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THE SHAPE OF THE SAGITTAL CURVATURES OF THE SPINE IN A HIGH-LEVEL ACROBATIC GYMNASTS – COMPARISON BY SEX

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Abstract: Specific loads on the spine and the very young age at which acrobatic gymnastics training is undertaken require monitoring the shape of the spine curvatures in gymnasts to detect possible postural abnormalities. The aim of this descriptive study was to assess and compare the shape of the spine in the sagittal plane in acrobatic gymnasts of both sexes and their associations with demographic and somatic variables.

The study group included 159 acrobatic gymnasts aged 12–19 (106 females and 53 males) from 16 European countries. The study was designed as a survey and measurements of somatic variables and the angles of inclination (using the Baseline Bubble inclinometer) at four topographic points of the spine: S1, L5/S1, Th12/L1, C7/Th1. Based on the angles of spinal inclination, the sizes of the sacral slope (SS), lumbar lordosis (LL), and thoracic kyphosis (TK) were calculated. Body posture was assessed based on Wolański's modified typology.

The angles of SS and LL were significantly higher in females, and TK did not differ between sexes. Training experience positively correlated only with the size of the SS in both sexes. Age and somatic variables were significantly correlated with the size of the sagittal curvatures, mainly in females. The majority of gymnasts had a normal angle of SS and TK and a flattened LL. The equivalent and lordotic types of body posture were more frequent in females, and the kyphotic type in males. The incorrect body posture was noted in 19.8% of females and 43.4% of males.

We concluded that acrobatic gymnasts are not at risk of increasing the size of spinal curvatures in the sagittal plane, but males show a tendency toward flattened LL and kyphotic type of body posture.

Key words: body posture, competitive sport, gymnastics,lumbar lordosis, thoracic kyphosis, sacral slope, spine

1. Introduction

The shape of the spine is the basic factor determining the human body posture, which is an integrated system of bone-joint and fascio-ligament-muscle structures controlled by the central nervous system (Drzał-Grabiec et al., 2016; Wilczyński et al., 2020). The correct body posture is characterized by symmetry in the frontal and transverse planes. In the sagittal plane, the spine has four physiological curves: the cervical and lumbar lordosis, and the thoracic and sacral kyphosis (Czaprowski et al., 2017; Grabara et al., 2017; Wilczyński et al., 2020). These curvatures are formed at successive stages of posturogenesis and are constantly changing. They are ultimately determined by a combination of movement habits and conditional reflexes for defying gravity that are created on the basis of unconditional postural, positional, support, static-kinetic, and motion-based reflexes (Czaprowski et al., 2017; Drzał-Grabiec et al., 2016; Wilczyński et al., 2020).

There are two critical periods when the risk of posture defects leading to spinal deformation increases. The first critical period of posturogenesis occurs at the age of 6–7 and is associated with a change in the child's lifestyle resulting from entering school. The second critical period occurs at the age of 11–13 in girls and 13–14 in boys and is associated with the pubertal leap (rapid changes in height and weight). The prepuberal phase and puberty are periods of life when the posture undergoes many adjustments and adaptations due to changes occurring in body proportions and to demanding psychosocial factors (Drzał-Grabiec et al., 2016; Grabara et al., 2017; Wilczyński et al., 2020; Twarowska-Grybałow & Truszczyńska-Baszak, 2023).

The shape of the spinal curvature also plays an important role in athletic performance and the health of athletes. Improper distribution of mechanical loads significantly affects spinal structures and can affect the stability of an athlete's body, as well as result in spinal injuries (Keller et al., 2005; Sainz de Baranda et al., 2020). Hence, these curvatures should be neither flattened nor increased to maintain a physiological, harmonic, and balanced posture. In this sense, having sagittal spinal curvatures within the normal ranges could favor the athlete's trunk mobility as well as improve their stability due to the lower center of gravity and the better distribution of the load. Therefore, sports professionals should be aware of the loads and overloads associated with sports training and their impact on the young athlete's spine (Sainz de Baranda et al., 2020).

A review of the scientific literature does not indicate clearly whether competitive practice in sport has a positive or negative impact on the shape of the spine. Some studies indicate that practiced sports don't determine spinal shape in a relax standing position (Muyor et al., 2013; López-Miñarro et al., 2017), while others show that the sagittal curvature of the spine can gradually adapt to the sport played if training is conducted intensively over a long period of time (Wojtys et al., 2000; Stošić et al., 2011; Sanz-Mengibar et al., 2018). Some predominantly "feminine" sport such as gymnastics, are characterized by an extremely large range of motion (ROM), and due to the repetitive flexion, extension, and rotation, gymnasts are particularly at risk for spine overloads (Kums et al., 2007; Stošić et al., 2011). Gymnastics requires from athletes a high level of flexibility, conditioning and complete body recruitment that is matched infrequently by other sports (Makovitch & Eng, 2020). In addition, these are sports in which intensive training begins in early childhood, with specialization soon afterward. Therefore, athletes who practice gymnastics may have a higher risk of improper development of the spine (Kruse & Lemen, 2009; Grabara, 2010).

Acrobatic gymnastics is the sport in which athletes compete on a floor area, performing routines composed of individual and group skills synchronized to music, presenting perfect body control, flexibility and artistry. Just like other gymnastics, this sport is managed in the global dimension by the International Gymnastics Federation (FIG) and in the European dimension, by European Gymnastics (until 2020 called the European Union of Gymnastics – UEG).

Competitive acrobatic gymnastics consists of five group formations: women's pair and men's pair, mixed pair (male and female), women's group (three females) and men's group (four males). In both pairs and groups, two fundamental roles are differentiated: "bases", who mainly carry out supporting, pitching, and catching roles, and "tops", who perform elements of flexibility, balance, and combinations thereof or dynamic elements with turns and rotations in the aerial phase (Taboada-Iglesias et al., 2017). The nature of acrobatic gymnastics means that the smaller partner of a pair and the smallest of a group act as the "top" that balances on the partner(s) or is the main flier in a dynamic exercises, assisted by the "base(s)" (Purnell et al., 2010; FIG, 2016).

The majority of acrobatic skills performed by skeletally immature and actively growing gymnasts require extreme spine mobility. Serious stretching of gymnasts often begins as early as age 5–6, and the required range of motion and level of flexibility increase as training progresses (Purnell et al., 2010; Sands et al., 2016). Body positions in different balance and dynamic acrobatic skills are based on a varied amount of hyperflexion, hyperextension, or vertical loadings that require great stability of the spine (Kruse & Lemen, 2009). Some skills, such as moving to and from the back-bend position from feet to hands or holding the handstand with a deep back-bend position, require repetitive hyperflexion and hyperextension of the trunk (Sands et al. 2016). Other skills, such as mounting, holding, and dismounting pyramids or catching, pitching and throwing in dynamic skills, require stability of the spine. Such specific spinal loads require monitoring of the posture of acrobats to detect possible postural abnormalities or diseases. To perform at a high level and meet the high technical demands, acrobatic gymnasts need to undertake sport training at a very young age and train for many hours (Vernetta-Santana et al., 2022). At competitive levels, acrobatic gymnasts frequently train for 4 to 6 hours per day, 5 to 6 days per week.

Previous research related to the shape and mobility of the spine or posture in gymnasts has focused on female and male artistic gymnastics athletes (Grabara, 2010; Radaković et al., 2016; Sanz-Mengibar et al., 2018), rhythmic gymnastics (Tanchev et al., 2000; Kums et al., 2007) and trampoline gymnastics (Sainz de Baranda et al., 2009; Sainz de Baranda et al., 2010; Grapton et al., 2013). Studies on this topic have rarely been conducted in acrobatic gymnastics. The exception is the study by Anwajler et al. (2005), in which one of the objectives was to assess the impact of acrobatic training on the mobility of the spine. The lack of studies indicating whether practicing acrobatic gymnastics affects the shape of the sagittal curvature of the spine prompted us to take up this topic.

The aim of this descriptive study was to assess and compare the shape of the spine in the sagittal plane in acrobatic gymnasts of both sexes and their associations with somatic and demographic variables.

2. Methods

2.1. Participants and study design

The study was approved by the Bioethics Committee at Rzeszow University, Poland (No. 10/6/2017) and followed by the guidelines of the Declaration of Helsinki.

This study was conducted during the European Age Group Competitions and the European Acrobatic Championships held in Poland. Participants of this study competed in all age groups (Age Groups 11–16, Age Groups 12–18, Juniors, and Seniors) and event categories provided by the FIG and UEG regulations. After prior approval of the study by the European Union of Gymnastics Technical Committee and local organizing committee, 667 gymnasts were invited to participate in this study.

The inclusion criteria were as follows: participation in the European Age Group Competitions or the European Championships in acrobatic gymnastics; written consent of the official or coach of the national team; and voluntary consent of the gymnasts.

The gymnasts' participation in the study was approved by the officials or coaches of the 16 national teams. After giving informed and voluntary consent to participate, 178 gymnasts joined the study. The exclusion criteria were age over 19 years and less than 3 years of training experience. For the final analysis, the results of 159 athletes aged 12–19 (with a mean age of 15.7 ±2.0, training experience of 7.4 ±2.7, and age of starting training of 8.3 ±2.3 years) were used.

The measurement protocol consisted of surveys, measurements of somatic variables (weight, height, percentage of body fat, estimated percentage of muscle), and measurements of the inclination at four topographic points of the spine (S1 vertebra and the intervertebral spaces L5/S1, Th12/L1, and C7/Th1).

2.2. Demographic and somatic variables

The survey and all measurements were taken during pre-competition training sessions. The tool used in the study was a questionnaire containing personal data including gender, age, training experience, country, role in a pair or acrobatic group and the category of competition in which they compete.

The somatic variables that were measured were body height, weight, total body fat percentage (Fat%), and predicted muscle mass percentage (PMM%). Gymnasts were measured barefoot, in competition attire or in a T-shirt and shorts. The body height measurement was made in accordance with the FIG rules (FIG, 2016) and with an accuracy of 0.1 cm. Each subject was in a lying position (on a line marked on the table) with the feet resting against the vertical wall, as presented in Figure 1.

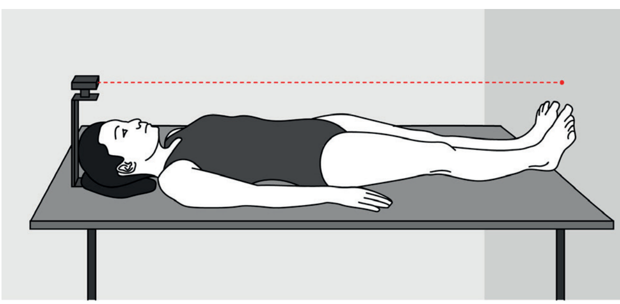

Figure 1. Body position during height measurement according to International Gymnastics Federation standards

Measurement was made with an electronic laser length measuring device (Bosch professional GLM 50 C; Robert Bosch GmbH, Germany) attached to a tripod so that the end of the device and the top of the gymnast's head were in the same vertical plane. The measurement result was a horizontal distance from the top of the gymnast's head to the wall, against which her/his feet were resting (FIG, 2016).

Weight was measured by a four-contact body composition analyzer, the Tanita MC-780MA S (Tanita Corporation, Tokyo, Japan), with an accuracy of 0.1 kg. Measurements made with the bioelectrical impedance method using GMON software (Medizin & Service, Chemnitz, Germany) provided, among others, values of total body fat percentage (Fat%) and predicted muscle mass percentage (PMM%).

2.3. Measurements and assessment of the shape of spinal curvatures

Among the available methods for measuring the size of the sagittal curvatures of the spine, the inclinometer method was chosen. The advantages of this method are its non-invasiveness, low costs and the short time needed to obtain objective results determining the size of sagittal curvatures as well as spine mobility. Numerous authors (Saur et al., 1996; Czaprowski et al., 2012; Muyor et al., 2013; Walicka-Cupryś et al., 2018) have shown high reliability and the usefulness of this tool in both clinical assessments and screening examinations.

The spinal curvatures were measured by the Baseline® Bubble Inclinometer (Fabrication Enterprices Inc., New York, USA) with an accuracy of 2 degrees. The measurements were carried out by a physiotherapist with 15 years of professional experience in body posture testing in accordance with the methodology proposed by Walicka-Cupryś & Drużbicki (2016). Each gymnast was asked to stand in a relaxed, habitual posture with bare feet, lower limbs hip-width apart, and upper limbs freely alongside the torso (Walicka-Cupryś & Drużbicki, 2016). The following oral instructions were given: "stand in a comfortable manner"; "do not bend your knees"; and "look straight". The subjects were not instructed to straighten up (MacIntyre et al. 2014; Walicka et al. 2018). During the measurements, the inclinometer was placed at four topographic points of the spine (presented in Figure 2) found by palpation. The inclinometer was targeted vertically and the measurement observation was carried out perpendicular to the device.

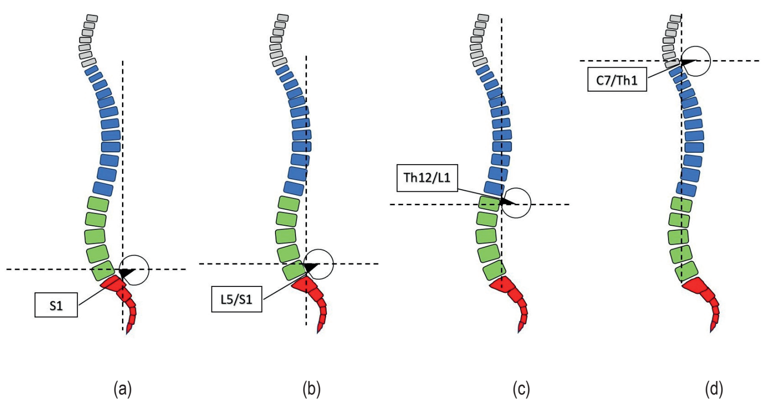

Figure 2. Inclinometer measurements at four topographic points of the spine: (a) midpoint of the S1 vertebra; (b) L5 and S1 intervertebral space; (c) Th12 and L1 intervertebral space; (d) C7 and Th1 intervertebral space

The four angles of inclination were determined:

- ALPHA 1 – the sacral slope angle (the center of the inclinometer was placed on the midpoint of the S1 vertebra in the line connecting the lower aspects of the posterior superior iliac spines);
- ALPHA 2 – the angle of inclination of the lumbosacral junction (the center of the inclinometer was placed on the L5/S1 intervertebral space in line connecting so-called Venus dimples);

– BETA – the angle of inclination of the thoracolumbar junction (the center of the inclinometer was placed on the Th12/L1 intervertebral space);
– GAMMA – the angle of inclination of the cervicothoracic junction (the top of the inclinometer foot was placed on the C7 vertebra).

The measurement was performed three times at each point, and then the extreme values were discarded. Middle measurement values were used to calculate the angle of the sacral slope (SS), the lumbar lordosis (LL), and the thoracic kyphosis (TK) by the following formulas:

$$SS = ALPHA\ 1 \qquad (1)$$

$$LL = ALPHA\ 2 + BETA \qquad (2)$$

$$TK = BETA + GAMMA \qquad (3)$$

To determine the sexual dimorphic differences in the range of the analyzed variables, the so-called dimorphism index (DI) based on Mollison's method (Ziółkowska et al., 2012), which was calculated according to the formula:

$$DI = (M_F - M_M) / sd_M \qquad (4)$$

Where: DI – Dimorphic index; M_F – Mean value of females; M_M – Mean value of males; sd_M – standard deviation of males.

For the assessment of spinal curvatures, the following ranges were used: 15°–30° for SS and 30°–40° for LL and TK (Saunders & Stultz, 1994). The values of angles less than the lower limit of the above ranges were interpreted as flattened curvature and those greater than the upper limit as increased curvature.

The differences in angular values of LL and TK were used for determining Wolański's types of body posture, modified by Zeyland-Malawka (Zeyland-Malawka, 1999). The following evaluation criteria were used:

– the equivalent type (E) - the difference between TK and LL in the range from 0 to 5° with subtypes: 0–2° = E I, 3–4° = E II, and 5° = E III.
– the lordotic type (L) in which LL was greater than TK by over 5° with subtypes: 6–10° = L I, 11-15° = L II, and 16–20° and above = L III.
– the kyphotic type (K) in which TK was greater than LL by over 5° with subtypes: 6–10° = K I, 11-15° = K II, and 16–20° and above = K III.

The body posture subtypes in which the difference between the values of LL and TK did not exceed 10 degrees were considered correct. The subtypes in which the difference was 11 or more degrees were classified as incorrect.

2.4. Statistical analysis

The normality of variable distributions was verified with the Shapiro-Wilk test and the homogeneity of variable variances with the Levene test. It was found that the assumptions of a normal distribution of the analyzed variables and homogeneity of variance in some variables were not met. In addition, the lack of equality among the subjects in the compared groups decided on the choice of the non-parametric Mann-Whitney U test. This test was used to assess differences in the values of quantitative variables between the groups. To determine the potential impact of age, training experience, and somatic variables on the angular value of the spinal curvatures, Pearson's r correlation coefficient or the Spearman correlation coefficient was applied. Differences among categorical variables were evaluated using the Pearson chi-square test.

All statistical analyses were performed using Statistica 13.0 (TIBCO Software Inc., Palo Alto, California, CA, USA) and Microsoft Office 365 (Redmont, Washington, DC, USA). The level of significance was set at α = 0.05.

3. Results

3.1. Analysis of age, training experience, and somatic variables

In the group of gymnasts included in the final analysis, 106 (67%) were females and 53 (33%) were males. Considering the role played in the acrobatic pairs or groups, the female group contained 48 (45%) "tops" and 58 (55%) "bases", and the male groups contained 14 (26%) "tops" and 39 (74%) "bases".

The female gymnasts represented 15 countries: Austria (n = 12), Azerbaijan (n = 1), Belarus (n = 10), Belgium (n = 6), Bulgaria (n = 3), Estonia (n = 4), Finland (n = 6), France (n = 13), Germany (n = 3), Italy (n = 9), Poland (n = 24), Portugal (n = 1), Spain (n = 4), Switzerland (n = 1), and Ukraine (n = 9). The male gymnasts represented 13 countries: Austria (n = 1), Azerbaijan (n = 2), Belarus (n = 8), Belgium (n = 6), Estonia (n = 1), France (n = 2), Germany (n = 2), Israel (n = 2), Italy (n = 1), Poland (n = 12), Spain (n = 1), Switzerland (n = 1), and Ukraine (n = 14).

The data collected in this study were used to compare age, training experience and somatic variables across groups based on sex. The results of these analyses are presented in Table 1.

Table 1. Baseline demographic and somatic characteristics of the sex groups

Variables	Group	n	M	sd	Min–Max	p	DI
Age (years)	Females	106	15.3	1.9	12.1–19.6	0.001*	–0.60
	Males	53	16.5	2.0	12.0–19.7		
Training experience (years)	Females	106	7.2	2.6	3.0–15.0	0.129	–0.25
	Males	53	7.9	2.8	3.0–14.0		
Height (cm)	Females	106	158.3	9.8	134.0–177.0	≤ 0.001*	–1.00
	Males	53	170.7	12.3	141.0–186.0		
Weight (kg)	Females	106	48.4	12.2	27.3–77.6	≤ 0.001*	–1.00
	Males	53	63.4	14.9	32.5–84.5		
Fat%	Females	106	19.25	3.27	11.20–28.10	≤ 0.001*	1.91
	Males	53	12.49	3.54	4.50–19.20		
PMM%	Females	106	76.63	3.09	68.30–84.31	≤ 0.001*	–1.91
	Males	53	83.07	3.37	76.81–90.83		

Note: *M* – mean; *sd* – standard deviation; *Min–Max* – minimum and maximum values; *DI* – dimorphism index; *p* – Mann–Whitney U test probability value. * – Differences were found to be statistically significant when $p \leq .05$.

Significant differences were noted between gender groups in terms of age and all somatic variables. The difference in training experience was not statistically significant. The mean values of age, height, weight and PMM% were higher in males than in females. Only the value of Fat% was higher in females than in males. The dimorphic index data suggest that the biggest variations between sexes were found in Fat% and PMM%.

3.2. Analysis of the spinal curvatures and their relations with demographic and somatic variables

Four angles of spinal inclination were determined: ALPHA 1, ALPHA 2, BETA and GAMMA. The values of these angles were substituted into formulas (1), (2), and (3) to calculate the sizes of SS, LL, and TK. The comparison of descriptive statistics for these variables is presented in Table 2.

Table 2. Descriptive statistics of the angles of spinal inclination and curvatures of the spine

Variables	Group	n	M	sd	Min–Max	p	DI
ALPHA 1 (°)	Females	106	19.9	5.1	8–30	0.019*	0.37
	Males	53	17.6	6.2	4–32		
ALPHA 2 (°)	Females	106	18.4	5.6	4–32	0.001*	0.52
	Males	53	15.4	5.8	6–30		
BETA (°)	Females	106	12.0	6.5	2–30	0.066	0.35
	Males	53	10.0	5.7	0–26		
GAMMA (°)	Females	106	20.4	5.9	8–34	≤ 0.001*	–0.56
	Males	53	24.0	6.4	4–40		
SS (°)	Females	106	19.9	5.1	8–30	0.019*	0.37
	Males	53	17.6	6.2	4–32		
LL (°)	Females	106	30.3	8.8	12–52	0.001*	0.73
	Males	53	25.4	6.7	14–46		
TK (°)	Females	106	32.4	10.4	10–60	0.301	–0.16
	Males	53	34.0	10.2	10–66		

Note: ALPHA 1 – angle of inclination of the sacrum on S1 vertebra; ALPHA 2 – angle of inclination of the lumbosacral junction; BETA – angle of inclination of the thoracolumbar junction; GAMMA – angle of inclination of the cervicothoracic junction; SS – the sacral slope angle; LL – the lumbar lordosis angle; TKA – the thoracic kyphosis angle; *M* – mean; *sd* – standard deviation; Min–Max – minimum and maximum values; *p* – Mann–Whitney U test probability value; *DI* – dimorphism index;. * – Differences were found to be statistically significant when $p \leq 0.05$.

This data presented in Table 2 indicate that statistically significant sex differences were noted in the angles of inclination at all measured points of the spine, with the exception of the BETA angle. A sex comparison of spinal curvatures showed that the angular values of SS and LL were higher in females than in males. The mean values of TK turned out to be slightly higher in the male group, but this difference was not statistically significant. The values of dimorphic indexes suggest that the angle of LL has the greatest difference between sexes.

The relations between the angular values of each spinal curvature and the values of age, training experience, and somatic variables were calculated. Correlation coefficients across sex groups are presented in Table 3.

Table 3. Correlations between angular values of spine curvatures and age, training experience, and somatic variables

Group	Spinal curvature	Age	Training experience	Height	**Weight**	**Fat%**	**PMM%**
Females	SS	**0.303***	**0.311***	0.047	0.127	–0.046	0.050
	LL	**0.233***	0.155	**0.240***	**0.303***	0.182	–0.178
	TK	0.084	–0.000	**0.224***	**0.275***	**0.360***	**–0.360***
Males	SS	0.117	**0.294***	**–0.290***	–0.114	0.180	–0.184
	LL	0.136	–0.002	–0.056	0.006	0.071	–0.068
	TK	0.130	0.010	0.265	**0.359***	0.188	–0.181

Note: * - Differences were found to be statistically significant when $p \leq .05$.

Only weak correlations between the size of spinal curvatures and the analyzed variables were noted. In females, the angle of SS was positively correlated with age and training experience, and the angle of LL with age, height, and weight. The angle of TK was positively correlated with height, weight, and Fat%, and negatively correlated with PMM%. The highest value of the correlation coefficient was noted in the relations between TK and Fat% as well as between TK and PMM%.

In males, the value of SS was positively correlated with training experience and negatively with height, and the angle of TK was positively correlated with weight only. The highest value of the correlation coefficient was noted in the relations between TK and weight.

3.3. The assessment of sagittal curvatures of the spine and body posture

To classify the analyzed curvatures of the spine as flattened, normal, or increased, the Saunders standards were used. The prevalence of normal and pathological (flattened or increased) curvatures of the spine is shown in Figure 3.

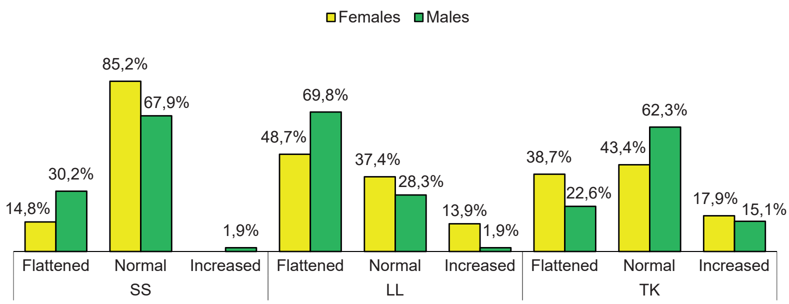

Figure 3. Percentage distributions of normal and pathological angular values of spinal curvatures in the sex groups

Note: SS – the sacral slope; LL – the lumbar lordosis; TK – the thoracic kyphosis.

The results presented above (Figure 4) indicate that in gymnasts of both sexes, the normal SS, flattened LL, and normal TK were noted as the most frequent. The prevalence of flattened SS and LL was more frequent in males, and flattened TK was more frequent in females. Increased SS was more frequent in males, and LL and TK in females.

Based on Pearson's chi-square test of independence, the prevalence of flattened, normal, or increased angles of SS (x^2 = 7.062; p = 0.008) as well as LL (x^2 = 9.520; p = 0.009) significantly differed between females and males. The prevalence of flattened, normal, or increased angles of TK did not differ between sexes (x^2 = 5.425; p = 0.066).

The difference between the angular values of LL and TK was used to classify the types and subtypes of body posture that characterized the acrobatic gymnasts. Comparison of the percentage distributions of body posture types and subtypes considering sex is presented in Figure 4.

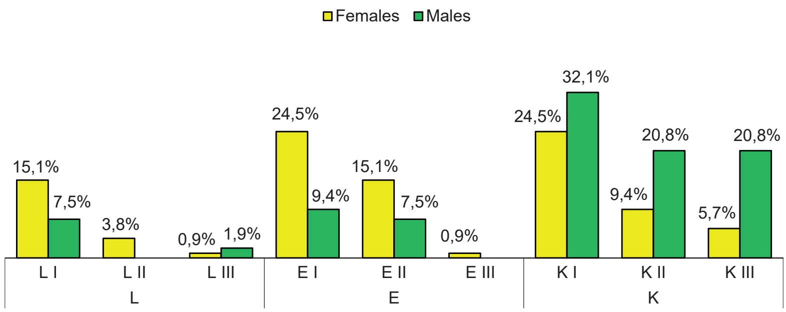

Figure 4. The percentage distributions of body posture types in the sex groups

Note: E is the equivalent type of posture with subtypes I, II, and III; K is the kyphotic type of posture with subtypes I, II, and III; and L is the lordotic type of posture with subtypes I, II, and III.

The analysis of body posture types showed that the lordotic type was found in 19.8% of females and 9.4% of males, the equivalent type in 40.5% of females and 16.9% of males, and the kyphotic type in 39.6% of females and 73.7% of males. Body posture subtypes E I, E II, E III, L I, and L II were more frequent in females, and K I, K II, K III, and L III in males.

According to Wolański's typology, modified by Zeyland-Malawka, it was assumed that subtypes E I, E II, E III, K I, and L I mean correct posture, and subtypes K II, K III, L II, and L III mean incorrect posture. The incorrect body posture was found in 43.4% of males (n = 23, including 4 "tops" and 19 "bases") and 19.8% of females (n = 21, including 7 "tops" and 14 "bases"). The prevalence of correct posture was more frequent in females (n = 85; 80.2%) than in males (n = 30; 56.6%). Based on Pearson's chi-square test of independence, the prevalence of correct or incorrect body posture in standing position was significantly differentiated by sex (x^2 = 9.820; p = 0.002).

4. Discussion

This descriptive study shows the characteristics of the shape of the spinal curvatures in sagittal planes in acrobatic gymnasts with a training experience of more than 3 years who competed at the international level. We also analyzed the differences in relations between spinal curvatures and age, training experience, and somatic variables in the compared groups.

Previous studies confirm that excessive physical exercise can have a negative effect on immature bone morphology and its mechanical integrity and may lead to the formation of postural disorders (Kruse & Lemmen, 2009; Grabara, 2010; Makovitch & Eng, 2020). Understanding the problem of how sport training affects the shape of the spine in young athletes is important because, over years of practicing sports, changes in their bodies become permanent and affect the next stages of ontogenesis. Any uncorrected deviations within the spine may lead to lower back pain, spine injuries, and overloading of the musculoskeletal system (Kruse & Lemen, 2009). This is because a reduction or increase in spinal curvatures may damage the different elements that make up the functional unit of the spine, such as vertebrae, intervertebral discs, ligaments, and muscles (Sainz de Baranda et al., 2010). These risks are especially relevant when sports training is undertaken in early childhood, such as in acrobatic gymnastics.

Previous studies have shown that one integral component of postural assessment is the measurement of pelvic position in the sagittal plane due to its significant association with pathologies in the spine and lower limbs (Schmidt et al., 2018). The physiological pelvic tilt in a relaxed standing position is approximately 14° (0–23°) on average (Preece et al., 2008) and is dependent on the structure of the pelvis and the action of muscular and ligament forces acting between the pelvis and the surrounding structures. It is closely related to the course of curvatures of the spine, which are responsible, among others, for the amortization of axial loads (Schmidt et al., 2018; Preece et al., 2008). In this study, the position of the pelvis was determined on the basis of the angle of the SS, which was significantly larger in females than in males. The prevalence of flattened, normal, or increased angles of SS differed between females and males. The normal SS was more frequent in females than in males, and the flattened SS was more frequent in males than in females. The increased SS was noted only in 1.9% of males. Similar correlations were found by Muyor et al. (2013) who noted that female tennis players aged 13-18 had a significantly larger SS than males (20.94° ±5.36° vs. 13.38° ±5.57°). The female acrobatic gymnasts also had a lower angle of SS compared to elite rhythmic gymnasts aged 13–17, whose SS was 23.1° ±7.6° (Kums et al. 2007).

In many studies, the basis for posture assessment is the size of the LL and TK. This is because the shape of the LL is associated with the appropriate distribution of shear and compression forces and the protection of the lumbosacral spine against overload. In turn, the shape of the TK is of key importance for the proper mobility of the chest and, consequently, for the efficiency of the circulatory and respiratory systems. It also plays an important role in the rotational stabilization of the spine (Czaprowski et al., 2012). Previous studies show that there are some gender patterns in the development of LL and TK in the growing spine. Gardner et al. (2018) showed that between males and females there is a difference in the size of LL (females have a greater LL versus males at the same age), but no difference in the size of TK. This study of 194 children aged 5–16 concluded that the size of LL and TK increases in a nonlinear fashion with age.

The results of our study show similar sex regularities. We noted that the LL angles were significantly higher in females than in males, but the TK angles were very close in both sexes. Such differences are partially consistent with those found by Sanz Mengibar et al. (2018) in the study conducted with an international group of 47 artistic gymnasts. They noted that LL was greater in females than males (30.5° ±11.1° versus 27.8° ±10.7°), but TK was greater in males than females (39.7° ±6.7° versus 31.9° ±8.7°). The difference between the sex groups in artistic gymnasts is close to that obtained in our study in LL, but much greater in TK. The study by Sainz de Baranda et al. (2009) of 69 trampoline gymnasts also shows that females tend to have a greater LL and males a greater TK. The female trampoline gymnasts were characterized by 40.3° ±10.0° of LL and 43.1° ±8.9° of TK and the male group by 32.1° ±7.7° of LL and 46.9° ±7.1° of TK. Also in this study, the angular values of LL and TK were greater in both men and women than those obtained in the gender groups of acrobatic gymnasts.

We also verified whether the size of spinal curvatures is related to the values of demographic or somatic variables. The previous studies (Wojtys et al., 2000; Stošić et al., 2011; Sanz-Mengibar et al., 2018) showed a positive correlation between LL and TK with the length of training experience, but in acrobatic gymnasts, such a relation was not found. There was only a weak positive correlation between the length of training experience and the size of the SS in both sexes. Age was positively correlated with SS and LL only in females. Body height was correlated positively with LL and TK size in females and negatively with the size of SS in males. Weight was positively correlated with the size of LL in females and with the size of TK in both sexes. It was found that only in females, the size of TK was correlated positively with Fat%, and negatively with PMM%. Similar relations have been reported by Mauricienė & Bačiulienė (2018), who found that in the group of non-athletes aged 11–13, height was correlated with the angle of TK in both sexes. Weight and fat mass were correlated with LL only in males and with TK in both sexes. Tizabi et al. (2012) noted that in the group of boys aged 12–18, weight was correlated with LL and TK, and height with TK only. Taspinar et al. (2017) found that in young adults aged 18–25, LL and TK angles had a positive relation with body fat ratio and a negative relation with muscle ratio.

The results presented in this study showed that sex significantly differentiates the prevalence of flattened, normal, or increased sizes of SS and LL. The prevalence of correct and incorrect sizes of TK is not sex-dependent. Normal SS, normal TK, and flattened LL (with the lowest value of 12° in females and 14° in males) were the most frequent in both sexes. The opposite findings were noted in a study of trampoline gymnasts, where normal LL and increased TK were the most frequent (Sainz de Baranda et al., 2009). The presented study may suggest that acrobatic gymnasts are not at risk of increasing their LL or TK. Such a problem was noted, for example, in a study by Wojtys et al. (2009), who observed that the athletes practicing gymnastics had the highest values of both LL (52.1° ±16.7°) and TK (42.4° ±13.4°) when compared with athletes practicing other sports. They observed that athletes aged 8–18 years who practiced soccer, gymnastics, hockey, swimming, and wrestling had higher values of LL and TK compared to those who practiced athletics or volleyball. These scientists also noted that age and sex did not appear to affect the size of spinal curvatures, but athletes participating in sports that required long-term maintenance of rigorous body positions were at higher risk of thoracic hyperkyphosis (Wojtys et al. 2000).

But it should be emphasized that so far, despite many attempts, it has not been possible to identify unambiguous normative ranges for the size of the sagittal curvatures of the spine and to clearly define the norm and pathology. In addition, the matter is complicated by the variety of measurement tools and methods used (Walicka-Cupryś et al., 2018). Different studies used different normative ranges for LL and TK in standing positions. In the radiographic and photogrammetric assessments, the range of 20−40 or 20−45 degrees for LL and TK is taken as norm (Wojtys et al., 2000; Sanz-Mengibar et al., 2018). When the assessment is based on the inclinometer measurements, the normative range 30−40 degrees is assumed (Saunders 1994).

The last comparisons of the sex groups concerned the typology of body posture, which was based on differences in the values of LL and TK. We noted that the equivalent and lordotic types of body posture were more frequent in females and the kyphotic type in males. Such results may indicate a more frequent occurrence of body posture errors in male gymnasts, associated with an increased angle of TK. However, in most of the subjects, the kyphotic type of body posture resulted from flattened LL, not increased TK. This study provides important information that indicates that long-term involvement in competitive acrobatic gymnastics increases the risk of flattening lordosis, especially in males.

The kyphotic posture was also the dominant type of body posture in athletes practicing sports other than gymnastics. Twarowskia-Grybałow & Truszczyńska-Baszak (2023) compared in their work the habitual posture of 247 athletes aged 9–14 and practicing various sports by using the Moiré method and a modified typology of Wolański. They noted that the kyphotic posture was less frequent in females than in males who practiced biathlon, taekwondo, football, and swimming. In the group of volleyball players, an equivalent posture was dominant. The tendency to flatten LL in acrobatic gymnasts may be related to the large amount of time spent in training on improving dance skills and mastering choreography in their routines. Previous studies have shown that in sports related to dancing abilities, the angular values of TK tend to be much lower than in other types of sports (Kums et al., 2007; Sainz de Baranda et al., 2020), and the size of LL and TK is smaller in people with longer dance experience (Castillo & Obregón, 2018).

The health consequences of such an abnormality have been demonstrated in previous studies. Kluszczyński et al. (2017) noted that reduction of LL can be a risk factor for lower back pain or degenerative spinal pathologies, particularly in men. This is because the lumbar section, as the base of the spine, takes over all the axial loads of the trunk and, at the same time, with high intersegmental mobility, it is exposed to non-physiological vectors of forces and overloads. Flattening of the LL may lead to degenerative and traumatic changes associated with the physiological processes of intervertebral disc degeneration and osteoporosis, as well as sudden damage to the fibrous ring with hernias. The lumbar region borders a very stiff pelvic girdle and sacroiliac joints, which causes shear force vectors to concentrate on the border between the movable and immobile parts, i.e., on the L5/S1 segment. This place is predisposed to the occurrence of damage to the intervertebral joints, spondylolisthesis, and even overload fractures of the intervertebral part of the vertebral arch (Kluszczyński et al., 2017; Gardner et al., 2018).

The results presented in this paper can provide evidence of the effectiveness of the FIG and the global gymnastics community's efforts to promote the proper development of young people who practice gymnastics. As in other sports of gymnastics, the FIG constantly modifies the official rules and the Code of Points applicable in acrobatic gymnastics (FIG, 2022a). In recent years, there has been a noticeable reduction in the emphasis on the extreme ROMs required of acrobats and their replacement with poses that emphasize the natural flexibility of the spine performed in partnering and choreographic combinations. The current demands of acrobatic gymnastics place less emphasis on extreme ROMs in poses, postures and skills while increasing the physical demands for strength and stability of the spine (Sands et al., 2016). The official FIG rules that govern competition in acrobatic gymnastics contain restrictions on exercises that could increase the risk of hyperlordosis and spinal injuries. These prohibitions take into account the different nature of spinal overload that occurs in "tops" and "bases". And so, the ban directed mainly at the "tops" applies to handstands with excessive arching of the back, in which the feet are lower than the point of hand support and Mexican handstands with gluteal muscles or legs resting on the head (FIG, 2022a). Restrictions aimed at the "bases" apply to the competition of age groups and juniors, i.e., gymnasts aged 11–19 years. The competition rules for these categories prohibit the following balance elements for groups: standing in a column of at least three gymnasts; standing on the shoulders with the "base" in split without hands on the floor; standing on the hips and chest of the "bases", which is in bridge with only two points of support; and support on the hips or buttocks with the "base" in excessive LL (FIG, 2022b).

However, while the direction of development of acrobatic gymnastics set by the FIG is correct, it should still take into account the risk of the negative impact of practicing this sport on the immature spine and body posture of young gymnasts. The fact that this problem in high-level acrobatic gymnasts is still present is confirmed by the results of the body posture assessment, which showed that incorrect body posture was present in 19.8% of females and 43.4% of males. Such findings show that coaches and medical staff working in competitive acrobatic gymnastics, should still remember that the spine of young athletes is in a very vulnerable stage of development. The planning of the training process should be approached with respect to the principles of growth and development.

The value of our study lies in the use of a new method of measuring body height, proposed by the FIG. It is also worth emphasizing that the presented study is the first to be devoted entirely to the sagittal shape of the spine in acrobatic gymnasts. This study was limited by the disproportion between the number of subjects in the sex-based groups. However, it reflects the typical proportion in the acrobatic gymnast population, where women are always the majority. Future research should be done with groups of comparable numbers of female and male gymnasts so that the results of comparisons become more reliable. Another limitation was that measurements of spinal curvatures were performed only in a relaxed standing position, which resulted from the limited time that gymnasts could devote to our study. The possibility of performing additional measurements, e.g., assessing the ROMs of the spine or performing three-dimensional assessment of the spine, would certainly provide new, interesting results. Therefore, we hope that further research on the shape of the spine and body posture in acrobatic gymnasts will include a larger range of measurements. It is certainly worth making an attempt to perform a long-term study that would show how the shape of the spine changes in acrobatic gymnasts over the years of training.

5. Conclusions

This study shows that in acrobatic gymnasts females had higher angular value of sacral slope and lumbar lordosis than males, and a similar value of thoracic kyphosis. Training experience positively correlates only with the size of the sacral slope in both sexes. Only in females weak-strength correlations between somatic variables and the size of spinal curvatures were found. Sex significantly differentiates the prevalence of incorrect size of sacral slope and lumbar lordosis. The equivalent and lordotic type of body posture was more frequent in females and kyphotic type in males. The incorrect body posture was noted in 19.8% of females and 43.4% of males.

It can be concluded that acrobatic gymnasts are not at risk of increasing the size of spinal curvatures in the sagittal plane but males show a tendency to flattened lumbar lordosis and kyphotic type of body posture.

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References

Anwajler, J., Wojna, D., Stepak, A., & Skolimowski, T. (2005). The influence of sports acrobatic training on the range of mobility of the spine and the upper and lower extremities. *Polish Journal of Physiotherapy, 5*(1), 57–64.

Castillo, E. D., & Obregón, R. (2018). Assessment of the sagittal spinal curvatures in dancers of Spanish dance. *Journal of Human Sport and Exercise*, *13*, 129–137. https://doi.org/10.14198/jhse.2018.131.13

Czaprowski, D., Pawłowska, P., Gębicka, A., Sitarski, D., & Kotwicki, T. (2012). Intra- and interobserver repeatability of the assessment of anteroposterior curvatures of the spine using Saunders digital inclinometer. *Ortopedia, traumatologia, rehabilitacja*, *14*(2), 145–153. https://doi.org/10.5604/15093492.992283

Czaprowski, D., Pawłowska, P., Kolwicz-Gańko, A., Sitarski, D., & Kędra, A. (2017). The Influence of the "Straighten Your Back" Command on the Sagittal Spinal Curvatures in Children with Generalized Joint Hypermobility. *BioMed research international*, *2017*, 9724021. https://doi.org/10.1155/2017/9724021

Drzał-Grabiec, J., Snela, S. & Truszczyńska, A. (2016).The development of anterior-posterior spinal curvature in children aged 7–12 years. *Biomedical Human Kinetics*, *8*(1), 72–82. https://doi.org/10.1515/bhk-2016-0011

FIG. (2016). Acrobatic Gymnastics Code of Points 2017–2020 (vs 09.06.2016). Retrieved from: https://www.gymnastics.sport (Accessed on 15.07.2017).

FIG. (2022a). Acrobatic Gymnastics Code of Points, Table of Difficulty 2022–2024. Retrieved from: https://www.gymnastics.sport/site/rules/#8 (Accessed on 20.10.2022).

FIG. (2022b). Acrobatic Gymnastics Age Group/Junior Rules 2022–2024. Retrieved from: https://www.gymnastics.sport/site/rules/#8 (Accessed on 20.10.2022).

Gardner, A., Berryman, F., & Pynsent, P. (2018). The Development of Kyphosis and Lordosis in the Growing Spine. *Spine*, *43*(19), E1109–E1115. https://doi.org/10.1097/BRS.0000000000002654

Grabara, M. (2010). Postural variables in girls practicing sport gymnastics. *Biomedical human kinetics, 2*(2), 74–77. https://doi.org/10.2478/v10101-0018-6

Grabara, M., Bieniec, A., & Nawrocka, A. (2017). Spinal curvatures of children and adolescents—A cross-sectional study. *Biomedical human kinetics, 9*, 69–74. https://doi.org/10.1515/bhk-2017-0011

Grapton, X., Lion, A., Gauchard, G. C., Barrault, D., & Perrin, P. P. (2013). Specific injuries induced by the practice of trampoline, tumbling and acrobatic gymnastics. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA*, *21*(2), 494–499. https://doi.org/10.1007/s00167-012-1982-x

Keller, T. S., Colloca, C. J., Harrison, D. E., Harrison, D. D., & Janik, T. J. (2005). Influence of spine morphology on intervertebral disc loads and stresses in asymptomatic adults: implications for the ideal spine. *The spine journal : official journal of the North American Spine Society*, *5*(3), 297–309. https://doi.org/10.1016/j.spinee.2004.10.050

Kluszczyński, M., Wąsik, J., Ortenburger, D., Zarzycki, D., & Siwik, P. (2017). Prognostic value of measuring the angles of lumbar lordosis and thoracic kyphosis with the Saunders inclinometer in patients with low back pain. *Polish annals of medicine*, *24*, 31–35. https://doi.org/10.1016/j.poamed.2016.10.001.

Kruse, D. W., & Lemmen, B. (2009). Spine Injuries in the Sport of Gymnastics. *Current Sports Medicine Reports*, *8*, 20–28. https://doi.org/10.1249/JSR.0b013e3181967ca6

Kums, T., Ereline, J., Gapeyeva, H., Pääsuke, M., & Vain, A. (2007). Spinal curvature and trunk muscle tone in rhythmic gymnasts and untrained girls. *Journal of Back and Musculoskeletal Rehabilitation*, *20*(2–3), 87–95. https://doi.org/10.3233/BMR-2007-202-306

López-Miñarro, P. Á., Vaquero-Cristóbal, R., Alacid, F., Isorna, M., & Muyor, J.M. (2017). Comparison of sagittal spinal curvatures and pelvic tilt in highly trained athletes from different sport disciplines. *Kinesiology*, *49*(1), 109–116. https://doi.org/10.26582/K.49.1.2

MacIntyre, N. J., Lorbergs, A.L., Adachi, J.D. (2014). Inclinometerbased measures of standing posture in older adults with low bone mass are reliable and associated with self-reported, but not performance-based, physical function. *Osteoporosis International*, *25*(2), 721–728. https://doi.org/10.1007/s00198-013-2484-5

Makovitch, S., & Eng, C. (2020). Spine Injuries in Gymnasts. In: E. Sweeney (ed.) Gymnastics Medicine. Evaluation, Management and Rehabilitation. Springer Nature. https://doi.org/10.1007/978-3-030-26288-4_8

Mauricienė, V., & Bačiulienė, K. (2018). Spine's Sagittal Plane Curves' Coherence with Anthropometric Parameters in Schoolchildren. *Baltic Journal of Sport and Health Sciences.*; n. pag. https://doi.org/10.33607/BJSHS.V3I57.635

Muyor, J. M., Sánchez-Sánchez, E., Sanz-Rivas, D., & López-Miñarro, P. A. (2013). Sagittal spinal morphology in highly trained adolescent tennis players. *Journal of sports science & medicine*, *12*(3), 588–593. PMID: 24149169

Preece, S. J., Willan, P., Nester, C. J., Graham-Smith, P., Herrington, L., & Bowker, P. (2008). Variation in pelvic morphology may prevent the identification of anterior pelvic tilt. *The Journal of manual & manipulative therapy*, *16*(2), 113–117. https://doi.org/10.1179/106698108790818459

Purnell, M., Shirley, D., Nicholson, L., & Adams, R. (2010). Acrobatic gymnastics injury: occurrence, site and training risk factors. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine*, *11*(2), 40–46. https://doi.org/10.1016/j.ptsp.2010.01.002

Radaković, M., Madić, D., Radaković, K., Protić-Gava, B., Radanović, D., & Marković, K. Ž. (2016). Comparison of posture between gymnasts and non-athletes. *Acta Kinesiologica*, *10*(1), 62–65.

Sainz de Baranda, P., Santonja, F., & Rodríguez-Iniesta, M. (2009). Valoración de la disposición sagital del raquis en gimnastas especialistas en trampolín. *Revista Internacional de Ciencias del Deporte*, *5*(16), 21–33. https://doi.org/10.5232/ricyde2009.016.02 [in Spanish]

Sainz de Baranda, P. S., Medina, F. S., & Rodríguez-Iniesta, M. (2010). Tiempo de entrenamiento y plano sagital del raquis en gimnastas de trampolín. *Revista Internacional de Medicina y Ciencias de la Actividad Fisica y del Deporte*, *10*, 521–536. [in Spanish]

Sainz de Baranda, P., Cejudo, A., Moreno-Alcaraz, V. J., Martinez-Romero, M. T., Aparicio-Sarmiento, A., & Santonja-Medina, F. (2020). Sagittal spinal morphotype assessment in 8 to 15 years old Inline Hockey players. *PeerJ.* 8:e8229. https://doi.org/10.7717/peerj.8229

Sands, W. A., McNeal, J. R., Penitente, G., Murray, S. R., Nassar, L., Jemni, M., Mizuguchi, S., & Stone, M. H. (2016). Stretching the Spines of Gymnasts: A Review. *Sports medicine (Auckland, N.Z.)*, *46*(3), 315–327. https://doi.org/10.1007/s40279-015-0424-6

Sanz-Mengibar, J. M., Sainz-de-Baranda, P., & Santonja-Medina, F. (2018). Training intensity and sagittal curvature of the spine in male and female artistic gymnasts. *The Journal of sports medicine and physical fitness*, *58*(4), 465–471. https://doi.org/10.23736/S0022-4707.17.06880-3

Saunders, H. D., & Stultz, M. R. (1994). Saunders Electronic Inclinometer Operator's Manual. Chaska, MN, USA: The Saunders Group.

Saur, P. M., Ensink, F.B., Frese, K., Seeger, D. & Hildebrandt, J. (1996). Lumbar range of motion: reliability and validity of the inclinometer technique in the clinical measurement of trunk flexibility. *Spine* 1:,1332–1338. https://doi.org/10.1097/00007632-199606010-00011

Schmidt, H., Bashkuev, M., Weerts, J., Altenscheidt, J., Maier, C., & Reitmaier, S. (2018). What does the shape of our back tell us? Correlation between sacrum orientation and lumbar lordosis. *The spine journal: official journal of the North American Spine Society*, *18*(4), 655–662. https://doi.org/10.1016/j.spinee.2017.11.005

Stošić, D., Milenković, S., & Živković, D. (2011). The influence of sport on the development of postural disorders in athletes. *Facta Universitatis, Series: Physical Education and Sport*, *9*(4), 375–384.

Taboada-Iglesias, Y., Santana, M. V., & Gutiérrez-Sánchez, Á. (2017). Anthropometric Profile in Different Event Categories of Acrobatic Gymnastics. *Journal of human kinetics*, *57*, 169–179. https://doi.org/10.1515/hukin-2017-0058

Tanchev, P. I., Dzherov, A. D., Parushev, A. D., Dikov, D. M., & Todorov, M. B. (2000). Scoliosis in rhythmic gymnasts. *Spine*, *25*(11), 1367–1372. https://doi.org/10.1097/00007632-200006010-00008

Taspinar, F., Saracoglu, I., Afsar, E., Okur, E. O., Seyyar, G. K., Kurt, G., & Taspinar, B. (2017). Assessing the Relationship between Body Composition and Spinal Curvatures in Young Adults. *Archives of Sports Medicine and Physiotherapy*, *2*(1), 010–015. https://doi.org/10.17352/asmp.000005

Tizabi, A. A.T ., Mahdavinejad, R., Azizi, A., Jafarnejadgero, T., & Sanjari M. (2012). Correlation between Height, Weight, BMI with Standing Thoracic and Lumbar Curvature in Growth Ages. *World Journal of Sport Sciences*, *7*(1), 54–56. https://doi.org/10.5829/idosi.wjss.2012.7.1.64109

Twarowska-Grybalow, N., & Truszczyńska-Baszak, A. (2023). The Sizes of Spine Curvatures of Children That Practice Selected Sports. *International journal of environmental research and public health*, *20*(3), 1826. https://doi.org/10.3390/ijerph20031826

UEG. (2016). Technical Regulation - Specific Rules – Acrobatic Gymnastics. Retrieved from the website of the European Union of Gymnastics, https://www.europeangymnastics.com/page/rules (Accessed on 15.06.2017)

Walicka-Cupryś, K., & Drużbicki, M. (2016). Methodology of gravitational inclinometer application in evaluation of anterior-posterior spinal curvature. *20th European Congress of Physical and Rehabilitation Medicine. Estoril – Lisbon*, 23–28.

Walicka-Cupryś, K., Wyszyńska, J., Podgórska-Bednarz, J., & Drzał-Grabiec, J. (2018). Concurrent validity of photogrammetric and inclinometric techniques based on assessment of anteroposterior spinal curvatures. *European spine journal: official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society*, *27*(2), 497–507. https://doi.org/10.1007/s00586-017-5409-8.

Wilczyński, J., Lipińska-Stańczak, M. & Wilczyński, I. (2020). Body Posture Defects and Body Composition in School-Age Children. *Children (Basel)*, 7(11), 204. https://doi.org/10.3390/children7110204.

Wojtys, E. M., Ashton-Miller, J. A., Huston, L. J., & Moga, P. J. (2000). The association between athletic training time and the sagittal curvature of the immature spine. *The American journal of sports medicine*, *28*(4), 490–498. https://doi.org/10.1177/03635465000280040801

Vernetta-Santana, M., Ariza-Vargas, L., Martínez-Patiño, M.J., & López-Bedoya, J. (2022). Injury profile in elite acrobatic gymnasts compared by gender. *Journal of human sport and exercise, 17*(4), 719–731. https://doi.org/10.14198/jhse.2022.174.01

Zeyland-Malawka, E. (1999).Classification and assessment of body posture in the modification of Wolanski method and New York Classification Test. *Fizjoterapia, 7*(4), 52–55. [in Polish]

Ziółkowska-Łajp, E., Demuth, A., Drozdowski, M., Czerniak, U., & Krzykała, M. (2012). The evaluation of sexual dimorphism of somatic features and body composition of young people doing water sports. *Antropomotoryka*, *59*, 79–90. [in Polish]

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