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RESEARCH

Sex-based comparison of trunk flexors and extensors functional and contractile characteristics in young gymnasts

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Abstract

Purpose Gymnastics is a sport characterized by acrobatic and postural strength exercises that require great trunk muscles activation and control. Males and females can be characterized by different morphological and neuromuscular characteristics of such muscles, and this might be of importance for training and injury prevention. The aim of this study was to measure different aspects of trunk flexors and extensors characteristics in a sample of young female and male gymnasts.

Methods Twenty-eight sub-elite adolescent female ($n = 14$, 16 y, 14–17) and male ($n = 14$, 17 y, 14–18) gymnasts participated in this cross-sectional study. Tensiomyography was used to assess muscle contractile properties of the rectus abdominis (m.RA) and erector spinae (m.ES), while muscle thickness was assessed for abdominal muscles and lumbar multifidus (m.LM) with ultrasound. Flexors, extensors, and lateral endurance tests were performed.

Results Females presented smaller m.ES radial displacement ($p < 0.001$, $p\eta^2 = 0.535$), smaller internal oblique thickness ($p < 0.001$, $p\eta^2 = 0.543$), and shorter lateral endurance ($p = 0.002$, $p\eta^2 = 0.302$). A significant side × sex interaction was found for the external oblique thickness ($p = 0.004$, $p\eta^2 = 0.276$).

Conclusion Present findings report sex-based differences in abdominal and lumbar muscles characteristics and support the development of different sex-based training and rehabilitation protocols in adolescent gymnasts.

Keywords Core muscles · Low back · Ultrasound · Tensiomyography · Sport

Introduction

Trunk muscles are essential for performing everyday activities and sports, and alterations of flexors and extensors could influence athletic performance and increase the risk of musculoskeletal injuries and low back pain [1]. Sex-based differences have been reported in morphological and neuromuscular characteristics of such muscles [2] and might be associated with different adaptations to training and clinical treatments [3].

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Sports characterized by acrobatic tasks, such as gymnastics, require repetitive extensions, rotations, and flexions of the spine, and, therefore, training of the trunk muscles represents a key characteristic for both performance and injury prevention in these athletes [4]. Passive, active and control sub-systems are involved in spine stabilization, providing joint stiffness and triggering muscle activity based on sensory feedback [5], and some evidence suggests that the decrease in muscle stiffness associated with fatigue may impair trunk stability [5].

Tensiomyography (TMG) is a validated non-invasive technique developed to assess skeletal muscles' mechanical characteristics by measuring the radial displacement of the muscle belly in response to a single twitch provocation at rest [6]. The TMG-derived parameters can be interpreted to evaluate muscles' asymmetries and changes as responses to different training protocols, fatigue, or injuries [7–10], and TMG has been suggested as a useful tool in sports medicine [11]. In particular, maximum radial displacement has been considered an indirect measure of muscle stiffness [12]; as such, TMG has been suggested as a valid tool to evaluate trunk muscles' characteristics, proposing sex-based differences in muscle stiffness and contractile characteristics [13]. These findings suggest that the above-mentioned sex differences in trunk muscles characteristics and performance might not only depend on anthropometric measures, but may also depend on intrinsic sex-based differences in muscles' contractile characteristics [14]. The importance of trunk flexors and extensors in maintaining postural stability and performing dynamic/acrobatic tasks, such as in gymnastics, suggests a potential role for example in developing low back pain and other related injuries [5, 15]. Therefore, a comprehensive evaluation of trunk muscles' morphological and functional characteristics could help to determine subjects at a higher risk and that might need personalized training/rehabilitation programs based on the evaluation's outcomes. Since the different apparatuses and training characteristics between male and female gymnasts [16, 17], it should be recommended to provide reference values that could be used to compare ultrasonographic and tensiomyographic profiles in gymnasts with lumbar injuries. In particular, stronger and larger muscles' are expected in males, with faster contraction time and larger radial displacement.

Therefore, considering the importance of trunk muscles in gymnastics and the possible differences in sex-characteristics, the present study aimed to assess functional, morphological, and contractile measures of trunk flexors and extensors, in a sample of young male and female gymnasts, in order to propose references values for the healthy population.

Methods

A prospective observational study was performed, comparing young male and female gymnasts. Participants were recruited among young sub-elite gymnasts from a local club who met the following and inclusion criteria and volunteered to participate in this study. Inclusion criteria were: participants from both sexes, aged between 14 and 18 y, training in gymnastics from not less than 3 y and not less than 3 h per week. Participants were excluded if they presented a history of severe traumas or surgery to the spine, back, or abdomen, and in particular if they reported acute and chronic injuries to the musculoskeletal system as well as lumbopelvic dysfunction or treatment within the previous 6 weeks. They were also excluded if they reported training in other sports in addition to gymnastics. All the participants and their legal guardians were informed about the study procedures and both participants and legal guardians were asked to sign the informed consent before participating in the study. All procedures were performed according to the principles of the Declaration of Helsinki and were approved by the ethical committee of the University of Trieste (122/2022).

Participants presented to assessments at least 48 h from their last training and in absence of pain, fatigue, or discomfort. They were also asked to refrain from caffeine or smoking for at least 2 h before testing. Female athletes were tested during the follicular phase of the menstrual cycle. After arrival at the laboratory, they were again instructed about the procedures and some anthropometric and demographic data were collected, including specific questions related to their sport experience. Body mass and height were measured with a scale and a stadiometer. Skinfolds were collected to estimate body density for each participant, using the Jackson & Pollock 7-skinfolds formula for males [18] and 4-skinfolds formula for females [19]; fat mass (FAT, %) was then calculated with the Siri equation [20]. All the assessments were performed between July and September 2022, with participants being assessed during the same period of the training season.

Procedures

Tensiomyography assessment was performed bilaterally on the erector spinae (m.ES) and rectus abdominis (m.RA) muscles, according to previous literature [13, 21]. For the ES assessment, participants were positioned supine on a physiotherapy examination bed, with their arms relaxed and aligned with the body, the face positioned in the ergonomic space to align the head, and a small tube pillow under their ankles. The electrodes were positioned according to the TMG manufacturer's instructions, at L3–L4 level, approximately 2 cm laterally of the spinous process, on the m.ES muscle belly. The muscle belly was identified via palpation and visual inspection by a trained researcher (BS). For the RA, the subjects were supine with a small pillow under their head, maintaining a relaxed and aligned position on the examination bed. The electrodes were positioned according the TMG manufacturer instruction 2 cm laterally to the belly button. For both m.ES and m.RA, an interelectrode distance of 3 cm was chosen, with the sensitive digital displacement sensors (TMG S2, TMG-BMC Ltd., Ljubljana, Slovenia) between the two electrodes. A single 1 ms maximal monophasic electrical impulse, delivered by the TMG S2 electrical stimulator, was used to elicit a twitch contraction that caused the muscle belly to oscillate. In each muscle, after checking for the correct positioning of the sensor and the time-radial displacement curve, the stimulation amplitude gradually increased (up to a maximum 110 mA intensity) until the amplitude of the radial twitch Dm (in millimetres) increased no further, with 15 s between each stimulation. From two maximal responses, all contractile parameters were estimated and average values of those parameters 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 [7]. 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 fibre fatigue status; Tr is actually considered the least reliable parameter across studies and should be further investigated [12]. In addition, the TMG software applied an algorithm to calculate the lateral symmetry (i.e., side symmetry for a specific muscle) [7, 11], which was defined as follows:

$$
\begin{aligned}
\mathrm{LS}(\%) &= 0.1\ \mathrm{x}\ (\mathrm{MIN}\ (\mathrm{TdR;TdL})\mathrm{MAX}\ (\mathrm{TdR;TdL}))\\
&+ 0.6\ \mathrm{x}\ (\mathrm{MIN}\ (\mathrm{TcR;TcL})\mathrm{MAX}\ (\mathrm{TcR;TcL}))\\
&+ 0.1\ \mathrm{x}\ (\mathrm{MIN}\ (\mathrm{TsR;TsL})\mathrm{MAX}\ (\mathrm{TsR;TsL}))\\
&+ 0.2\ \mathrm{x}\ (\mathrm{MIN}\ (\mathrm{DmR;DmL})\mathrm{MAX}\ (\mathrm{DmR;DmL})) \times 100
\end{aligned}
$$

where MIN is the minimum, MAX is the maximum, R is right muscle parameters and L is left muscle parameters.

To assess muscles' morphological characteristics, lumbar multifidus (m.LM) and abdominal muscles were investigated bilaterally with ultrasound (US) by an experienced researcher (ABS). A portable imaging unit set in B mode (Vscan Extend, General Electric Co., USA) with a 3–12 MHz linear array transducer was used, and abundant gel was applied, while the transducer was gently applied to the skin to reduce mechanical alterations [22]. Muscle thickness was measured by two images of each muscle imported on the ImageJ software (NIH, USA) using the predisposed tool. The mean of the two measurements was used in the statistical analyses. In a pilot study on 8 healthy participants, all selected muscles were assessed twice 30 min apart, with test–retest reliability ranging from 0.864 (m.LM) to 0.933 (m.RA). For m.LM, 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 m.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 m.LM [23]. For abdominal muscles, the participants were positioned in supine crook-lying while pillows were placed under their head and knees [24]. 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 abdominal content. The following muscles were selected: rectus abdominis (m.RA) (2–3 cm above the umbilicus, 2–3 cm from the midline), external oblique (m.EO), internal oblique (m.IO), and transversus abdominis (m.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 [23, 24].

Finally, functional tests were performed to assess trunk muscles' flexors and extensors endurance capacity, according to McGill's torso endurance battery [25]. The flexor endurance test required the participant to sit on the test bench and place the upper body against a support with an

Table 1 Anthropometric and training characteristics of the included sample

	Females $n = 14$	Males $N = 14$	Significance
Age (y)	16 (14–17)	17 (14–18)	0.150
Body mass (kg)	54.5 (50.0–57.8)	66.3 (62.9–68.0)	**0.001**
Body height (cm)	162 (158–168)	173 (166–180)	**0.021**
BMI (kg/m^2)	19.9 (18.7–22.5)	21.7 (21.0–23.9)	0.246
FAT (%	19.5 (18.2–21.5)	8.0 (7.6–9.0)	**< 0.001**
Training years (y)	6 (4–8)	10 (5–11)	**0.024**
Frequency of training (times/wk)	3 (2–3)	5 (3–5)	**0.001**
Volume of training (h/wk)	5 (3–6)	14 (10–15)	**< 0.00**

Medians (25–75th percentile) and proportions

BMI body mass index, *FAT* fat percentage of body weight

Bold values for $p < 0.05$ at the Mann–Whitney *U* test

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 the 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 [26]. 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° [27]. 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 (Flex/Ext) ratio was calculated by dividing the flexor endurance test time by the extensor endurance test time.

Statistical analysis

All statistical analyses were performed with the SPSS v.22 (IBM inc.) software. Shapiro–Wilk test for normality of distribution was performed. Data are reported as the medians and 25th–75th percentile, or counts and proportions (%) as appropriate. The Mann–Whitney U test was used to assess differences between males and females for continuous variables. A mixed-factors analysis of variance (ANOVA) with between-subjects (group: males and females) and within-subjects (side: right and left) effects was performed for measures including assessments on the two body sides. In case of significant main effects, Sidak's post hoc tests were performed. Partial eta square ($p\eta^2$) was chosen as a measure of effect size. To investigate the association between the endurance performance of the trunk muscles and the morphological and tensiomyographic parameters, a partial correlation (controlled for sex) was performed. Statistical significance was set at $p < 0.05$ for all statistical analyses.

Results

Fourteen female (16 y, 14–17) and 14 male (17 y, 14–18) gymnasts were recruited and participated in the study. Compared to females, males were characterized by a significantly higher body mass ($p = 0.001$), body height ($p = 0.021$) and lower %FAT ($p < 0.001$). In addition, they reported longer training history in gymnastics ($p = 0.024$) and higher weekly training volume ($p < 0.001$) (Table 1).

TMG analysis showed no significant side × sex interaction effect for none of the parameters, nor side effect.

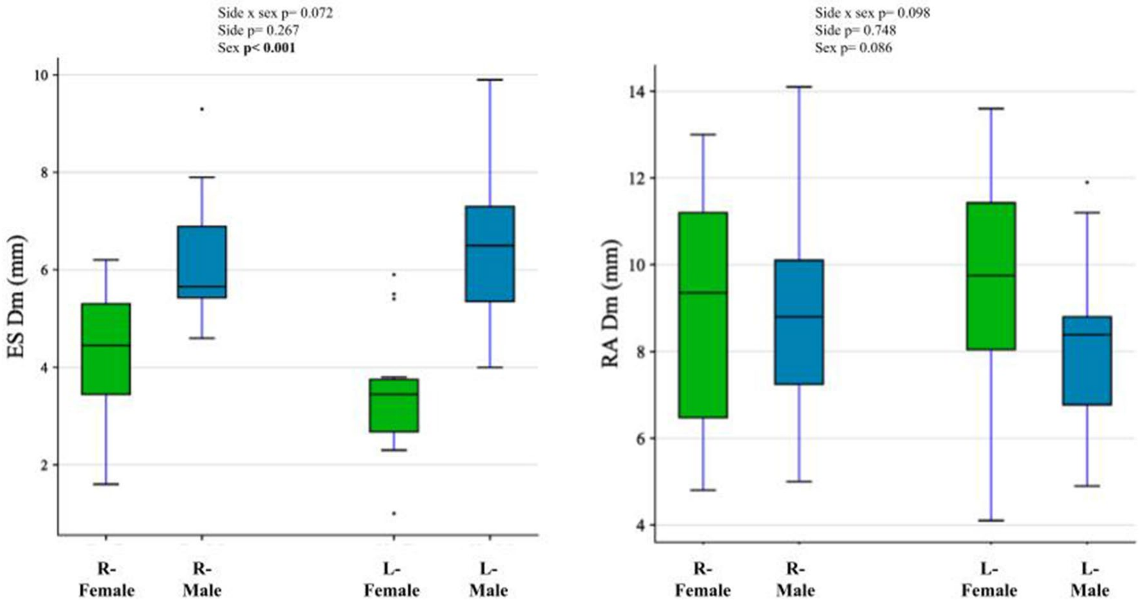

Fig. 1 Boxplots representing the difference in the right (R) and left (L) erector spinae (ES) and rectus abdominis (RA) radial displacement (Dm, mm) in female ($n = 14$, green) and male ($n = 14$, blue) gymnasts. Significance for mixed-factors ANOVA (within group: side; between group: sex) (colour figure online)

In contrast, significant group effects were found for ES Ts ($F_{1,26} = 25.875$, $p < 0.001$, $p\eta^2 = 0.499$), ES Tr ($F_{1,26} = 13.015$, $p = 0.001$, $p\eta^2 = 0.334$), and ES Dm ($F_{1,26} = 29.913$, $p < 0.001$, $p\eta^2 = 0.535$) (Fig. 1). In particular, males were found to have overall longer ES Ts (123.6 ms, 95% CI: 73.7–173.6) and ES Tr (75.0 ms, 95% CI: 32.3–117.8), and overall larger ES Dm (2.4 mm, 95% CI: 1.5–3.3 mm) (Table 2).

Muscle US showed a significant side x sex interaction only for m.EO ($F_{1,26} = 9.894$, $p = 0.004$, $p\eta^2 = 0.276$) (Fig. 2). No significant side effects were found for the other muscles, whereas a significant group effect was found also for m.OI ($F_{1,26} = 30.878$, $p < 0.001$, $p\eta^2 = 0.543$) (Fig. 2). In particular, males were found to have an overall larger m.IO (2.6 mm, 95% CI: 1.6–3.6) (Table 3).

Finally, trunk flexors and extensors endurance revealed a significant side x sex interaction for side plank ($F_{1,26} = 11.246$, $p = 0.002$, $p\eta^2 = 0.302$) (Fig. 3). Males also performed significantly longer during the frontal plank endurance test ($p = 0.001$) (Table 4).

Significant correlations were found between right side plank performance and right m.RA thickness ($r = 0.599$, $p = 0.001$), left m.LM thickness ($r = 0.421$, $p = 0.029$), left m.ES Dm ($r = 0.528$, $p = 0.005$), and a tendency for right m.MF thickness ($r = 0.377$, $p = 0.053$); between left side plank performance and right m.RA thickness ($r = 0.571$, $p = 0.002$), left m.IO thickness ($r = 0.034$, $p = -0.409$), and a tendency for left m.RA thickness ($r = 0.355$, $p = 0.069$) and left m.MF thickness ($r = 0.371$, $p = 0.057$).

Discussion

Results from the present study confirm some previous findings on morphological differences of trunk muscles in different populations and provide preliminary evidence of significant alterations in mechanical muscles' properties assessed with a non-invasive and reliable technique such as TMG. Expectedly, males performed longer during static side (in particular on the left side) and front plank endurance tests; however, no differences were observed between males and females during the flexors, extensors, and dynamic endurance tests. These findings seem to be consistent with previous findings in adolescents showing males had higher lateral torso endurance than females [28]. Males also presented larger m.OE and m.OI muscles, whereas no significant differences were found in other abdominal or lumbar muscles. Abdominal muscles thickness evaluated with ultrasound was found to be consistent with previous literature suggesting a transverse abdominis < external oblique < internal oblique < rectus abdominis pattern, with sex-linked differences [24]. Nevertheless, in the present study, this difference was significantly evident in abdominal oblique muscles. A significant side × sex interaction was reported for m.OE, showing that compared to females, males had significantly thicker m.OE on the left side, consistently with the findings on lateral endurance, and this might be hypothesized to depend on the specific activation of this muscle during sex-specific gymnastics exercises [29]. The importance of

Table 2 Tensiomyography parameters of the included sample

	Females $n = 14$	Males $N = 14$	Significance group difference
m.ES Td (ms)			0.569
Right	20.6 (19.6–22.0)	21.2 (20.6–22.3)	
Left	20.8 (19.7–22.7)	21.4 (21.1–21.7)	
m.ES Tc (ms)			0.372
Right	16.2 (15.7–17.1)	16.0 (15.7–19.0)	
Left	16.5 (15.5–17.3)	16.1 (15.4–17.9)	
m.ES Ts (ms)			**< 0.001**
Right	82.0 (37.1–144.6)	246.1 (183.9–264.3)	
Left	38.5 (33.2–105.2)	188.1 (178.0–250.1)	
m.ES Tr (ms)			**0.001**
Right	61.1 (17.4–123.6)	130.3 (106.0–210.3)	
Left	14.8 (10.9–83.1)	113.1 (57.4–161.6)	
m.ES Dm (mm)			**< 0.001**
Right	4.4 (3.4–5.3)	5.6 (5.4–6.9)	
Left	3.5 (2.7–3.8)	6.5 (5.3–7.3)	
m.ES symmetry (%)	85.3 (81.4–90.7)	87.7 (86.9–89.3)	0.352
m.RA Td (ms)			0.309
Right	27.3 (26.6–28.8)	25.7 (23.7–28.7)	
Left	27.5 (25.6–28.2)	26.4 (25.2–27.3)	
m.RA Tc (ms)			0.419
Right	35.1 (31.4–38.4)	38.1 (36.6–41.5)	
Left	33.8 (30.7–37.7)	34.7 (31.7–37.8)	
m.RA Ts (ms)			0.308
Right	219.2 (162.5–254.6)	180.0 (144.0–205.4)	
Left	200.8 (179.9–233.6)	174.7 (148.3–208.6)	
m.RA Tr (ms)			0.344
Right	78.9 (62.7–141.4)	65.5 (59.6–93.4)	
Left	78.5(64.3–106.2)	78.9 (63.1–91.7)	
m.RA Dm (mm)			0.388
Right	9.4 (6.5–11.2)	8.8 (7.3–10.1)	
Left	9.7 (8.0–11.4)	8.4 (6.8–8.8)	
m.RA symmetry (%)	89.6 (82.8–92.6)	84.1 (80.9–89.5)	0.210

Medians (25–75th percentile)

m.ES erector spinae, *m.RA* rectus abdominis, *Td* time of delay, *Tc* time of contraction, *Ts* time of sustain, *Tr* time of relaxation, *Dm* radial discplament

Bold values for $p < 0.05$ at the mixed-factors ANOVA (side; sex) sex main effect

abdominal oblique muscles in gymnastics and the difference in their thickness between males and females might be explained by the fact that compared to females, the male gymnasts from our sample performed more turns and rotations (including off-axis jumps) during their training activities. Our findings suggest that sex differences might be present in ES TMG parameters, and in particular Dm can be larger in males compared to females (~172%), in line with previous findings in healthy participants [14]. Although it did not reach statistical significance, females were found to present smaller lumbar muscles thickness compared to males, and this might have affected the mechanical responses to the electrical stimulus, as previously suggested [14]. In addition, the findings from the present study, suggesting a lower ES Dm in females than males, confirm the previous observations from Lohr and colleagues [14], and considering the various hypothesis explaining the such difference, it should be considered that regional adipose tissue distribution might have affected the TMG responses causing larger noncontractile tissue oscillations after the contraction in the female participants [14]. Nevertheless, other factors should be considered, as despite we found a general correlation between body fat percentage and ES Dm, when corrected for sex, it was

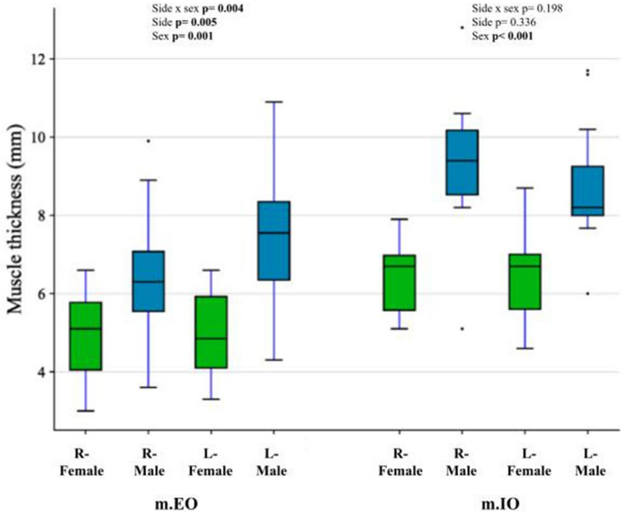

Fig. 2 Boxplots representing the difference in the right (R) and left (L) external oblique (m.OE) and internal oblique (m.OI) muscle thickness (mm) in female ($n = 14$, green) and male ($n = 14$, blue) gymnasts. Significance for mixed-factors ANOVA (within group: side; between group: sex) (colour figure online)

Table 3 Muscle thickness of the trunk flexor and extensor muscles of the included sample

	Females $n = 14$	Males $N = 14$	Significance group difference
m.LM (mm)			0.086
Right	29.9 (26.6–32.7)	34.8 (31.2–37.0)	
Left	30.1 (28.7–33.6)	32.2 (29.2–35.1)	
m.RA (mm)			0.086
Right	11.8 (10.9–12.9)	14.2 (11.7–16.1)	
Left	11.6 (10.9–12.3)	11.6 (10.2–17.3)	
m.EO (mm)			**0.001**
Right	5.1 (4.0–5.8)	6.3 (5.6–7.1)	
Left	4.9 (4.1–5.9)	7.6 (6.4–8.4)	
m.IO (mm)			**< 0.001**
Right	6.7 (5.6–6.9)	9.4 (8.5–10.2)	
Left	6.7 (5.6–7.0)	8.2 (8.0–9.2)	
m.TrA (mm)			0.591
Right	3.3 (3.0–3.4)	3.6 (3.0–3.7)	

Medians (25–75th percentile)

m.LM lumbar multifidus, *m.RA* rectus abdominis, *m.EO* external oblique, *m.IO* internal oblique, *m.TrA* transverse abdominis

Bold values for $p < 0.05$ at the mixed-factors ANOVA (side; sex) sex main effect

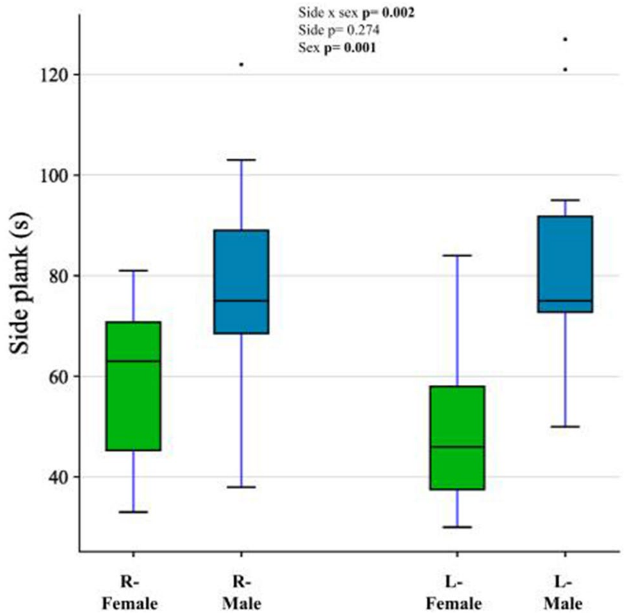

Fig. 3 Boxplots representing the difference in the right (R) and left (L) side plank endurance (s) in female ($n = 14$, green) and male ($n = 14$, blue) gymnasts. Significance for mixed-factors ANOVA (within group: side; between group: sex) (colour figure online)

Table 4 Trunk flexors and extensors endurance test of the included sample

	Females $n = 14$	Males $N = 14$	Significance group difference
Side plank (s)			**< 0.001**
Right	63 (45–71)	75 (69–89)	
Left	46 (38–58)	75 (73–92)	
Flexors (s)	180 (173–180)	180 (174–180)	0.910
Extensors (s)	64 (59–102)	82 (68–89)	0.352
Front plank (s)	86 (62–137)	180 (162–180	**0.001**
Dynamic (s)	130 (89–171)	144 (112–173)	0.401
Flex/Ext	2.8 (1.6–3.0)	2.2 (1.9–2.4)	0.503

Medians (25–75th percentile)

Flex/Ext ratio between flexors and extensors endurance

Bold values for $p < 0.05$ at the mixed-factors ANOVA (side; sex) sex main effect, and for Mann–Whitney *U* test

not significant anymore. Other TMG parameters of the ES have been found to differ between males and females, as Ts and Tr; nonetheless, more studies are needed to provide a better understanding of the physiological significance of such parameters and, therefore, it is not possible to hypothesize if these differences depended on different muscle contractile properties, if they depended on variability [12].

It should be noted that the modest sample size of this study was not sufficient to exclude possible bias arising from interindividual differences, and in particular, we reported that males from this sample trained at higher volumes compared to females, and this might have affected the results. In addition, different gymnastics apparatuses are used by male and female gymnasts, with peculiar characteristics and required motor skills that might explain the observed difference [16, 17]. Participants were sub-elite gymnasts, and differences might be present compared to elite athletes; nonetheless, it should be important to consider sub-elite athletes as representing the majority of the sports population and also be at risk of musculoskeletal injuries. In addition, despite more research being needed, females might be characterized by different responses depending on the phase of the menstrual cycle they are tested [30], and, therefore, future studies should focus on such differences. Other measures of stiffness, such as myotonometry or shear wave ultrasound might have provided additional insights into sex differences in this interesting parameter [13, 31, 32]. However, the sex-based differences in low back TMG parameters are consistent with previous findings suggesting significant differences in trunk extensors muscle stiffness and contractile characteristics between males and females [14, 31], and this might be relevant for the increased risk for musculoskeletal injuries and overuse, as in low back pain [33, 34].

This study provides preliminary evidence of sex-based differences in trunk flexors and extensors characteristics in adolescent sub-elite gymnasts. In particular, it is suggested that females can present lower lateral torso endurance, smaller lumbar multifidus thickness, and reduced erector spinae radial displacement, which might be an indirect measure of increased muscle stiffness. Gymnastics is a sport that presents similar fundamentals, such as highly dynamic movement, strength and postural control tasks, although males and females perform different exercises and, therefore, might present muscular morphological and functional differences. Despite the moderate sample size, this study encourages future research to globally investigate trunk muscles' characteristics and sex-linked differences as they offer the opportunity to better tailor training and rehabilitation programs in this sport.

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Data availability Anonymized data can be requested upon reasonable request to the corresponding author.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval All procedures were approved by the ethical committee of the University of Trieste (protocol code 122/2022, 23.05.2022).

Informed consent All the participants and their legal guardians were requested to sign an informed consent.

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