Structural asymmetry of foot arch formation in early school-age children

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Summary

Study aim: the purpose of the study was to compare foot shapes in early school-age boys and girls.

Material and methods: the study included 90 boys and 98 girls aged seven to nine years old. The shape of the foot arch was examined using a podoscope. The longitudinal arch was assessed according to the Clarke angle value on the basis of Kasperczyk's classification. The transverse arch was assessed according to the Wejsflog index. An analysis of variance, a post-hoc LSD test and a chi-square test were performed.

Results: normal transverse arches in both feet appeared in 84% of the examined children. An analysis of the average value of the Wejsflog index showed that it is similar and within limits in all of the test groups indiscriminately when it comes to gender and age. Normally, longitudinal arches in both feet occurr in 44% of children. The average value of Clarke's index in a test group of school-age girls was within normal range while a functionally flattened foot appeared in the case of seven and eight-year-old boys.

Conclusions: the outcomes of the present study conducted on a randomly chosen group of developing boys and girls show that changes in foot structure are mostly symmetrical in nature (almost 90%), meaning that if the left foot is normal, the right one is normal, too. Gender had no effect on the foot build or arch type in either foot. The right and left feet showed symmetrical structure in the majority of the children.

Key words: Foot assessment – Arch formation – Early school-age children – Photometric method

Introduction

For many years, the dimensional relationship between the foot and other parts of the body has been the subject of many anatomy and anthropology research studies. This publication is one of these studies; however, the importance of children's feet in the scope of morphological asymmetry has not yet been explored.

In the course of ontogenetic development, so-called "critical and sensitive periods" appear. This concept describes phases in which we can observe increased sensitivity to external stimuli. One critical period that is important for the development of the shape of the foot arch is that of early school-age and preschool. In both the development of the structure of the foot and its arch, there is potential for sexual dimorphism and morphological and functional asymmetry [1, 13, 17, 18, 29, 32].

All children are born with "flat feet" under the physiological definition. However, Kanatli et al. [16] and Villarroya et al. [30] believe that the definition of "flat foot" is not standardized. Although there is a general consensus that the height of the medial longitudinal arch is the principal observed and measured parameter, foot flatness in children is also the result of extensive midfoot plantar fat pad thickness [4], which masks the actual set of structures relative to each other. This midfoot plantar fat pad thickness disappears by the time a child is five years old [18, 19, 26]. Bertsch et al. [3] and Hallemans et al. [14] indicate that the longitudinal arch fat pad plays a crucial role in protecting the paediatric foot from overloading. The most intensive changes in the shape of the foot arch occur between the ages of two and six [3, 10, 18, 30]. Progressive development of the shape of the foot arch ends by about 12 years of age in most girls and 15 years of age in boys, although bone ossification does not end until the fifteenth year of age in girls and the eighteenth year of age in boys [8, 28]. This development has a certain autonomy compared to overall somatic development [6, 25].

Evaluation of the proper shape of the foot arch is important from a diagnostic point of view. The information from this study may be useful in a diagnostic sense to characterize health problems in the young generation, but should also be invaluable in helping determine prevention

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programs. Based on these results, we can create effective recommendations to correct defects in foot morphology. Therefore, the purpose of this study was the assessment of foot structure in early school-age children, taking into consideration the longitudinal and transverse arches in a weight-bearing position with respect to gender and age. The experiment also included the assessment of the occurrence of foot deformities in the studied children.

Material and methods

Participants

The research involved 188 primary-school children from the city of Wroclaw. Gender distribution in the study population was 90 boys and 98 girls aged seven to nine (early school-age). The participants were divided into three groups based on age: seven years old, eight years old and nine years old. Each age group had 30 boys, while the number of girls varied: 32 were seven years old, 31 were eight years old and 35 were nine years old. In this school period, compared to children aged 10 to 14 years old, the children participate in regular, low intensity and unstructured forms of physical activity. These are mainly various forms of games and play activities lasting 45 minutes, twice a week. The studied children had no innate foot deformities. In total, the feet (left and right) of 376 children were examined under weight-bearing conditions. The measurement was carried out prior to any sports activities that could have changed the result (i.e. due to foot overload from physical exercise). The main goal of the study and the experimental procedures to be undertaken were explained in detail to the children's parents. Informed consent from parents was obtained before the experiment began. The experimental protocol of the study was approved by the local Ethics Committee.

Measurement procedure

The structure of the foot was examined in an upright (standing) position using a podoscope. The measurements were carried out using an advanced tool for digital analysis of footprints and plantar loads consisting of both a digital camera (videography 2D) and a high resolution podoscanner (Podoscope – Podo-scanner 2D, Sensor Medica, Rome, Italy). In addition to an accurate plantocontourogram, we collected information on the spatial formation of the foot arch. The participants stood barefoot on the measurement device with feet 5 cm apart in a relaxed position and hands at the sides. The plantar region of the foot was measured when the load was exerted evenly on each foot. In order to maintain a stable posture and get an accurate measurement, two footprints each of the right and left foot were taken to obtain a permanent image of the plantar surface of the foot. In order to make the measurement

repeatable, the footprint picture was taken under specified conditions (equal parameters of the optic system, constant measurement distance, horizontal placement of the camera and identical position of subject during examination). Before the measurement, the location of the five metatarsal heads was marked for each participant.

Free Step software (Sensor Medica, Rome, Italy) allowed us to capture and store the images, automatically measure the spatial formation of foot arches (changes in longitudinal and transverse arch) and angles (the Clarke index, heel angle Gamma, hallux valgus angle) and compare possible asymmetries (the relation between the length and width of the foot – the Wejsflog index). To characterize the degree of flat-footedness, each child's arch height was estimated from the footprints. The longitudinal arch was assessed according to the Clarke index value on the basis of Kasperczyk's classification [24]: a range below 28 degrees characterizes a substantially flat foot; 28–40 degrees characterizes a functionally flattened foot; 40–51 degrees characterizes a normally arched foot; over 51 degrees characterizes hollow arches (feet with excessively high arches). The transverse arch was assessed according to the Wejsflog index. The correct quotient of foot length to foot width is 3:1 [24]. Values between 2.55 and 3.00 designate a normal arch (healthy transverse arch), and values between 2.00 and 2.50 denote transversely flat feet [24]. In this study, $V_{Cramér}$ rate was used. This rate is a measure of the association between two nominal variables. In addition to these measurements, basic anthropometric measurements including body mass, body height and BMI were taken, as well as measurements of both feet including length, width, heel width and foot surface.

Statistical analysis

The mean and standard deviation (SD) were calculated. A comparison of mean-value results among several groups (depending on subjects' gender and age) was performed using the factorial analysis of variance (age × sex) for repeated measurements (right and left foot) and a post-hoc LSD test. A chi-square test (χ^2) with a critical value of p = 0.05 was used to evaluate the frequency of the appearance of different types of foot arch formations in the examined girls and boys and to show the relationship (or lack thereof) between the type of foot arch in the left and right feet. The level of statistical significance was set at α = 0.05 and is indicated in bold. The results were analysed using Statistica v9.1.

Results

According to the subject literature in the field of anthropology, the average values of somatic parameters increase with age among both boys and girls (Table 1).

Table 1. Selected anthropometric descriptive statistics for the children's population sample (N = 188)

Feature	Boys (N = 90)			Girls (N = 98)		
	age 7 years N = 32	age 8 years N = 31	age 9 years N = 35	age 7 years N = 30	age 8 years N = 30	age 9 years N = 30
	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
Body mass [kg]	24.73 ± 3.52	28.43 ± 4.52	33.43 ± 6.20	24.41 ± 4.22	26.97 ± 5.80	30.34 ± 3.36
Height [cm]	125.60 ± 4.67	131.00 ± 6.52	138.37 ± 5.57	124.97 ± 5.20	131.39 ± 5.64	137.03 ± 5.23
BMI	15.63 ± 1.53	16.51 ± 2.04	17.36 ± 2.41	15.54 ± 1.79	15.49 ± 2.15	16.14 ± 1.28

The analysis of the mean values of the length and width of the feet, the width of the heel and the area of the foot's contact surface revealed increases in these parameters with age. The exception to this was the width of the heel in examined girls, which had similar mean values regardless of age. The analysis of parameters in age categories performed separately for girls and boys showed higher values in male groups than in female groups (Table 2).

The results of the analysis of variance on repeated measurements of inter-gender and age differences of the selected foot dimensions, arch angles and arch indexes of the examined children's feet are presented in Table 3. After taking gender into account, statistically significant differences were limited only to the Wejsflog index (p = 0.0200).

In terms of age, statistically significant differences were reported in the valgus angle of the big toe (p = 0.0133) and width of the heel (p=0.0226). The influence of age and gender on the variance of repeated measurements showed that only the width of the heel was statistically significant (p = 0.0218) (Table 3).

The largest number of statistically significant differences between boys and girls was observed in the group of nine-year-old children. Differentiating parameters included the length of both feet, the width of both feet, the width of both heels and the area of the contact surface of the left foot (Table 4).

Statistically significant differences between the width of the left and right feet occurred in the group of seven-

Table 2. Basic statistics of surveyed children's foot's morphological structure

Feature	Foot	Boys			Girls		
		age 7 years	age 8 years	age 9 years	age 7 years	age 8 years	age 9 years
		mean ±SD	mean ±SD	mean ±SD	mean ±SD	mean ±SD	mean ±SD
Length foot [mm]	right	189.37 ± 10.00	200.03 ± 13.25	211.87 ± 10.13	187.72 ± 10.64	195.16 ± 9.49	206.11 ± 9.26
	left	189.43 ± 10.12	199.93 ± 13.33	211.67 ± 11.59	188.44 ± 10.75	196.48 ± 9.08	205.97 ± 10.27
Width foot [mm]	right	73.90 ± 4.54	77.80 ± 4.64	80.37 ± 4.94	72.75 ± 5.64	75.65 ± 6.09	77.91 ± 4.08
	left	74.77 ± 3.96	77.00 ± 4.44	80.80 ± 4.11	71.31 ± 6.28	75.23 ± 6.42	77.86 ± 3.77
Width heel [mm]	right	39.39 ± 3.35	41.87 ± 5.39	43.17 ± 3.41	40.03 ± 2.03	39.63 ± 4.24	40.83 ± 3.10
	left	39.22 ± 3.93	41.71 ± 5.20	43.27 ± 2.93	38.26 ± 2.91	40.64 ± 3.26	40.30 ± 3.40
Surface foot [mm^2]	right	138.61 ± 14.84	151.10 ± 17.85	165.46 ± 15.10	132.92 ± 15.72	143.37 ± 15.69	158.47 ± 14.50
	left	136.40 ± 12.49	149.78 ± 18.09	165.69 ± 17.42	131.55 ± 15.25	146.22 ± 14.12	154.23 ± 13.34
Valgus α angle of big toe foot [°]	right	8.02 ± 4.80	5.77 ± 3.81	4.63 ± 3.40	6.85 ± 3.79	5.04 ± 4.58	5.30 ± 5.02
	left	5.95 ± 3.85	5.62 ± 4.36	4.91 ± 3.76	5.75 ± 4.99	5.62 ± 4.44	6.95 ± 4.53
Varus β angle of V toe foot [°]	right	14.65 ± 7.06	16.21 ± 5.79	16.56 ± 6.20	13.84 ± 6.45	13.63 ± 6.27	15.13 ± 6.77
	left	15.03 ± 5.52	14.35 ± 4.76	14.19 ± 5.33	12.87 ± 5.33	13.94 ± 4.82	13.60 ± 5.61
Heel γ angle foot [°]	right	17.77 ± 2.24	16.28 ± 2.25	16.57 ± 2.18	16.43 ± 2.25	16.60 ± 2.99	16.79 ± 1.91
	left	17.53 ± 3.37	17.11 ± 2.12	16.61 ± 2.56	17.24 ± 2.57	17.43 ± 3.30	16.99 ± 2.23
Wejsflog's index foot	right	2.57 ± 0.18	2.57 ± 0.09	2.64 ± 0.13	2.59 ± 0.19	2.59 ± 0.17	2.65 ± 0.13
	left	2,54 ± 0,13	2,60 ± 0,10	2,62 ± 0,13	2,65 ± 0,20	2,62 ± 0,17	2,65 ± 0,11
Clarke's index foot	right	38,72 ± 12,20	39,61 ± 9,20	47,02 ± 10,96	45,84 ± 7,73	43,51 ± 8,39	49,24 ± 6,48
	left	38,24 ± 10,98	36,33 ± 11,70	45,32 ± 9,73	43,66 ± 9,05	42,91 ± 8,97	44,65 ± 9,60

Table 3. Main effects of analysis of morphological structure of right and left foot based on repeatable measurements of feet parameters; probabilities p<0.05 are marked bold

| Feature | Repetition [Main] effect | | | | | | | |
| | measures right–left | | Repetition effect × sex | | Repetition effect × age | | Repetition effect × sex × age | |
	F	p	F	p	F	p	F	p
Length foot	1.03	0.3127	1.68	0.1965	0.73	0.4822	0.52	0.5949
Width foot	1.06	0.3056	3.08	0.0811	1.03	0.3598	2.93	0.0558
Width heel	1.57	0.2114	0.75	0.3875	3.87	**0.0226**	3.91	**0.0218**
Surface foot	1.49	0.2240	0.01	0.9127	1.14	0.3223	2.32	0.1011
Valgus α angle of big toe foot	0.14	0.7053	2.00	0.1589	4.43	**0.0133**	0.06	0.9374
Varus β angle of V toe foot	5.45	**0.0207**	0.41	0.5247	1.31	0.2724	1.39	0.2516
Heel γ angle foot	6.96	**0.0091**	1.71	0.1924	1.89	0.1539	1.09	0.3398
Wejsflog's index foot	1.33	0.2507	5.51	**0.0200**	2.27	0.1063	2.61	0.0760
Clarke's index foot	15.19	**0.0001**	0.34	0.5591	0.96	0.3852	2.37	0.0965

Table 4. Comparison of *post-hoc* tests on average value of parameters analyzed by LSD test for differences between genders and morphological structure of each feet; probabilities p < 0.05 are marked bold

| Feature | right – left foot | | | | | | boys–girls | | | | | |
| | boys | | | girls | | | age 7 years | | age 8 years | | age 9 years | |
	age 7 years	age 8 years	age 9 years	age 7 years	age 8 years	age 9 years	right	left	right	left	right	left
Length foot	0.9226	0.8841	0.7707	0.2800	0.0512	0.8221	0.5456	0.7149	0.0773	0.2101	**0.0321**	**0.0338**
Width foot	0.1324	0.1646	0.4508	**0.0104**	0.4581	0.9144	0.3652	**0.0069**	0.0930	0.1662	**0.0494**	**0.0186**
Width heel	0.7386	0.7534	0.8546	**0.0004**	**0.0457**	0.2656	0.4947	0.3048	**0.0183**	0.2550	**0.0111**	**0.0014**
Surface foot	0.2867	0.5248	0.9130	0.4968	0.1643	**0.0283**	0.1476	0.2175	0.0515	0.3680	0.0693	**0.0031**
Valgus α angle of big toe foot	**0.0228**	0.8651	0.7536	0.2078	0.5134	0.0505	0.2878	0.8533	0.5095	0.9981	0.5301	0.0594
Varus β angle of V toe foot	0.7262	0.0866	**0.0295**	0.3523	0.7740	0.1278	0.5882	0.1477	0.0874	0.7865	0.3282	0.6871
Heel γ angle foot	0.5342	**0.0343**	0.9321	**0.0331**	**0.0317**	0.5703	**0.0383**	0.6602	0.6253	0.6264	0.7326	0.5385
Wejsflog's index foot	0.1364	0.2247	0.2489	**0.0027**	0.1388	0.8196	0.5656	**0.0020**	0.5532	0.4644	0.8326	0.4450
Clarke's index foot	0.7285	**0.0178**	0.2184	0.1026	0.6535	**0.0004**	**0.0040**	**0.0281**	0.1158	**0.0084**	0.3557	0.7791

year-old girls. Another set of differences was investigated in groups of seven – and eight-year-old girls in relation to the width of both heels and, in the case of the nine-year-old girls, the area of the contact surface. When it comes to the discussed parameters, there were basically no statistically significant differences between the morphological structure of the left and right feet of the surveyed population of boys (Table 4).

In all age groups among both boys and girls, the value of the valgus angle of the big toe was within the normal range. The mean value of this angle decreased with age with the exception of the left foot in nine-year-old girls (Table 2). Statistically significant differences between the left and right valgus angle of the big toe were observed only in the case of the seven-year-old boys (Table 4). The analysis of the varus angle of the V toe exceeded the normal range for this parameter. Greater values of the varus deformity were observed in the male groups than in the female groups (Table 2). Statistically significant differences between the left and right varus angle of the V toe were observed only in the case of the nine-year-old boys (Table 4). The value of the heel angle was similar in the test groups and decreased slightly with age (Table 2). Statistically significant differences between each foot were found in groups of seven – and eight-year-old girls and eight-year-old boys. In the discussed cases, the difference in angle parameters between genders was statistically significant only in the case of the right heel angle in groups of

Table 5. Comparison of *post-hoc* tests on average value of parameters analyzed by LSD test for differences in case of boys and girls age groups; probabilities p<0.05 are marked bold

Feature	boys right foot			boys left foot			girls right foot			girls left foot		
	7–8	7–9	8–9	7–8	7–9	8–9	7–8	7–9	8–9	7–8	7–9	8–9
Length foot	0.0002	0.0000	0.0000	0.0002	0.0000	0.0000	0.0064	0.0000	0.0001	0.0032	0.0000	0.0004
Width foot	0.0028	0.0000	0.0475	0.0843	0.0000	0.0035	0.0222	0.0000	0.0664	0.0021	0.0000	0.0335
Width heel	0.0098	0.0001	0.1735	0.0095	0.0000	0.1042	0.6632	0.3813	0.1896	0.0112	0.0246	0.7126
Surface foot	0.0019	0.0000	0.0004	0.0009	0.0000	0.0001	0.0076	0.0000	0.0001	0.0002	0.0000	0.0363
Valgus α angle of big toe foot	0.0447	0.0025	0.3052	0.7655	0.3508	0.5253	0.0975	0.1437	0.8069	0.9070	0.2591	0.2157
Varus β angle of V toe foot	0.3047	0.2091	0.8177	0.6512	0.5773	0.9161	0.8865	0.3710	0.3018	0.4693	0.6112	0.8139
Heel γ angle foot	0.0233	0.0681	0.6537	0.5274	0.1601	0.4386	0.7953	0.5641	0.7588	0.7715	0.6871	0.4865
Wejsflog's index foot	0.9446	0.0503	0.0590	0.1106	0.0319	0.5781	0.9247	0.0916	0.1147	0.4450	0.8501	0.5531
Clarke's index foot	0.7204	0.0010	0.0033	0.4444	0.0049	0.0004	0.3398	0.1514	0.0169	0.7563	0.6767	0.4652

seven-year-old children (Table 4). An analysis of the average value of the Wejsflog index showed that it is similar and within limits in all of the test groups indiscriminately when it comes to gender and age (Table 2). Statistically significant differences between genders occurred in seven-year-old children in the case of the left foot and in the seven-year-old girls concerning differences between the left and right feet (Table 4). The average value of the Clarke index in the test group of school-age girls was within normal range, while the case of seven – and eight-year-old boys showed the presence of a functionally flattened foot (Table 2). Statistically significant differences between genders occurred in the case of seven-year-old children and eight-year-old children in case of left feet. Statistically significant differences between the right and left feet were observed in the case of eight-year-old boys and nine-year-old girls (Table 4).

There was a statistically significant increase in the length and width of the foot, the width of the heels and the area of plantar pressure in relation to age without regard to gender and feet. The Clarke index value increased with age, especially in the boys' groups (Table 5).

Most of the studied children (over 50%, excluding the eight-year-old boys) presented a normally arched foot, taking into account the distribution by age group, gender and the left and right feet. The largest number of participants with a normal foot arch was among the eight-year-old girls (74%) and concerned only the left foot. The lowest percentage (37%) of normally arched feet was among eight-year-old boys and also concerned the left foot. The second kind of longitudinal arch of the foot which prevailed among the examined children was the functionally flattened foot. This type of arch was present among 40% of the eight-year-old boys. An interesting observation was made concerning the hollow foot for nine-year-old girls and boys, as the value reached 20%, but only for the right

foot (Figure 1). For the transverse foot arch, over 80% of the studied population was judged as having a normally arched foot. This statistic covers all of the boys and girls from seven to nine years of age without dissimilarities regarding the left and right feet, with one significant exception in the case of seven-year-old boys. The largest percentage of properly arched feet was found among the right feet of nine-year-old boys at 97%; the left-foot value was only 3% smaller. Meanwhile, the test group of nine-year-old girls had a higher percentage of properly arched feet regarding the left foot (97%), with a slightly lesser percentage in the right foot (94%) (Figure 2).

In turn, the χ^2 test showed no association between the type of foot build and sex for either the right or left foot. In the case of the Wejsflog index (indicator), the right foot had values of $\chi^2_{Yatesa} = 0.00$, p = 0.9884, $V_{Cramér} = -0.018$, and for the left foot $\chi^2_{Yatesa} = 0,83$, p = 0.3619, $V_{Cramér} = 0.084$. Similarly, with respect to the Clarke index (indicator), the right foot had values of $\chi^2 = 7.19$, p = 0.0660 and $V_{Cramér.} = 0.196$ and the left foot had values of $\chi^2 = 7.18$, p = 0,0662 and $V_{Cramér} = 0.195$.

Because gender did not affect the type of foot build in the group of children, a comparison of the right foot to the left foot was conducted jointly for boys and girls. A comparison of the occurrence of different types of foot arch formations between the right and left foot showed that the ratio of the Wejsflog index ($\chi^2_{Yatesa} = 45,43$, p = 0.0000, $V_{Cramér} = 0.518$), in addition to the Clarke index ($\chi^2 = 104.83$, p = 0.0000, $V_{Cramér} = 0.431$), indicates a link between the two feet.

A total of 84% of the examined children had normal transverse arches in both feet. Feet that were flattened laterally on both sides were observed in 6% of the children, while 5% of them only had a laterally flattened right foot; the presence of the same characteristic in only the left foot was found in 4% of the cases. Normally, longitudinal
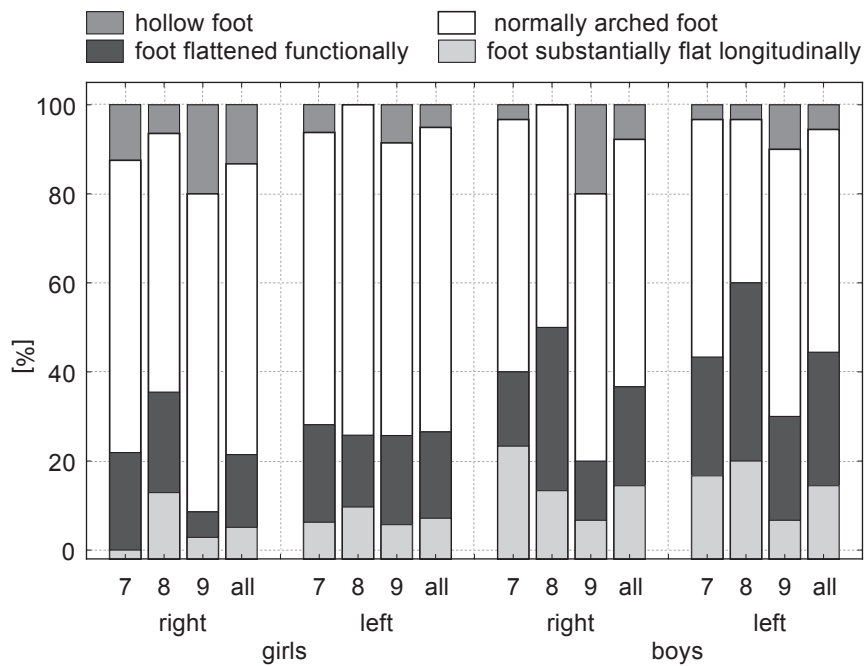
Fig. 1. The percentage (%) values of longitudinal arches of different footprint types for left and right feet among boys and girls of different ages (n = 188)
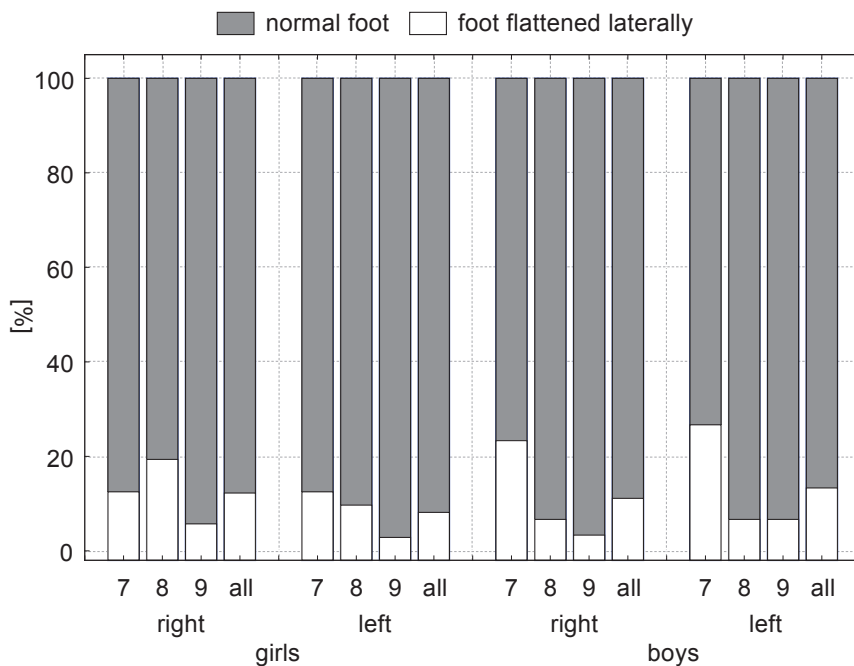

Fig. 2. The percentage (%) values of transverse arches of different footprint types for left and right feet among boys and girls of different ages (n = 188)

arches in both feet occur in 44% of children. It was found that both feet of 6% of the examined children were substantially longitudinally flat, 9% had feet that were flattened functionally and 3% had hollow feet. In the case of the remaining 38% of children from the test group, one of the feet possessed a regular longitudinal arch while the other foot was marked by one of the flaws noted above.

Discussion

The aim of this study was to assess the shape of the feet of early school-age children, considering the longitudinal and transverse arches in a weight-bearing position depending on gender and age.

Many authors believe that the preschool and early school period is critical for posturogenesis, which determines the quality of posture and the arch shape of the feet [11, 25, 28]. During the early school-age years (seven to nine years), the posture of girls and boys is characterized by low sexual dimorphism [10]. Based on our review of the literature on the development of the medial longitudinal arch, we can distinguish the age range (three to fifteen years) where the essential changes occur [15, 17, 27]. Moreover, greater differences and higher mean values of arch sizes in both feet were observed in girls than in boys. This is related to the occurrence of sexual dimorphism in children. The highest increase of the mean value of the Clarke index was observed in children of early school-age. Prior studies have shown a trend of lowering the age range in which significant changes in feet morphology occur [5, 10, 12]. Our study confirmed this observation.

No significant differences were observed in the shape of transverse arches between boys and girls in each age category for either the left or right foot. With age, the shape of transverse arches decreases, as is evidenced by an increase in the value of the Clarke index. The feet of most children have been properly developed and occur between 2.55 and 3.0 on the basis of Kasperczyk's classification [24], which indicates a normally arched foot. It was also observed that the Clarke index values reveal normal longitudinal arches (ranging between 40–51 degrees for both left and right feet) for all girls. A functionally flattened foot (28–40 degrees) appeared predominantly in seven – and eight-year-old boys. Only a majority of nine-year-olds showed a normal arch.

Some authors have shown that a higher percentage of girls have feet with the proper medial longitudinal arch, while a higher percentage of boys have functionally flattened feet. It was therefore concluded that the longitudinal arch of the foot is better developed in seven – and eight-year-old girls compared to boys of the same age [11, 15, 17]. Also, further studies indicate a greater proportion of flat feet in boys than in girls (between five and thirteen years), a trend which decreases with age. The same findings were observed between three and six years of age in the case of bilateral flat feet [6, 7]. One of the reasons that boys have more flattened feet at the age of four is the existence of a thicker fat pad under the medial longitudinal arch [18].

A separate analysis of arch parameters in our study, conducted within individual age groups, showed a certain trend in the shaping of foot arches. The older the children were, the smaller the chances for improvement of their transverse arches were. The best transverse foot arches were observed in the nine-year-olds, and the worst were observed in the seven – and eight-year-olds for both the left and right feet. The opposite was observed in the case of longitudinal arches in children of different age groups.

The lowest value of normal feet was observed in the eight-year-old boys (50% and 36% respectively for the right and left foot). The highest values among functionally flattened feet were observed among the eight-year-old boys, too (36% and 40% respectively for both the right and left feet).

The literature has shown significant differences between the right and left feet of children aged five to seven years, both in normal and flattened feet [21, 22]. In the group of seven-year-old girls, a greater proportion of feet with normal longitudinal arches was observed [12]. However, different results were found in previous studies in which only seven-year-old boys were characterized by the normal construction of the longitudinal foot arch [2]. Also, in the same study, there were no flattened feet in children aged seven to ten years, which our study did not confirm. After considering ontogenetic development, we can assume that the shaping process of the longitudinal arches of girls' feet appears to move faster than in boys. According to Mickle et al. [18], the development of the medial longitudinal arch may progress at a slower rate in boys than in girls.

In our study, an improvement was observed in both longitudinal and transverse arches as children got older. A significantly higher percentage (approximately 84%) of properly developed feet (with normal arches) was identified among transverse arches for both boys and girls.

The literature devotes much less attention to the characteristics of the transverse arch. The changes in the developmental age within this feature are rarely recognized. Some studies [6, 25, 29, 31] demonstrate that flattened feet, both longitudinal and transversal, occur at similar rates in about 10–15% of cases. It was also found that this defect occurs more often in girls than in boys in the right foot in both weight-bearing and non-weight bearing positions [21]. In addition, a correlation was observed between the length of the foot, body height and the transverse arch [23]. The transverse arch can be assessed on the basis of the Wejsflog index and heel angle. A heel angle of 18° indicates a transverse flat foot, while values between 15 and 18° are within the normal limits. More than half of the population of children between seven and ten years of age had feet with a correct transverse arch [18, 27]. In another age range, the angle of the heel had different values. Less than half of children aged four to twelve years were found to have a normal transverse arch [2].

Our study confirmed all of these results. Among the studied children, most had a normally arched foot, taking into account the distribution by age group, gender and both the left and right feet. The second kind of longitudinally arched foot which prevailed among the surveyed children was the functionally flattened foot. In the transverse foot arch, the highest percentage of the studied population (about 84%) showed normal feet; this group was

dominated by both boys and girls from seven to nine years of age, divided into the left and right feet.

Differences in the structure of the left and right feet can result from age, activity, body mass, multiple and often repetitive injuries such as sprains, dislocations, etc., as well as various types of diseases and complications after treatments [9, 20, 33]. The results of the present study conducted on a randomly chosen group of developing boys and girls show that changes in feet structure are mostly symmetrical in nature (almost 90%), meaning that if the left foot is normal, the right one is normal, too. Only in a small percentage of the examined people did the right foot have a different type of arch than the left foot.

Conclusions

The evaluation of the appearance of differences in foot build between right and left feet showed no influence of gender on the type of arch. The results of the χ^2 test showed that the right and left feet of the examined group of children in relation to each other and each other and to the general population showed a symmetrical structure.

References

1. Agic A., Nikolic V., Mijovir B. (2006) Foot anthropometry and morphology phenomena. *Coll. Antropol.,* 30(4): 815–821.

2. Bac A., Woźniacka R., Szaporów T. (2008) The amount and kind of feet defects with relation to normal feet in kindergarten and primary school children. *Family Med. Prim. Care Rev.,* 10(4): 1278–1282.

3. Bertsch C., Unger H., Winkelmann W., Rosenbaum D. (2004) Evaluation of early walking patterns from plantar pressure distribution measurements. First year results of 42 children. *Gait Posture,* 19(3): 235–242.

4. Cavanagh P.R. (1999) Plantar soft tissue thickness during ground contact in walking. *J. Biomech.,* 32(6): 623–628.

5. Chang H.W., Lin C.J., Kuo L.C., Tsai M.J., Chieh H.F., Su F.C. (2012) Three-dimensional measurement of foot arch in preschool children. *Biomed. Eng. Online,* 11: 76.

6. Chen J.P., Chung M.J., Wang M.J. (2009) Flatfoot Prevalence and Foot Dimensions of 5 – to 13-Year-Old Children in Taiwan. *Foot Ankle Int.,* 30(4): 326–332.

7. Chen K.C., Yeh C.J., Tung L.C., Yang J.F., Yang S.F., Wang C.H. (2011) Relevant factors influencing flatfoot in preschool-aged children. *Eur. J. Pediatr.,* 170(7): 931–936.

8. Cowley E., Marsden J. (2013) The effects of prolonged running on foot posture: a repeated measures study of half marathon runners using the foot posture index and navicular height, *J. Foot Ankle Res.,* 6: 20. The electronic

version of this article is the complete one and can be found online at: http://www.jfootankleres.com/content/6/1/20.

9. Dowling A.M., Steele J.R., Baur L.A. (2001) Does obesity influence foot structure and plantar pressure patterns in prepubescent children? *Int. J. Obes. Relat. Metab. Disord.,* 25(6): 845–852.

10. Echarri J.J., Forriol F. (2003) The development in footprint morphology in 1851 Congolese children from urban and rural areas and the relationship between this and wearing shoes. *J. Pediat Orthop. B.,* 2(2): 141–146.

11. Evans A.M. (2011) The pediatric flat foot and general anthropometry in 140 Australian school children aged 7–10 years. *J. Foot Ankle Res.,* 4: 1–12.

12. Forriol F., Pascual J. (1990) Footprint analysis between three and seventeen years of age. *Foot Ankle Int.,* 11(2): 101–104.

13. Gilmour J.C., Burns Y. (2001) The measurement of the medial longitudinal arch in children. *Foot Ankle Int.,* 22(6): 493–498.

14. Hallemans A., De Clercq D., Aerts P. (2005) Using pressure distribution technology for evaluating foot function in toddlers. *Clin. Biomech.,* (20): 1–15.

15. Jenkins D.B. (1991) Hollinshead's functional anatomy of the limbs and back. 6th edition. Philadelphia: W.B. Saunders, USA.

16. Kanatli U., Yetkin H., Cila E. (2001) Footprint and radiogeaphic rnalysis of the feet. *J. Pediatr. Orthop.,* 21(2): 225–228.

17. Matsuda S., Demura S. (2013) Age-related, interindividual, and right/left differences in anterior-posterior foot pressure ratio in preschool children. *J. Physiol. Anthropol.,* 32(20): 1–8.

18. Mickle K.J., Steel J.R., Munro B.J. (2008) Is the foot structure of preschool children moderated by gender? *J. Pediatr. Orthop.,* 28(5): 593–596.

19. Mosca V.S. (2010) Flexible flatfoot in children and adolescents. *J. Child. Orthop.,* 4(2): 107–121.

20. Neufeld S.K., Myerson M.S. (2001) Complications of surgical treatments for adult flatfoot deformities. *Foot Ankle Clin.,* 6: 179–191.

21. Pfeiffer M., Kotz R., Ledl T., Hauser G., Sluga M. (2006) Prevalence of flat foot in preschool-aged children. *Pediatrics,* 118 (2): 634–639.

22. Pourhoseingholi E., Pourhoseingholi M.A. (2013) Comparison of Arch Index of flat foot and healthy foot in pre-school children. *Thrita Journal of Medical Sciences,* 2(3): 15–18.

23. Puszczałowska-Lizis E. (2011) The relationship between transvers foot arch and selected morphological features in young people and adults) *Fizjoterapia* (*Physiotherapy*), 19(1): 13–9, (in Polish, abstract in English).

24. Rykała J., Snela S., Drzał-Grabiec J., Podgórska J., Nowicka J., Kosiba W. (2013) Evaluation parameters of longitudinal and transverse arches of the feet in both non-

weight bearing and weight-bearing conditions in children aged from 7 to 10. *Przegląd Medyczny Uniwersytetu Rzeszowskiego i Narodowego Instytutu Leków w War-szawie,* 2, 183–193, (In English).

25. Scott G., Menz H.B., Newcombe L. (2007) Age-related differences in foot structure and function. *Gait Posture,* 26(1): 68–75.

26. Shih Y.F., Chen C.Y., Chen W.Y., Lin H.C. (2012) Lower extremity kinematics in children with and without flex-ible flatfoot: a comparative study. *BMC Musculoskeletal Disorders,* 13: 1–9.

27. Staheli L.T., Chew D.E., Corbett M. (1987) The longi-tudinal arch. A survey of eight hundred and eighty-two feet in normal children and adults. *J. Bone. Joint. Surg.,* 69(3): 426–428.

28. Stavlas P., Grivas T.B., Michas C., Vasiliadis E., Po-lyzois V. (2005) The evolution of foot morphology in children between 6 and 17 years of age: a cross-sectional study based on footprints in a Mediterranean population. *J. Foot Ankle Surg.,* 44(6): 424–428.

29. Stewart S. (1970) Human gait and the human foot: an ethnological study of flatfoot. *I. Clin. Orthop. Relat. Res.,* 70: 111–123.

30. Villarroya M.A., Esquivel J.M., Tomás C., Moreno L.A., Buenafé A., Bueno G. (2009) Assessment of the medial longitudinal arch in children and adolescents with obe-sity: footprints and radiographic study. *Eur. J. Pediatr.,* 168(5): 559–567.

31. Vittore D., Patella V., Petrera M., Cazzi G., Ranieri M., Putignano P., Spinarelli A. (2009) Extensor deficiency: first cause of childhood flexible flat foot. *Orthopedics,* 32(1): 28.

32. Volpon J.B. (1994) Footprint analysis during the growth period. *J. Pediatr. Orthop.,* 14(1): 83–85.

33. Willems T.M., De Clercq D., Delbaere K., Vanderstra-eten G., De Cock A., Witvrouw E. (2006) A prospective study of gait related risk factors for exercise-related low-er leg pain. *Gait Posture,* 23: 91-98.