasts with LBP were found to perform shorter time both in the right and left side plank (−18.1%, $p = 0.040$; −34.7%, $p = 0.040$, respectively), and during the extensors testing (−25.3%, $p = 0.035$). The ratio between flexors and extensors was found to be higher in the LBP group compared to healthy gymnasts (57.6%, $p = 0.005$) (Table 2). Regarding side plank, no significant effect for side ($F_{1,23} = 1.137$, $p = 0.297$, $\eta^2_p = 0.047$) nor side × group effect ($F_{1,23} = 0.031$, $p = 0.861$, $\eta^2_p = 0.001$) and group effect was found ($F_{1,23} = 2.974$, $p = 0.098$, $\eta^2_p = 0.114$).

3.2 Muscle ultrasound

Gymnasts with LBP had smaller right and left EO (−27.4%, $p = 0.002$; −26.2%; $p = 0.010$, respectively) and right IO (−26.5%, $p = 0.004$) muscle thickness, as well as smaller right and left LM (−13.5%, $p = 0.040$; −23.8%; $p = 0.035$, respectively) (Table 2). Regarding EO, no significant effect for side ($F_{1,23} = 3.721$, $p = 0.066$, $\eta_{2p} = 0.139$) nor side × group effect ($F_{1,23} = 0.000$, $p = 0.993$, $\eta_{2p} = 0.000$) were found, whereas a significant group effect was found ($F_{1,23} = 11.150$, $p = 0.003$, $\eta^2_p = 0.327$), with gymnasts with LBP being characterized by a smaller muscle thickness of −1.891 mm (95% CI: −3.062–-0.719). IO showed no significant effect for side ($F_{1,23} = 0–120$, $p = 0.732$, $\eta^2_p = 0.005$), whereas significant side × group effect ($F_{1,23} = 7.532$, $p = 0.012$, η [2]$_p = 0.247$) and group effect ($F_{1,23} = 5.437$, $p = 0.029$, $\eta^2_p = 0.191$) were found, with gymnasts with LBP being characterized by a smaller muscle thickness of −1.609 mm (95% CI: −3.037–-0.102). Also, LM showed no significant effect for side ($F_{1,23} = 0.725$, $p = 0.403$, $\eta^2_p = 0.031$) nor side × group effect ($F_{1,23} = 0.028$, $p = 0.869$, $\eta^2_p = 0.001$) were found, whereas a significant group effect was found ($F_{1,23} = 4.885$, $p = 0.037$, $\eta^2_p = 0.175$), with gymnasts with LBP being characterized by a smaller muscle thickness of −3.480 mm (95% CI: −6.737–-0.223).

3.3 Tensiomyography

Gymnasts with LBP were found to have a smaller right and left ES Dm compared to healthy athletes (−18.2 %, $p = 0.040$; −34.5%; $p = 0.046$, respectively) (Table 2). Regarding ES Dm, no significant effect for side ($F_{1,23} = 1.163$, $p = 0.292$, $\eta^2_p = 0.048$) nor side × group effect ($F_{1,23} = 0.010$, $p = 0.922$, $\eta^2_p = 0.000$) were found, whereas a significant group effect was found ($F_{1,23} = 4.654$, $p = 0.042$, $\eta^2_p = 0.168$), with gymnasts with LBP being characterized by a smaller Dm of −1.396 mm (95% CI: −2.736–-0.570). Lateral symmetry in both RA and ES muscles did not show significant differences between groups ($p = 0.411$ and $p = 0.111$, respectively).

3.4 ROC and regression analyses

The area under the curve was 0.817, 0.760, and 0.795 for FlexExt, bilateral LM, and bilateral ES Dm, respectively (Figure 4). Regarding FlexExt, a cutoff of 2.18 was found to provide a sensibility of 83.3% and sensitivity of 69.2%, while a cutoff value of 2.59 was associated with a sensibility of 75% and sensitivity of 85%. A mean bilateral LM thickness of 30.6 mm and a mean bilateral ES Dm of 4.6 mm showed a sensibility of 84.6% and sensitivity of 75.0%. When the participants were grouped according to the above-mentioned cutoff

Table 1. Demographics, training characteristics, health and low back pain of the included sample. Medians (25th-75th percentile) and proportions, as appropriate.

	Participants(n= 25)
Demographics	
Age, y	16 (14-18)
Females, n (%)	14 (56.0)
Body mass, kg	57.0 (55.0-66.2)
Body height, m	1.68 (1.58-1.76)
BMI, kg/m2	20.2 (19.5-21.7)
FAT, %	17.0 (8.0-20.0)
Training characteristics	
Duration of gymnastics, y	7 (4-10)
Competition level, n (%)	
Recreational	10 (40.0)
National/International	15 (60.0)
Training frequency, training/wk	3 (2-5)
Training volume, h/wk	6.0 (3.0-14.5)
Training with weights, n (%)	0 (0.0)
Spine strength exercise, n (%)	5 (25.0)
Stretching, n (%)	25 (100.0)
Spine stretching, n (%)	25 (100.0)
Health and low back pain	
LBP, n (%)	
Monolateral	0 (0.0)
Bilateral	12 (48.0)
LBP intensity, 1-10	5 (4-6)
PIT, n (%)	
Absent	15 (60.0)
Negative	1 (4.0)
Positive	9 (36.0)

Note: BMI: body mass index; FAT: fat mass; LBP: low back pain; PIT: prone instability test.

Table 2. Differences in demographics, training characteristics, trunk muscles' function, ultrasound, and tensiomyography in gymnasts with (LBP) and without (healthy) low back pain. Medians (25th-75th percentile) and proportions, as appropriate.

	LBP(n= 12)	Healthy(n= 13)	Significance
Demographics			
Age, y	16.0 (14.0-17.0)	17.0 (14.0-18.0)	0.27
Females, n (%)	5 (41.7)	9 (69.2)	0.11
Body mass, kg	55.5 (51.0-61.5)	59.0 (52.0-68.9)	0.27
Body height, m	1.67 (1.58-1.71)	1.69 (1.57-1.79)	0.57
BMI, kg/m^2	20.5 (19.1-21.2)	20.8 (19.9-21.8)	0.20
FAT, %	19.0 (10.2-20.0)	11.0 (8.0-18.5)	0.32
Training characteristics			
Duration of gymnastics, y	5.5 (3.2-9.0)	8.0 (4.0-12.0)	0.19
Competition level, n (%)			0.41
Recreational	8 (75.0)	2 (15.4)	
National/International	4 (25.0)	11 (84.6)	
Training frequency, training/wk	2.0 (2.0-3.0)	5.0 (3.0-5.0)	**0.002**
Training volume, h/wk	3.0 (3.0-6.0)	12.0 (6.0-15.0)	**0.002**
Training with weights, n (%)	0 (0.0)	0 (0.0)	>0.99
Spine strength exercise, n (%)	0 (0.0)	5 (38.4)	**0.04**
Stretching, n (%)	11 (100.0)	13 (100.0)	>0.99
Spine stretching, n (%)	11 (100.0)	13 (100.0)	>0.99
Trunk muscles' function			
Flexors, s	180 (180-180)	180 (134-180)	0.44
Side plank right, s	59 (37-71)	72 (64-86)	**0.04**
Side plank left, s	47 (37-59)	72 (55-88)	**0.04**
Extensors,s	62 (53-75)	83 (65-112)	**0.03**
Plank, s	86 (62-170)	148 (108-180)	0.15
Dynamic, s	100 (65-148)	151 (119-180)	0.06
FlexExt asymmetry	2.90 (2.33-3.10)	1.84 (1.50-2.32)	**0.005**
Ultrasound			
RA, mm			
Right	11.4 (10.6-13.4)	12.2 (11.3-15.7)	0.22
Left	11.8 (10.8-13.5)	12.3 (10.9-15.8)	0.57
EO, mm			
Right	4.5 (3.7-5.6)	6.2 (5.4-7.3)	**0.002**
Left	4.8 (4.1-6.0)	6.5 (5.8-8.3)	**0.01**
IO, mm			
Right	6.1 (5.1-7.7)	8.3 (6.9-10.2)	**0.004**
Left	6.8 (5.6-8.3)	8.1 (6.8-9.2)	0.17
TrA, mm			
Right	3.3 (3.1-3.6)	3.5 (3.1-3.7)	0.41
Left	3.3 (2.9-3.9)	3.3 (2.9-3.6)	0.44
LM, mm			
Right	24.4 (20.6-27.9)	28.2 (25.2-31.7)	**0.04**
Left	24.8 (22.0-26.8)	29.1 (26.3-31.2)	**0.03**
Tensiomyography			
RA right			
Td, ms	27.1 (23.4-30.7)	27.1 (25.6-27.9)	0.98
Tc, ms	35.8 (29.5-38.9)	36.9 (27.9-44.0)	0.38
Ts, ms	198.4 (153.1-256.1)	189.5 (155.6-229.6)	0.69
Tr, ms	74.1 (56.7-139.7)	72.3 (52.1-86.7)	0.27
Dm, mm	10.6 (6.8-11.7)	8.8 (6.6-10.4)	0.69
RA left			
Td, ms	26.5 (24.6-28.0)	27.2 (24.3-30.3)	0.61
Tc, ms	33.0 (31.4-36.4)	37.6 (31.4-46.8)	0.57
Ts, ms	200.8 (150.5-295.6)	188.5 (139.9-255.9)	0.65
Tr, ms	81.0 (64.3-160.7)	77.3 (54.2-106.7)	0.15
Dm, mm	9.1 (8.1-12.2)	7.4 (6.1-9.9)	0.35
ES right			
Td, ms	21.0 (20.0-22.3)	20.9 (19.9-22.3)	>0.99
Tc, ms	16.1 (15.6-17.8)	16.1 (14.8-17.3)	0.61
Ts, ms	98.9 (37.1-171.2)	218.6 (86.0-261.9)	0.15
Tr, ms	75.4 (17.4-139.8)	110.6 (67.0-221.0)	0.12
Dm, mm	4.4 (3.4-5.2)	5.5 (5.1-6.4)	**0.04**
ES left			
Td, ms	20.9 (18.9-22.8)	21.5 (20.0-21.8)	0.98
Tc, ms	16.5 (14.8-18.8)	16.0 (15.4-17.2)	0.81
Ts, ms	42.4 (33.2-171.9)	176.6 (46.3-243.0)	0.09
Tr, ms	17.4 (10.2-104.0)	103.4 (25.4-189.3)	0.05
Dm, mm	3.5 (2.6-4.6)	5.5 (4.4-6.8)	**0.04**

Note: BMI: body mass index; FAT: fat mass; LBP: low back pain; FlexExt asymmetry: ratio between flexors and extensors endurance; RA: rectus abdominis; EO: external oblique; IO: internal oblique; TrA: transversus abdominis; LM: lumbar multifidus. ES: erector spinae; Td: time of delay; Tc: time of contraction; Ts: time of sustain; Tr: time of relaxation; Dm: displacement. Significance for Mann-Whitney U Test and Fisher's exact test between males and females, bold values for $p < 0.05$.

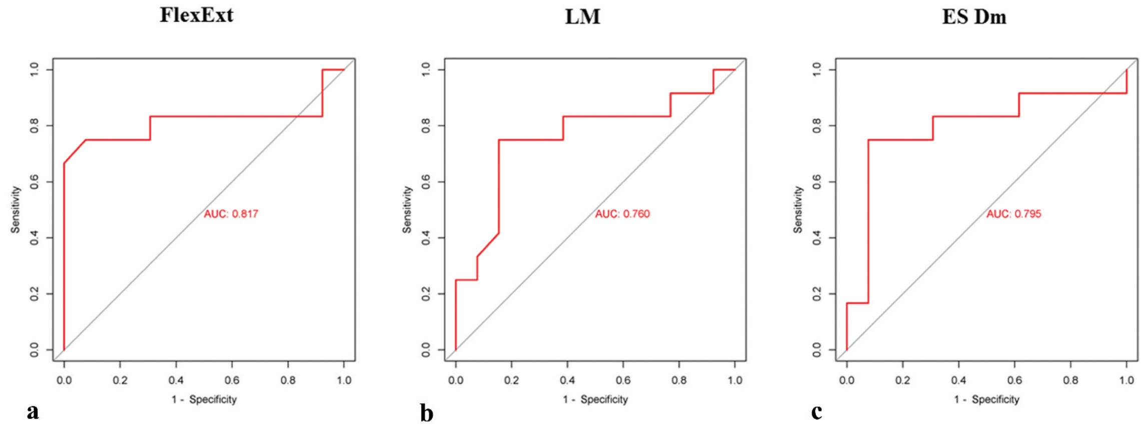

Figure 4. Receiver operating characteristic (ROC) curves for chronic low back pain (LBP) and the ratio between flexors and extensors endurance (FlexExt, a), mean bilateral lumbar multifidus thickness (LM, b), and mean bilateral erector spinae radial displacement (ES Dm, c).

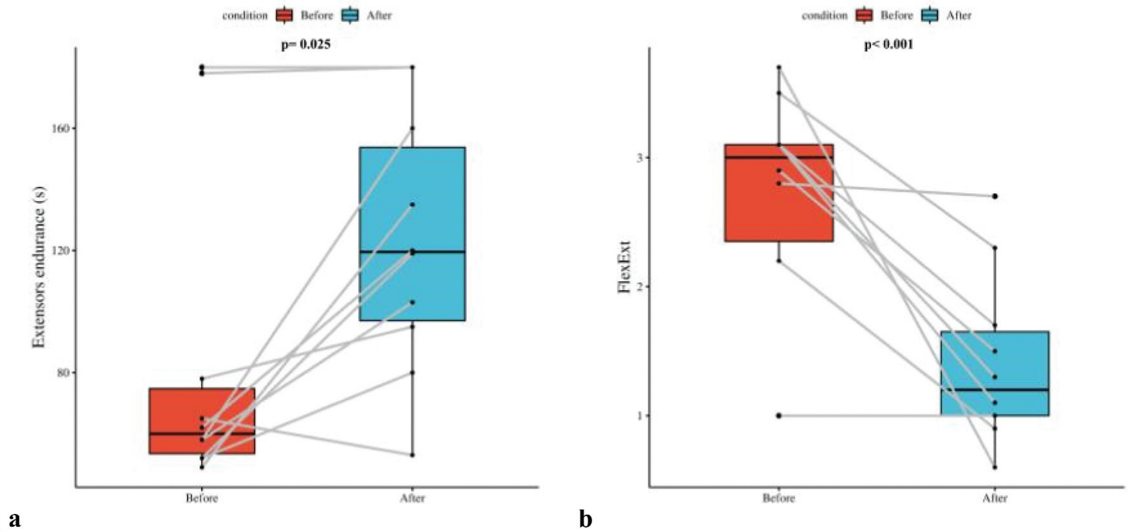

Figure 5. a) Boxplots representing the difference in the extensors' endurance of gymnasts with low back pain ($n = 10$) before (red) and after (blue) the physiotherapy intervention. b) Boxplots representing the difference in the ratio between flexors and extensors endurance (FlexExt) of gymnasts with low back pain ($n = 10$) before (red) and after (blue) the physiotherapy intervention. Wilcoxon signed-rank test was used to report differences between the two time points.

values, the univariate binary logistic regression found a significant effect for FlexExt (OR 11.250, 95% CI: 1.647–76.849, $p = 0.014$), mean LM (OR 16.500, 95% CI: 2.246–121.228, $p = 0.006$), and mean ES Dm (OR 16.500, 95% CI: 2.246–121.228, $p = 0.006$). However, when those factors were included in a multivariate analysis, none reached statistical significance ($p =$ 0.650, $p = 0.900$, $p = 0.900$, respectively).

3.5 Physiotherapy intervention

Among the participants with LBP, two of them did not consent to participate in the physiotherapy intervention, therefore 10 participants were assessed before and after the treatment. Due to the limited sample size, a single-arm design was proposed. Five participants (50%) reported a complete resolution of the symptoms, reporting the absence of any pain attack during the treatment period and the 1-month follow-up. All the remaining 5 participants reported a reduction in the frequency of the symptoms, and 3 of them (80%) reported a reduction also in pain intensity.

Compared to the assessment before the physiotherapy intervention, a significant improvement was found in the right plank endurance test (52 s, 37–69 vs 65 s, 54–90; $p = 0.018$), extensors endurance test (60 s, 53–75 vs 120 s, 95–160; $p = 0.025$), and FlexExt (2.98, 2.34–3.10 vs 1.13, 1.00–1.74; $p < 0.001$) (Figure 5). Muscle ultrasound parameters were not found to significantly change after the intervention, nor most of the TMG parameters showed any significant difference before and after the physiotherapy intervention, despite a reduced RA Dm ($p = 0.009$ and $p = 0.036$, respectively) (Table 3).

Table 3. Differences in trunk muscles' function, ultrasound, and tensiomyography in gymnasts with low back pain (LBP) before and after the physiotherapy intervention. Medians (25th-75th percentile) and proportions, as appropriate.

	LBP before(n= 10)	LBP after(n= 10)	Significance (effect size)
Trunk muscles' function			
Flexors, s	180 (180-180)	180 (144-180)	0.10
Side plank right, s	52 (37-69)	64 (51-87)	**0.02 (0.71)**
Side plank left, s	44 (37-58)	68 (51-80)	0.06 (0.62)
Extensors,s	60 (53-75)	120 (95-160)	**0.02 (0.76)**
Plank, s	86 (68-137)	83 (78-157)	0.59 (0.32)
Dynamic, s	118 (68-148)	180 (76-180)	0.17 (0.40)
FlexExt asymmetry	2.98 (2.33-3.10)	1.13 (1.00-1.74)	**<0.001 (0.84)**
Ultrasound			
RA, mm			
Right	11.9 (10.9-14.0)	11.8 (10.9-13.7)	0.55 (0.19)
Left	12.2 (11.2-15.1)	12.1 (11.1-15.0)	0.96 (0.02)
EO, mm			
Right	4.8 (3.8-5.8)	4.9 (3.9-6.1)	0.28 (0.33)
Left	5.1 (3.9-6.1)	5.2 (3.9-6.2)	0.54 (0.19)
IO, mm			
Right	6.4 (5.3-8.1)	6.0 (5.4-8.1)	>0.99 (0.00)
Left	7.1 (5.4-8.4)	7.1 (5.6-8.2)	0.28 (0.32)
TrA, mm			
Right	3.3 (3.1-3.7)	3.4 (3.1-3.7)	0.68 (0.13)
Left	3.5 (3.0-3.9)	3.6 (3.2-3.9)	0.38 (0.27)
LM, mm			
Right	29.4 (25.6-33.8)	29.8 (25.6-33.8)	0.72 (0.11)
Left	30.1 (28.3-33.5)	30.0 (28.4-33.6)	0.61 (0.16)
Tensiomyography			
RA right			
Td, ms	26.7 (23.4-28.3)	26.6 (23.4-31.6)	0.70 (0.08)
Tc, ms	35.8 (32.5-37.8)	38.9 (37.6-41.9)	0.24 (0.47)
Ts, ms	198.4 (154.6-250.1)	187.2 (145.1-198.1)	0.12 (0.43)
Tr, ms	74.1 (60.3-135.1)	78.7 (53.4-109.6)	0.65 (0.14)
Dm, mm	11.1 (6.9-11.7)	6.4 (5.2-7.6)	**0.009 (0.82)**
RA left			
Td, ms	25.8 (24.6-27.5)	27.8 (24.7-28.9)	0.27 (0.53)
Tc, ms	33.0 (32.0-35.0)	36.4 (30.9-41.9)	0.36 (0.27)
Ts, ms	200.8 (162.4-293.5)	179.5 (164.1-200.1)	0.34 (0.27)
Tr, ms	82.5 (72.9-160.8)	75.7 (72.5-111.1)	0.45 (0.43)
Dm, mm	9.3 (8.1-12.2)	6.0 (4.6-7.9)	**0.04 (0.66)**
ES right			
Td, ms	21.0 (20.0-22.0)	20.4 (18.4-21.2)	0.22 (0.43)
Tc, ms	16.1 (15.7-17.6)	17.4 (15.1-18.0)	0.72 (0.11)
Ts, ms	80.4 (37.1-105.2)	31.0 (26.1-194.1)	0.42 (0.14)
Tr, ms	57.4 (17.4-84.9)	12.3 (8.9-151.8)	0.79 (0.11)
Dm, mm	4.5 (3.4-5.3)	3.8 (3.4-4.7)	0.11 (0.53)
ES left			
Td, ms	20.9 (18.9-22.7)	20.1 (18.5-20.6)	0.17 (0.43)
Tc, ms	16.4 (14.8-18.0)	15.0 (14.5-16.6)	0.11 (0.59)
Ts, ms	37.8 (32.2-51.2)	28.4 (27.8-31.0)	0.83 (0.53)
Tr, ms	14.5 (10.2-21.4)	10.6 (9.4-16.3)	0.96 (0.31)
Dm, mm	3.0 (2.7-3.8)	4.0 (2.7-4.8)	0.19 (0.37)

Note: LBP: low back pain; FlexExt asymmetry: ratio between flexors and extensors endurance; RA: rectus abdominis; EO: external oblique; IO: internal oblique; TrA: transversus abdominis; LM: lumbar multifidus. ES: erector spinae; Td: time of delay; Tc: time of contraction; Ts: time of sustain; Tr: time of relaxation; Dm: displacement. Significance for Wilcoxon signed-rank test before and after the treatment, bold values for $p < 0.05$. The effect size was determined as proposed by Rosenthal (1994).

4. Discussion

Trunk muscles are fundamental for physical fitness and sport-specific performance [64], and are associated with functional capacity and spine health [65]. Gymnasts are subject to repetitive extension, flexion, and rotation of the spine, and the musculoskeletal component can be primarily involved in LBP [8] This study conducted on young gymnasts confirms some previous findings on morphological differences of trunk muscles in different populations and provides preliminary evidence of significant alterations in mechanical muscles' properties assessed with a noninvasive and reliable technique such as TMG. Indeed, although some of these findings were already suggested in previous literature, to the best of the authors' knowledge this is the first study that proposed all three different assessments (functional, morphological and contractile) on young gymnasts with LBP compared to healthy controls.

We found an imbalance between the flexor and extensor muscles in the core endurance test. In particular, it seems that extensor muscles presented lower endurance with respect to flexor muscles. A possible explanation for this finding may be that the posterior chain muscles play a key role in the motor control, strength, and performance of the spine [66,67]; as such, the muscle imbalance between flexors and extensors due to weaker extensors might be correlated with low back pain, whereas stronger extensors with respect to flexors can be correlated with better spine performance [68]. In-line with these observations, in our sample all the gymnasts who reported commonly performing extensors strengthening exercises did not complain about LBP.

Muscle ultrasound imaging is considered a reliable and valid technique to assess muscles' morphological characteristics, like thickness, cross-sectional area, and echogenicity [69,70], and might be well-associated with functional and clinical characteristics [70,71]. In the present study, smaller LM muscle thickness has been found in gymnasts with LBP compared to healthy gymnasts (from −13.5 % to −23.8 %). LM is fundamental for lumbar spine segmental stiffness and changes in its morphology have been found to be associated with LBP [7,72]. Indeed, despite some conflicting results, smaller LM has been suggested to be associated with LBP, at rest and during movement and activation [73,74]. Some authors have suggested that it might be also useful to detect side differences [75]; however, all the gymnasts with LBP in our sample reported bilateral pain and therefore no lateral asymmetries were found nor expected. In addition to lumbar muscles, abdominal muscles might have a role in LBP, despite some conflicting results might be present [76–78]. In athletes and physically active adolescents, lower abdominal muscles thickness has been reported [76,77]. In agreement with these studies, in our sample, we found smaller EO and IO muscle thickness (~ −26.5 %).

TMG represents a useful and promising tool to detect mechanical properties and alterations in sports medicine [16,62], and might be useful to detect changes and asymmetries in people with low back pain [20]. Dm, or peak radial displacement, signifies the absolute spatial transverse deformation of the muscle, and reduced Dm is interpreted as an increase in muscle stiffness [59,62,79]. As such, Dm has been suggested to potentially describe muscle stiffness as a mechanism underlying LBP. In the present study, we observed lower bilateral ES Dm values (from −18.2% to −34.5%) in gymnasts with LBP compared to healthy gymnast, suggesting a potential association between lumbar muscles' stiffness and pain. Such observation is consistent with previous findings using shear-wave elastography, which detected greater resting lumbar muscle stiffness in individuals with LBP than asymptomatic controls, and its association with self-reported pain and disability [58,80].

The ROC analyses performed on the three main outcomes of this study (FlexExt, LM thickness, and ES Dm), and the following binary logistic regression, suggest such outcomes as possible risk factors for LBP (Figure 6). In particular, the FlexExt ratio can be useful, inexpensive, and can be easily adopted by trainers and physiotherapists in different settings, whereas muscle thickness measurement and TMG parameters could provide instrumental support to the diagnosis and description of LBP.

The effects of the physiotherapy intervention protocol proposed in this study were primarily related to the reduction of the symptoms and a concomitant improvement of the flexors-to-extensors endurance ration, mainly due to an increase of the extensors' capacity. The absence of significant changes in the morphological and contractile properties of the investigated muscles is not surprising, as the short period of treatment would have unlikely affected both muscles' thickness and contractile components. In contrast, the improvement observed could more likely result from participants' better ability to control their trunk muscles, and in particular to properly activate the lumbar muscles. Therefore, by restoring the balance between anterior and posterior trunk muscles it could be speculated that this might also affect the symptoms of low back pain, reducing its frequency and intensity.

4.1 Limitations and future perspectives

The results from this study provide evidence of possible functional, morphological, and contractile differences in young gymnasts according to the presence of LBP. From a clinical perspective, the proposed protocol could help the therapist to identify muscles that could be characterized by either reduced endurance capacity, thickness, or increased stiffness; as such, it might be possible to design specific training and rehabilitation protocols based on such findings. In particular, it is possible to suggest that gymnasts with LBP could benefit from improving extensors muscles endurance, lumbar multifidus and oblique muscles mass, and providing relaxation to the erector spinae muscles. However, the moderate sample size and inter-individual differences recommend caution and further studies in larger samples should be encouraged to provide additional evidence of such alterations, in particular when referring to LBP. Indeed, LBP is a clinical condition that might be characterized by heterogeneous causes, risk factors, and manifestations [1]. In addition, its diagnosis, especially in sports, can be complicated and often relies on subjective reporting [4]. In our sample, the participants reported a subjective rating of LBP, and experienced physiotherapists, combining the subjective reporting and physical examination, provided an a priori participants' classification. During the measurements, the participants were 'pain-free'; therefore, future assessments could be performed during periods when pain is manifesting. Other measures could be collected, such as passive vs active muscles ultrasound measurements or other mechanical properties examinations, as well as the measurement of quantitative pain sensitivity. Indeed, since TMG is performed after the administration of electrical stimulation, it is not possible to clearly determine if the observed responses were only dependent on mechanical alterations (such as stiffness), or if they might reflect also pain-associated responses (spasms). Finally, the proposed protocol of treatment

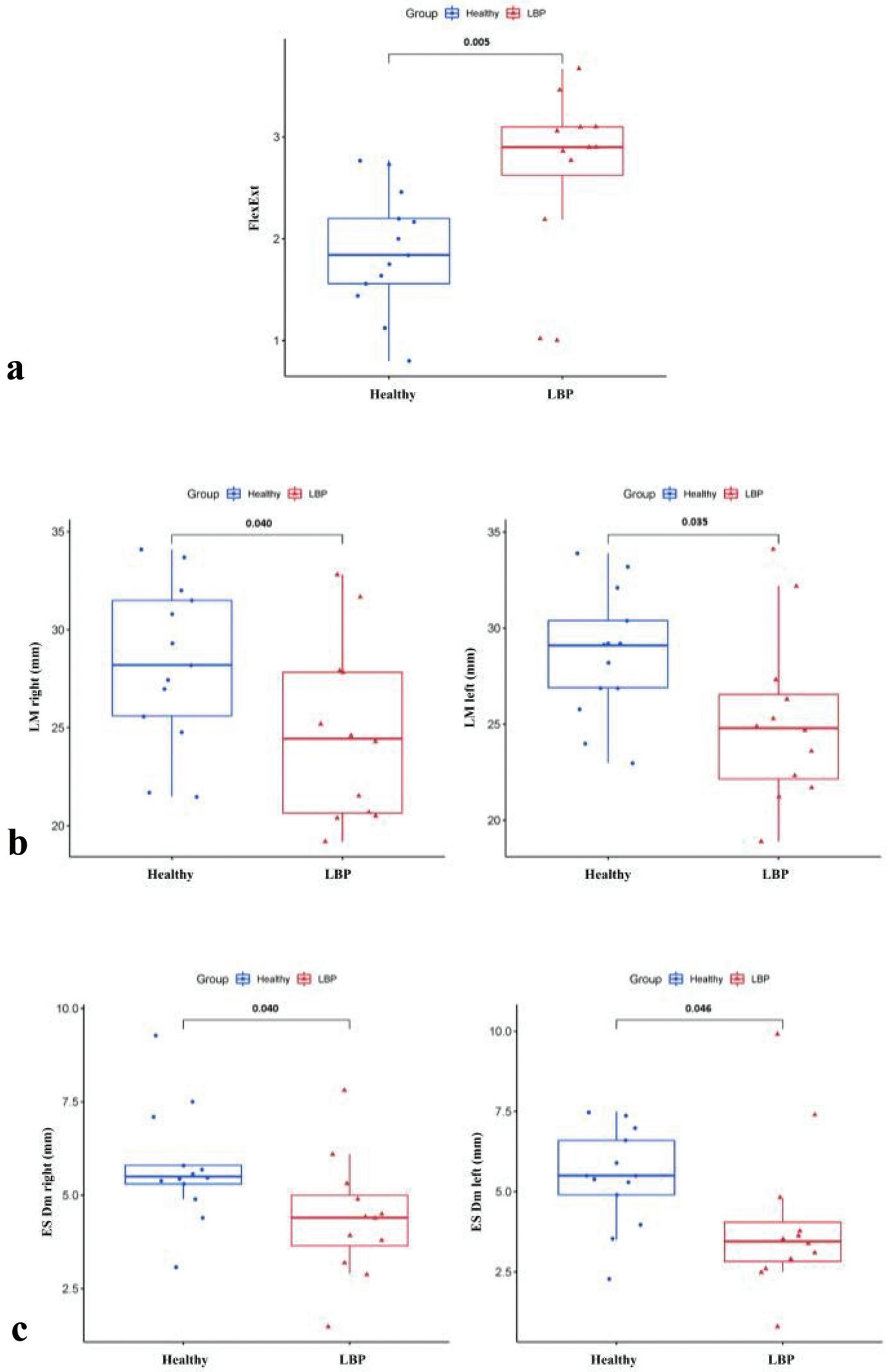

Figure 6. a) Boxplots representing the difference in the ratio between flexors and extensors endurance (FlexExt) of gymnasts without low back pain ($n = 13$, healthy, blue) and with low back pain ($n = 12$, LBP, red). b) Boxplots representing the difference in the right and left lumbar multifidus thickness (LM, mm) of gymnasts without low back pain ($n = 13$, healthy, blue) and with low back pain ($n = 12$, LBP, red). Overall significant group (LBP) effect ($p = 0.037$). **C)** Boxplots representing the difference in the right and left erector spinae radial displacement (ES Dm, mm) of gymnasts without low back pain ($n = 13$, healthy, blue) and with low back pain ($n = 12$, LBP, red). Overall significant group (LBP) effect ($p = 0.042$).

was performed in a limited sample of participants, including a potential for chance findings, and without a control group; therefore, it is not possible to conclude about the effects of the physiotherapy intervention including the postural reeducation protocol, although considering the chronic nature of the low back pain in the present sample, these findings encourage the application of such protocol in randomized controlled trials [81].

5. Conclusions

In summary, young gymnasts with LBP might be characterized by a greater flexor-extensors endurance ratio, with lumbar muscles characterized by reduced thickness and greater stiffness; taken together, these findings suggest that lumbar muscles might be principally involved in LBP in this population and that the combination of strengthening and releasing exercise, as in postural reeducation programs, might be appropriate and encouraged.

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Disclosure statement

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Ethical approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the [omitted for review only] (protocol code 122 of 23 of May 2022).

Data availability statement

Anonymized data are available upon reasonable request to the corresponding author according to the standard institutional procedure.

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