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Influence of body posture on foot load distribution in young school-age children

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Young school-age children are particularly prone to postural defects because they are in a period of development of the spine that is exposed to a number of factors impairing its normal growth. A change in the shape of the spinal column causes a shift in the centre of gravity. Therefore, this study attempted to assess the influence of body posture on distribution of the load transferred by the lower limbs. *Methods:* For each of the examined children, this study determined the parameters describing the body posture with the use of the photogrammetric method and the parameters describing plantar force distribution. The statistical analyses were performed using the U Mann–Whitney test and the student's *t*-test. The correlations between the parameters of the body posture and the parameters describing the foot load distribution were analysed using the Pearson correlation coefficient. These analyses were performed at a statistically significant level of $p < 0.05$. *Results:* The tests conducted showed an occurrence of postural defects in about 42% of the subjects and excessively uneven loading of the lower limbs in about 65% of the children. *Conclusions:* The authors obtained a medium intensity correlation between the analysed parameters for the groups of boys and girls.

Key words: *body posture, postural defects, photogrammetric method, plantar force, children*

1. Introduction

Changes in the body posture that deviate from the normal state are called postural defects and are now one of the most serious problems related to the development of children [24]. Despite the fact that it is very difficult to define the correct body posture, an incorrect posture is defined as a body shape detrimental to the organism, resulting from the anatomy and habitual or involuntary positioning of individual body parts [15], [24]. Epidemiological studies show a large percentage of children with abnormal body posture (as high as 50%) and complaining of spinal pain. These numbers increase with age [15], [17]. During postural development, two particularly dangerous periods have been observed in which formation of faulty posture is common. The first one is related to the start of schooling of a child (aged 6–7 years), while the other one occurs during the puberty [15], [11].

Young school-age children are in a period of development of the skeletal system and their spine is characterized by rapid growth and high susceptibility to disorders resulting from external factors. During this period, the anteroposterior curvatures of the spine develop yet, stabilization has not been completed. A drastic change of lifestyle occurs when children begin their school education, which involves many hours spent sitting at a school desk, followed by homework done in the sitting position [4]. Other factors that disrupt the normal development of body posture include: lack of physical activity, long hours of watching television, and the manner of spending free time often in an undesirable body position that is conducive to overloading of the supporting structure of the spine [24], [12]. It is worth noting that the skyrocketing rate of obesity among children is also listed

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as a factor affecting the normal development of the skeletal system [24], [13]. Studies conducted among children aged 6–9 living in the European Union showed that in 2008 a quarter of them was obese or overweight. That percentage increased in 2010 to one third and, unfortunately, it continues to increase, also among children under the age of five [6]. It would seem that frequent physical activity would eliminate the possibility of faulty body postures as well as obesity or overweight. However, we should keep in mind that intensive sports activities with very heavy training loads promote the development of abnormal curvatures of the spine, especially among young players [21].

Abnormal development of body posture not only affects the functioning of the upper part of the body and causes pain but also results in deformations of the entire musculoskeletal system and muscular disorders, especially within the trunk muscles [1]. The changed shape of the spinal column as well as obesity and overweight shift the centre of gravity, which causes a disturbance in the distribution of the body load transferred by feet [22]. Previous studies on the issue of postural defects in children or analysing the loads on the lower limbs have focused mainly on early detection of defects, which is an indication for corrective exercises to eliminate development of irregularities and on the impact of increased body weight, the weight of school backpacks, and lack of physical activity on the presented aspects of body posture [24], [12]. However, the authors of this study could find no studies that would investigate the relationship between the existing postural defects and disturbances in the distribution of loads transferred by feet, even though the above factors seem to be strictly dependent on one another [22], [17]. Therefore, this study attempted to determine the impact of the body posture on the distribution of foot loads in young school-age children.

2. Materials and methods

2.1. Participants

The study involved 78 children enrolled in grades 1–3 of primary schools in Wrocław (Poland), aged 6–8, with an average weight of 25.6 ± 4.3 kg and a height of 125.0 ± 6.3 cm. For the purposes of the analysis of the results, the test subjects were divided into two groups differentiated by gender (42 girls, 36 boys). Detailed data characterising the groups are presented in Table 1.

Table 1. Numerical descriptive analysis of the participants' anthropometric data

Sex [–]	Heigh [cm]	Weight [kg]	BMI [kg/m^2]
Girls (n = 42)			16.3
Mean	124.9	25.5	2.0
SD	6.2	4.3	
Boys (n = 36)			
Mean	125.2	25.8	16.4
SD	6.5	4.5	2.0

SD – standard deviation.

Anthropometric measurements of body height and weight were made using scales with height rod (WPT 60/150 OW, Radwag, Poland) with an accuracy of ±0.1 cm and ±0.1 kg. The obtained data were used to calculate the body mass index (BMI), then, the weight of each subject was assessed using centile charts. The study was conducted with the approval of the Ethics Committee at the University School of Physical Education in Wroclaw (No. 18/2016), according the 1964 Helsinki declaration and its later amendments or comparable ethical standards and with the consent of the parents and all examined children.

2.2. Design and procedures

Measurements of the body posture were performed by means of the photogrammetric method, using a Mora 4G (CQ Electronics System, Poland). The study was conducted according to generally accepted principles provided by the manufacturer. An experienced physiotherapist non-invasively marked characteristic anthropometric points on the back of each child being examined. The conducted studies enabled an analysis of the parameters characterising

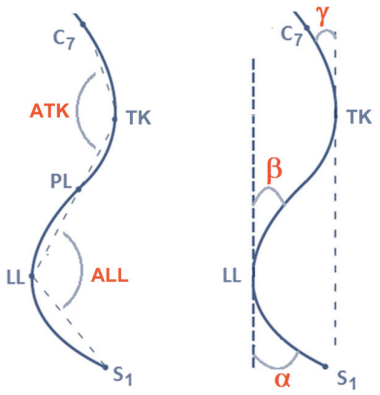

Fig. 1. Method of determining angles (α, β, and γ) and parameters (ATK; ALL) describing the body posture in the sagittal plane (scheme courtesy of Artur Świerc, http://www.cq.com.pl/, modified by the authors)

the body posture in the sagittal lane, designation method of which is shown in Fig. 1. The conducted measurements were used to obtain the angles of inclination of the respective segments of the spine (α, β, and γ). Then, the Wolański method was used to calculate the angle of thoracic kyphosis (ATK) and the angle of lumbar lordosis (ALL) [14].

Foot plantar pressures and lower limb load symmetry were assessed using static tests on a FreeMed baropodometric pressure platform (real-time sampling frequency up to 400 Hz, Sensor Medica, Guidonia Montecelio, Rome, Italy). During the test, the children adopted a free-standing posture, characterised by natural spacing and angle between feet. The arms of the subjects were hanging down freely along the torso and their sight was directed straight ahead. The parameters describing the body load distribution were determined for each child examined. The obtained data served to calculate the lower limb load symmetry index while standing (SI) as the ratio of greater to smaller pressure on one side of the body. According to literature, the range of 1–1.15 was adopted as the correct (normal) SI [10]. The hindfoot load was assumed to be 40% of the loaded foot length.

2.3. Statistical analysis

The results obtained in the study were analysed statistically (Statistica 12, StatSoft Inc., USA) and presented as mean values with standard deviations (SD). Statistical analysis was performed to compare the obtained results between the study groups. The data characterising the body posture were analysed using the Mann–Whitney U test while the data on foot load distribution were analysed using the Student's *t*-test. Moreover, an analysis of the parameters describing the body posture in both studied groups was performed using the Kruskal–Wallis test. In the case of foot load distribution, student's *t*-test was used for dependent samples. The relationship between the parameters concerning the body posture and the parameters describing the distribution of foot loads was determined using the Pearson correlation coefficient. These analyses were performed at a statistically significant level of $p < 0.05$.

3. Results

Analysis of the determined values of the individual angles of inclination of the spinal segments revealed a significant progression of the spine curvature of the lumbosacral spine (α) in the group of girls (Table 2). The average value α was smaller by about 45% in the group of boys ($p < 0.01$). Statistically significant differences were also observed in the angle of lumbar lordosis (ALL), which was by about 4% greater in the group of boys ($p < 0.05$). An analysis of the angles of inclination of the spinal segments within each gender showed that in the group of girls statistically significant differences were present between β and α ($p < 0.05$). In the group of boys, statistically significant differences were observed between γ and β ($p < 0.05$) as well as between γ and α ($p < 0.01$).

Table 2. The analysed parameters characterising body posture obtained for the examined groups

Sex	γ [°]	β [°]	α [°]	ATK [°]	ALL [°]
Girls					
Mean	10.8	8.4	12.6	161.9	158.2
SD	5.5	5.6	7.5	8,8	12.2
Boys					
Mean	11.0	7.1	6.9	162.1	164.9
SD	6.0	4.0	5.2	7.1	9.6
% difference	1.9	–15.5	–45.2	0.1	4.2
p	n/a	n/a	0.0019	n/a	0.0166

SD – standard deviation, *p* – statistical significance ($p < 0.05$), n/a – no applicable difference.

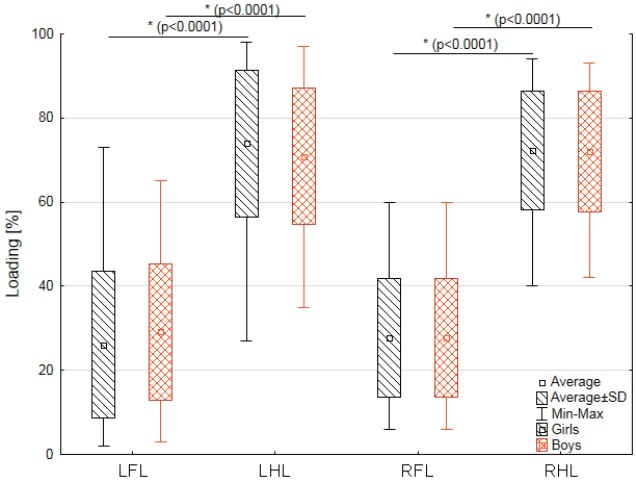

Fig. 2. The chart comparing the load transferred by the forefoot (LFL, RFL) and hindfoot (LHL, RHL) of both feet in the examined groups (* – statistical significance)

The results obtained for total load distribution transferred by the left and right lower limb of the children examined showed that in the group of girls the load was transferred to a greater extent by the right foot ($p < 0.001$). By contract, in the group of boys the load was transferred evenly by the left and right feet,

Table 3. The analysed parameters obtained for the distribution of total load transferred by the left and right lower limbs obtained for the examined groups (girls, boys)

Sex	Left foot			Right foot			SI [–]
	TLL [%]	LFL [%]	LHL [%]	TRL [%]	RFL [%]	RHL [%]	
Girls							
Mean	46.3	26.1	74.0	53.5	27.7	72.3	1.42
SD	9.2	17.5	17.5	9.5	14.1	14.1	0.39
Boys							
Mean	49.6	29.1	70.9	50.4	28.0	72.0	1.31
SD	7.7	16.2	16.2	7.7	14.4	14.4	0.25
% difference	7.1	11.5	–4.2	–5.8	1.1	–0.4	–7.7

SD – standard deviation.

Table 4. Correlation between the parameters describing the body posture and the distribution of loads transferred by the feet

Relationship between the parameters	r (p value)	Interpretation
Girls		
LFL/LHL vs. ALL	0.37 (0.047)	The greater the angle of ALL, the lower the load transferred by the left foot forefoot
LFL/LHL vs. ATK	0.35 (0.060)	The greater the angle of ATK, the lower the load transferred by the left foot forefoot
LFL/LHL vs. β	0.33 (0.077)	The greater the angle β, the greater the load transferred by the left foot forefoot
Boys		
RFL/RHL vs. α	0.39 (0.074)	The greater the angle α, the greater the load transferred by the right foot forefoot

r – Pearson correlation coefficient, p – statistical significance.

with the right foot being slightly more loaded. Both boys and girls put less load (about 27–28% on average) on the forefoot. Similarly, the load on the hindfoot was greater by about 73% in the group of girls and greater by about 71% in the group of boys. In both groups, statistically significant differences were found between the loads carried by the forefoot and hindfoot of both examined feet (for both groups $p < 0.0001$, Fig. 2, Table 3).

The results obtained showed that the habitual posture of children was characterised by significant disturbances of the lower limb load symmetry. The SI index was, on average, 1.42 in the group of girls and 1.31 in the group of boys. Although the percentage difference in the load transferred by the lower limbs in the group of boys was not significant, the SI index obtained for that group of subjects was outside the normal range. In both groups, only in about 35% of the examined children the obtained SI index was within the correct range while in the case of up to about 65% the analysed factor showed excessive lower limb load asymmetry.

The results obtained showed a medium intensity relationship (r in the range of $0.3 \leq r < 0.5$) between LFL/LHL compared with ALL, ATK, and β in the group of girls and between RFL/RHL compared with α in the group of boys (Table 4).

4. Discussion

The study group consisted of children aged 6–8 years, whose spine is particularly vulnerable to the development of abnormal curvatures and for whom the probability of postural defects increases with the commencement of primary school education. This is mainly due to a change to a more sedentary lifestyle, which significantly affects the skeletal system [4], [12].

An additional burden on the body posture is excess body weight, which can be seen in increasingly younger children. An international study by Cole [3] determined the normative ranges of the body mass index, defining the overweight and obesity in children. According to the results obtained in that study, girls aged 6–7 are overweight if their BMI is above 17.5 kg/m^2 and they are obese if their BMI is above 20.8 kg/m^2.

For boys, the above values are. 17.7 kg/m^2 in the case of overweight and 20.2 kg/m^2 in the case of obesity. Comparing the normative ranges defined by Cole [3] with the mean values from the conducted tests it was shown that, on average, the examined groups were characterized by normal body weight. A comparison of the BMI values obtained by the authors of that study with the centile charts showed occurrences of abnormal body weight, including underweight and excess body weight, in children from both examined groups. Girls and boys with healthy, normal body weight accounted for about 70% of the children in their respective groups. Boys were more often underweight (8%), compared to girls (2%). By contrast, as many as 29% girls had excess weight (of whom 26% were overweight and 3% were obese) compared to 22% of boys (of whom 14% were overweight and 8% were obese). In the present study, the authors observed a greater proportion of children with excess body weight, compared to the subjects examined by Maciałczyk-Paprocka [13] who were determining the effect of child obesity on the occurrence of faulty body posture. The latter study of a group of almost 3,000 children showed normal body weight in about 85% of children aged 3 to 12 years. In the age group of 3–6 years, excess weight was observed almost twice as often as obesity (both among boys and girls). In the case of boys attending primary schools (6–12 years old), the proportion of overweight and obese children was similar, i.e., about 7.5%, while in the case of girls obesity was more frequent (9%) than overweight (about 5%).

The tests performed using the Moire method showed abnormal body posture in about 42% children, including about 40% of girls and about 44% of boys. Those results are consistent with the results obtained by other authors, according to whom abnormal body posture occurs in about 40–80% of the population of children [9]. Łubkowska [12] observed abnormal body posture in the sagittal plane in 35% of the boys aged 7 and 33% of the boys aged 8, while Kratenova [8] observed it in about 38% of the children aged 7–15.

The authors of this paper found that the body posture of boys more often showed thoracic hyperkyphosis (about 53% of the subjects), which is consistent with the results presented by other authors [23], [16]. In contrast, the body posture of girls most often showed lumbar hyperlordosis (in about 40%), which among boys occurred in only about 28% of people. A similar relationship was presented by Penha [15] who observed hyperlordosis in 55% of the examined girls aged 7 and in 61% of the girls aged 8. Gender differences in the progression of particular spinal curvatures may be caused by different growth dynamics and body weights of girls and boys in early school age, which is evident in more harmonious development of males.

An analysis of the distribution of the body weight transferred by the feet of the subjects showed that in both groups the load was transferred to a greater degree by the hindfoot (amounting, on average, to about 74% in the group of girls and about 68% in the group of boys). These results are in accordance with the results obtained by other authors [2], [19]. A study by Rodrigues [19] showed that in 10-year-old pupils the hindfoot is loaded in about 65%. On the other hand, Cavanagh [2] demonstrated that in adults the hindfoot is loaded in about 60%. Comparison of the results obtained by different authors may suggest that with age the percentage of load transferred by the hindfoot slightly decreases, which may be related to the process of development of the body posture and curvatures of the spine in the sagittal plane as well as development of better stability. What is worrying is the fact that in both groups the average SI value is outside the normal range, with higher value recorded in the group of girls. The studies conducted showed that 75% of the examined children load their lower limbs excessively unevenly, which may be a consequence of their postural defects.

Many authors point out that girls are more prove than boys to develop undesirable changes in the spinal column [7], [20]. This relationship is visible both in the case of physically inactive persons [20] and persons practising various sport disciplines [25]. As demonstrated by Trobisch [20], spinal defects occur six times more often in 10-year-old girls than in the case of opposite gender. The authors of this study found no statistically significant gender differences regarding the changes occurring in the shape of the spinal column and the foot load distribution. This may be the result of the young age of the subjects and the fact that their posture (because of the start of the school age) is only beginning to be subjected to many factors conducive to the development of abnormal changes in the skeletal system. The obtained lack of differences with respect to sexual dimorphism is consistent with the results obtained by other authors [5], [18].

The tests performed showed that in the group of girls there was a moderate correlation between the load transferred by the forefoot/hindfoot of the left lower limb of the subjects, and between the angle of inclination in the thoracolumbar spine, the angle of thoracic kyphosis, and the angle of lumbar lordosis. The greater the angles of ATK and ALL, the greater

the percentage of load transferred by the hindfoot of the left lower limb of girls. In contrast, greater angle of inclination in the thoracolumbar segment correlated with greater load transferred by the forefoot also of the left lower limb as a consequence of the forward shift of the centre of gravity. In the group of boys, on the other hand, there was a medium intensity relationship between the angle of inclination in the lumbosacral segment and the load on the forefoot/hindfoot of the right lower limb. The tests showed that in boys an increase in the angle of α was accompanied by an increase in the load transferred by the hindfoot of the right lower limb.

Tests of symmetry of lower limb loads, together with tests of development of body posture, provide physiotherapists with more information that make the process of elimination of defects, e.g., by corrective gymnastics or manual therapies more effective. An additional advantage of this approach is the ability to treat the problem holistically rather than focusing only on locally occurring changes within the spinal column.

5. Conclusions

The tests performed in this study showed abnormal body posture in about 42% children, including about 40% of girls and about 44% of boys. There was also large lower limb load asymmetry in about 65% of children. However, the authors found no statistically significant differences in the occurring changes in the shape of the spinal column and the foot load distribution with respect to gender. The attempted evaluation of the impact of the body posture on the distribution of the load transferred by the lower limbs of young school-age children showed a medium intensity correlation between the angle of inclination in the thoracolumbar spine, the angle of thoracic kyphosis, and the angle of lumbar lordosis and between the load transferred by the forefoot/hindfoot of the left lower limb of girls. In the group of boys, on the other hand, there was a medium intensity correlation between the angle of inclination in the lumbosacral segment and the load on the forefoot/hindfoot of the right lower limb.

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