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Sex-related differences in the sagittal plane spinal angles in preschool and school-age children

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Abstract

Study aim: The study aimed to assess the differences in the magnitude of the anterior-posterior spinal curvatures depending on sex in children aged 5 and 9 years.

*Material and method*s: This prospective longitudinal observational study included 67 children (29 girls and 38 boys) in preschool-age and school-age phases (the first examination at 5 years old and the second examination at 9 years old). Measurements of body weight and height were recorded. The computerized assessment of body posture was performed with the photogrammetric method (MORA 4 Generation). The normality of the distribution of variables was assessed with the Shapiro-Wilk test. The Mann-Whitney U test was used to analyze the differences between the sexes in terms of body posture parameters and somatic parameters.

Results: There were no statistically significant sex-related differences in the values of parameters of the anterior-posterior spinal curvatures in 5-year-old children. In the group of 9-year-old children in the angle of lumbar lordosis, a significant difference between the sexes was found ($U = 387.00$, $p < 0.05$). Girls aged 9 had a significantly higher mean value of the angle of lumbar lordosis than boys at the same age ($p < 0.05$).

Conclusions: A sex-related difference was found in the magnitude of lumbar lordosis in school-age children. Understanding the gender differentiation of lumbar lordosis is the first step towards explaining the wide variability of normal lumbar lordosis in adults and the developmental and biomechanical differences between male and female lumbar spines.

Keywords: Posture – Photogrammetry – Children – Anteroposterior spinal curvatures

Introduction

Body posture is the alignment of its segments relative to each other in a certain way and relations between them. This is a motor habit that depends on the appropriate interplay between nervous, muscular, and skeletal systems. Body posture is constantly regulated by feedback reflexes, mainly due to proprioceptors located in muscles, tendons, and joint capsules. It is the proprioceptors that provide the central and peripheral nervous system with information about the tension and length of the muscles and the position of the trunk and limbs in relation to each other [20]. Abnormalities in the alignment of body segments or the cooperation of systems may cause postural defects [14].

Attention should be paid to the body posture's variability in phylogenetic and ontogenetic processes. In the posturogenesis processes, physiological curvatures of the spine are gradually formed. Sagittal posture evolution occurs between the ages of four and twelve and is thought to be a consequence of the normal maturation of the musculoskeletal system or an adaptation process to maintain balance in the sagittal plane [4]. Along with motor development, anterior-posterior spinal curvatures are formed, which are shaped under the influence of various internal and external forces. The mutual dependence and the magnitude of these curvatures also change as the child grows, from infancy to full maturity. Between the ages of 3 and 5, the dominance of thoracic kyphosis can be observed in body posture, while lumbar lordosis is constantly increasing. As a result of the weak tension of the muscles stabilizing the spine, the curvature of the spine is still unstable in children aged 6−7 years. Initially, thoracic kyphosis dominates the curvature system. Cervical lordosis stabilizes first around the age of 7. As the strength of the back muscles increases, around 8−11 years of life, there is an increase in lumbar lordosis [25, 27]. Thus, within the given age range, the child's posture undergoes a great transformation to achieve a balance in line with the proper body proportions [11].

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Body posture may become abnormal during the so-called critical periods of postural development. Research shows that a high risk of changes in body posture occurs during intensive developmental changes in a child (around the age of 6–7 and adolescence) [12]. In the period from 6 to 10 years of age, a rapid increase in the frequency and severity of postural defects is observed [19, 26]. Although school age is not marked by great biological changes, it is a time in which the body is required to adapt to the new conditions in school. The first three years of schooling are conducive to the deterioration of body posture due to the new conditions, such as a change in lifestyle from spontaneous physical activity to a specific system of work at school, restriction of the child's natural mobility, sitting for many hours at a desk, carrying a heavy school bag, stress resulting from acquiring new experiences, negative experiences, and disturbing postural stabilization, leading to uneven tension of muscles and ligaments, which in turn may lead to overload and deepening of posture asymmetry [19, 26]. The second period of unsteadiness in shaping the correct body posture results from intensified developmental changes in the puberty growth spurt. Rapid height gain changes the position of the center of gravity, and the growth of the body does not cause muscle growth, which in turn creates unfavorable conditions for maintaining the correct body posture [14].

Gender may also influence the formation of body posture. Gender differences exist in childhood and can be attributed to various factors, e.g. biological, physical, and psychological. Maturation differences between girls and boys exist not only in terms of physical, hormonal, and sexual development but also in terms of central nervous structures. Gender differences in affective processing and responses are also reported in infancy. It was found that the structure and development of the brain differed between the genders in the infancy period. Infant girls show lower activity levels, greater sensitivity to environmental changes, and greater fearfulness compared to boys [1]. The results showed a naturalistic tendency in the development of posture – parameters changed dynamically with age [5, 8, 11]. Individual development is characterized by stages due to the uneven pace of development of individual structures and functions. Thus, differences in body posture can be observed in children of different ages and gender groups [12].

To the best of our knowledge, the available literature on the subject lacks studies covering several years of observations of changes in anterior-posterior spinal curvatures in children. One-time observations show the frequent occurrence of body posture defects in preschool-age and school-age children [8, 9, 11, 16]. In the literature on the subject, there is a small number of studies taking into account gender differences in body posture. Moreover, there are no studies that take into account the homogeneity of the study group. Therefore, the study aimed to assess the differences in the magnitude of the anterior-posterior spinal curvatures depending on sex in children aged 5 and 9 years.

Material and methods

Participants

This is a prospective longitudinal observational study. The first examination included 5-year-old children and was carried out in 2015. The following inclusion criteria were adopted: a child born in 2010, consent of parents or legal guardians for the child's participation in the study, Posterior Trunk Symmetry Index (POTSI) > 27. POTSI, described by Suzuki et al. [29], is used for the analysis of deformities in the frontal plane. Ideal symmetry of the back is equivalent to a POTSI equaling 0. Suzuki et al. [29] defined the upper limit of normal as 27.0. Based on the specified inclusion criteria, a group of 125 children (50 girls and 75 boys) with deformity of the trunk in the frontal plane were identified. This group was invited to the second examination in 2018. The following inclusion criteria were used for the second stage of examination: the child's participation in the first examination, the consent of parents to re-participate in the research, and the consent of children to re-participate in the research. The exclusion criteria were: absence from research due to illness, lack of consent of the child's parents or legal guardians to use the findings in publications, no contact with the child's parents or legal guardians, lack of consent of the child to the assessment of body posture, withdrawal of the parents' or legal guardians' consent to their child's participation in the research.

Finally, the research group after the first and second stage of examination included 67 children (29 girls and 38 boys) aged 9 years.

The first examinations were performed in 2015 (project DS. 246 "The psychophysical condition of Biała Podlaska five-year-olds") and the second in 2018 (project DM. 74 "Changes in body posture of children between 5 and 9"), in the Body Posture Laboratory at the Regional Centre for Research and Development of the University College in Biała Podlaska (Poland). The study was conducted by an experienced physiotherapist in the morning, with all security, intimacy and privacy measures in place. Written informed consent was obtained from the parents or legal guardians of all the children to participate in the observations and use the results for scientific purposes.

Both projects received positive consent from the Faculty and Senate Committee on the Ethics of Scientific Research at Józef Piłsudski Academy of Physical Education in Warsaw (DM. 74 – SKE 01 30/2018; DS. 246 – SKE 01-01/2014). All procedures performed in the studies were

in line with the 1964 Helsinki Declaration and its later amendments.

Measurement of somatic parameters

To calculate the BMI (body mass index) [24], body weight [kg] and height [cm] were measured. Measurements were made on an electronic scale, which was calibrated with an accuracy of 0.01.

Measurement of body posture

The computerized assessment of body posture was performed using a MORA 4 Generation device, CQ Electronic System [30]. The height of the measuring station was adjusted to the child's height. Before the test, the measuring device was calibrated.

Before the measurement, the following points were marked with a dermograph on the back of the subjects, as suggested by the Society on Scoliosis Orthopedic and Rehabilitation Treatment (SOSORT) [17]: spinous processes C7-S1, acromion, lower angles of the scapulas, posterior superior iliac spines. During the examination, children without outerwear stood with their backs to the camera at a distance of 2.6 m, in a relaxed and unforced position − feet hip-width apart, legs straightened, arms along the torso, and the eyes looking straight ahead. The height of the measuring station was adjusted to the child's height. The room was darkened. The body posture was assessed by a qualified person (physiotherapist, teacher) with several years of experience.

Research has provided good evidence for the reliability and validity of MT as a screening and diagnostic tool [6, 15, 21, 22, 32]. MT evaluation has good repeatability (intraobserver error = 1.9°, interobserver error = 0.8°) for the Surface Trunk Rotation (STR) parameter [6]. Also, a study reported very high intraobserver and interobserver correlation (interclass correlation index: Deformity in the Horizontal Plane Index (DHOPI) = 0.983, POTSI = 0.959, Columnar Profile (PC) = 0.984 for intraobserver measures; DHOPI = 0.987, POTSI = 0.978, PC = 0.969 for interobserver measures) [21]. To evaluate the shape of anterior-posterior spinal curvatures the following parameters in the sagittal plane were used (Figure 1):

1. Length and depth parameters – expressed in millimeter [mm]:
- DCK – spine height – length between the seventh cervical vertebra (C7) and the first sacral vertebra (S1),
- DKP – length between the seventh cervical vertebra (C7) and the peak of thoracic kyphosis (KP),
- RKP – length between the seventh cervical vertebra (C7) and the thoracic-lumbar transition (PL),
- DLL – length between the first sacral vertebra (S1) and the peak of lumbar lordosis (LL),
- RLL – length between the first sacral vertebra (S1) and the thoracic-lumbar transition (PL),
- GKP – depth of thoracic kyphosis, the distance between the peak of thoracic kyphosis (KP) and the thoracic-lumbar transition (PL),
- GLL – depth of lumbar lordosis, the distance between the peak of lumbar lordosis (LL) and the thoracic-lumbar transition (PL);

2. Angular parameters – expressed in degrees [°]:
- the inclination of the lumbosacral vertebral segment (α),
- the inclination of the thoracolumbar vertebral segment (β),
- the inclination of the upper thoracic vertebral segment (γ),
- the angle of thoracic kyphosis (KKP) − KKP = 180 – (BETA + GAMMA),
- the angle of lumbar lordosis (KLL) − KLL = 180 – (ALFA + BETA);

3. Indicators:
- compensation index (MI) − MI = KKP – KLL.

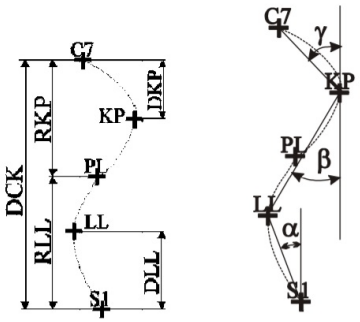


Figure 1. Tested parameters in the sagittal plane [30]

Statistical analysis

The parameters were described using basic measurements of descriptive statistics, i.e. mean, standard deviation (SD), median (Me). The normality of the distribution of variables was assessed with the Shapiro-Wilk test. The normality of the data was rejected. The Mann-Whitney U test was used to analyze the differences between the sexes in terms of body posture parameters and somatic parameters (body weight, body height, BMI). Statistical analysis was performed in Statistica 13 (STATISTICA 13.0, StatSoft, PL).

Results

Table 1 shows the general characteristics of the study groups. In the group of 5-year-olds, there were no statistically significant differences in somatic parameters between girls and boys. There was a statistically significant difference ($p = 0.045$) in body height between girls and boys at 9 years old (Table 1).

Table 1. General groups characteristic

Parameters	Girls (n = 29)	Boys (n = 38)	p
	Me	Me	
5 years old			
Body weight [kg]	20.0	19.0	0.858
Body height [cm]	113.0	114.0	0.780
BMI [kg/m^2]	15.2	14.7	0.470
9 years old			
Body weight [kg]	29.5	30.6	0.089
Body height [cm]	134.0	136.2	0.045
BMI [kg/m^2]	16.4	16.4	0.242

Table 2. Characterization of the anterior-posterior spinal curvatures values, taking into account the sex category and significance levels from the Mann-Whitney U test in 5 years old children

Parameters	Girls (n = 29)		Boys (n = 38)		p
	Mean ± SD	Me	Mean ± SD	Me	
5 years old					
DCK	311.7 ± 18.0	310.4	316.5 ± 15.3	319.0	0.276
DKP	105.5 ± 20.8	112.2	111.6 ± 17.9	113.6	0.210
RKP	186.8 ± 21.5	181.0	190.5 ± 17.9	193.6	0.448
DLL	57.7 ± 21.0	56.3	56.7 ± 18.9	56.8	0.218
RLL	124.9 ± 18.9	123.2	126.0 ± 18.1	122.2	0.965
GKP	11.7 ± 7.3	11.1	10.2 ± 7.6	10.7	0.648
GLL	–11.3 ± 5.3	–1.9	–9.8 ± 6.5	–9.1	0.281
α	7.9 ± 3.9	8.2	7.6 ± 3.3	8.4	0.718
β	8.4 ± 3.6	8.3	7.9 ± 3.6	7.2	0.548
γ	9.5 ± 3.3	9.8	9.4 ± 4.1	9.4	0.879
KKP	162.3 ± 6.0	162.3	163.1 ± 6.9	162.9	0.510
KLL	163.7 ± 7.3	163.1	164.9 ± 6.1	163.5	0.515
MI	1.3 ± 6.1	1.7	1.8 ± 5.9	2.4	0.573

Median (Me), statistical significance was set at $p < 0.05$, length C7-S1 (DCK), length C7-KP (DKP), length C7-PL (RKP), length S1-LL (DLL), length S1-PL (RLL), depth KP-PL (GKP), depth LL-PL (GLL), the inclination of the lumbosacral vertebral segment (α), the inclination of the thoracolumbar vertebral segment (β), the inclination of the upper thoracic vertebral segment (γ), the angle of thoracic kyphosis (KKP), the angle of lumbar lordosis (KLL), compensation index (MI).

There were no statistically significant sex-related differences in the parameters of the anterior-posterior spinal curvatures in 5-year-old children (Table 2). In the group of 9-year-old children, in the angle of lumbar lordosis, there was a significant difference between the sexes ($U = 387.00$, $p = 0.05$). Girls aged 9 had a significantly higher mean value of the angle of lumbar lordosis than boys at the same age ($p = 0.05$) (Table 3).

Table 3. Characterization of the anterior-posterior spinal curvatures values, taking into account the sex category and significance levels from the Mann-Whitney U test in 9 years old children

Parameters	Girls (n = 29)		Boys (n = 38)		p
	Mean ± SD	Me	Mean ± SD	Me	
9 years old					
DCK	295.8 ± 23.3	293.7	297.8 ± 16.2	298.4	0.123
DKP	100.1 ± 24.6	101.7	106.5 ± 22.6	107.7	0.422
RKP	176.3 ± 30.4	163.8	184.0 ± 23.9	185.0	0.314
DLL	49.9 ± 20.9	38.2	46.2 ± 20.7	41.8	0.914
RLL	119.5 ± 26.8	121.3	113.8 ± 24.3	108.6	0.317
GKP	9.5 ± 5.4	9.5	10.8 ± 4.5	10.7	0.436
GLL	–10.2 ± 5.9	–10.3	–11.7 ± 4.6	–11.9	0.271
α	6.0 ± 4.5	5.9	7.3 ± 4.1	7.4	0.162
β	7.4 ± 3.6	7.2	8.5 ± 2.5	8.5	0.190
γ	10.4 ± 3.9	10.5	9.3 ± 2.9	9.3	0.220
KKP	162.5 ± 6.4	163.8	162.0 ± 4.9	161.5	0.352
KLL	166.7 ± 7.1	166.5	163.8 ± 6.5	164.2	0.05
MI	5.4 ± 8.0	6.2	3.4 ± 6.4	3.3	0.130

Median (Me), statistical significance was set at $p < 0.05$, length C7-S1 (DCK), length C7-KP (DKP), length C7-PL (RKP), length S1-LL (DLL), length S1-PL (RLL), depth KP-PL (GKP), depth LL-PL (GLL), the inclination of the lumbosacral vertebral segment (α), the inclination of the thoracolumbar vertebral segment (β), the inclination of the upper thoracic vertebral segment (γ), the angle of thoracic kyphosis (KKP), the angle of lumbar lordosis (KLL), compensation index (MI)

Discussion

The issue of changes in anterior-posterior spinal curvatures in children has been discussed in numerous scientific publications [2, 6, 8, 9, 11, 16, 33]. Nevertheless, a review of the literature indicates a lack of research in this area based on the longitudinal comparison strategy that was the subject of the conducted research. At this point, it should be emphasized that it is difficult to relate the obtained research results to the study of other authors because, according to the best of our knowledge, there are no longitudinal studies which were repeated after several years in the same study group, and which verified changes in anterior-posterior spinal curvatures in children after several years.

Compared with previous studies, the unique value of this research is that it quantified sexual dimorphism in the magnitude of lumbar lordosis in school-age children. These results confirm that girls aged 9 had a significantly higher mean value of the angle of lumbar lordosis than boys at the same age, suggesting a potentially greater range of motion in the female spine. Moreover, sex differences in the lumbar spine appear to be supported by postural differences in sacral orientation and morphological differences in vertebral wedging [3]. Understanding the functional cause of greater lordosis in women than in men is important to understand the developmental and biomechanical differences between male and female lumbar spines, and to explore potential trade-offs that may accompany greater lumbar lordosis in women. Previous studies have suggested that sexual dimorphism in the lumbar spine is caused by the burden on the fetus during pregnancy [31]. Sex differences in vertebral wedging, however, may suggest gender differences in stress, possibly starting with sex differences in growth and

development during skeletal maturation [7]. Moreover, differences in weight distribution in the upper body of men and women or changes in the curvature of the spine in the cervical and thoracic spine may affect the degree of lumbar lordosis required to maintain a stable posture [13]. Alternatively, sex differences in lordosis may only be a byproduct of the sexual dimorphism of the human pelvis [28]. Musculoskeletal differences in the hip can influence sacral orientation. Differences in lordosis may be primarily due to differences in sacral orientation due to pelvic dimorphism between women and men.

One-time scientific reports describing the magnitude of the anterior-posterior spinal curvatures in the examined children revealed dimorphism. Drzal-Grabiec et al. [11], examining a group of children aged 7−12, observed significant differences between the sexes in the 7-year-old and 9-year-old groups in the parameters of lumbar lordosis. Girls had more severe lordosis than boys. Also, Araujo et al. [2] found that girls had higher values of the lumbar angle when examining children at 4 and 7 years of age. The results of another study performed to assess the prevalence of postural disorders in children (mean aged 8.52) showed a greater prevalence of lordotic posture in girls than in boys, but this difference was not statistically significant [6]. Also, a cross-sectional study of a school screening program in southern China including children in primary school, junior high school, and senior high school students by Yang et al. [33] indicated that girls had a higher incidence of abnormal body posture than boys. Medojevic and Jaksic [16] observed that the differences related to sex dimorphism appear in children at the age of 9 to 10. The authors explain this phenomenon by the fact that girls enter puberty at the age when they are more prone to certain postural disorders. In boys, this period begins later (11−13 years). The research conducted by Ciric et al. [8] revealed that girls were significantly more likely to have postural problems compared to their male peers in terms of lumbar lordosis, while boys had a more pronounced deformity of the thoracic kyphosis.

Diagnosing the needs in terms of body posture is the basis for planning appropriate preventive and therapeutic activities. This research project has contributed to the identification of differences in the anterior-posterior spinal curvatures depending on sex and age in children. Therefore, it is particularly important to focus on the selection of exercises and their adaptation to be more relevant to the health needs of children. In addition, it is crucial to monitor the body posture of children of all ages, especially in the early school and school period, and to educate them in the field of ergonomics of positioning during everyday activities.

The recommendation for future research is to take into account specific groups when assessing sex differences in the examined parameters of body posture. It is also worth considering the position of the pelvis and the sacral spine in the examinations.

The value of these studies is that they take into account the specific groups of the studied children, not the age range, and the use of an objective method of assessing body posture. A specific group characterized by asymmetry of the torso in the frontal plane was identified (based on the POTSI index).

Certain limitations of the study should be taken into account. The size of the study group was small. The study was prospective, but it was not possible to design a randomized study.

In conclusion, we found that lumbar lordosis exhibits sexual dimorphism and girls have greater lordosis than boys. This result, along with the findings that morphological and postural differences contribute to sex differences in lumbar lordosis, has functional and clinical implications for lumbosacral alignment. Understanding the gender differentiation of lumbar lordosis is the first step towards explaining the wide variability of normal lumbar lordosis in adults.

Conflict of interest: Authors state no conflict of interest.

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