DYNAMICS OF CHANGES IN SELECTED PARAMETERS OF FOOT ARCHING IN CHILDREN BETWEEN 5 AND 9 YEARS OLD

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Abstract

The foot is an important element of the locomotor apparatus and performs a number of functions in our body. Abnormalities in its shape can affect everyday functioning. Therefore, it is worth paying attention to the proper development of the feet in children. The aim of the study was to assess the dynamics of changes in selected parameters of foot development in younger children of school age. The study involved 70 children. The observations were conducted twice in the same children, aged 5 and 9 years. Their feet were examined using a podoscope. Clarke's method was used to assess the longitudinal arch of the feet, and the Wejsflog length-width index for assessing the transverse arch. In addition, parameters such as the length and width of the foot, the position of the big toe, the little toe and the back of the heel were analysed. Longer and wider feet were characteristic of boys. As the children became older, the longitudinal arch of the feet fell, while only girls showed a slight improvement in the lateral arch of the foot. There was a high rate of flat feet. The children examined, who were aged 5 and 9 years, had a correctly positioned toe and heel, while there was varus of the little toe. The length-width dimensions of the feet changed significantly over time. Girls and boys differed significantly in the values of the Clarke's angle defining the longitudinal arch of the feet, while no significant differences in the lateral arch of the feet were noted. With age, there was no change in the position of the toe, toe and heel.

***Key words**: Foot arching, foot dimensions, angle of the big toe, the little toe and back of the heel, children*

Introduction

The foot is an important component of the locomotor apparatus. It has three basic functions: shock absorbing, supporting and locomotive. Thanks to the complex architecture of the internal and external skeletal system, it supports the weight of the body, and is capable of adjusting to changing surfaces and absorbing shocks during locomotion (Di Giovanni, & Greisberg, 2007). For the foot to perform properly in both static and dynamic functions depends on its morphological structure and the shape of its arches: longitudinal and transverse (Pauk, Ezerskiy, Raso, & Rogalski, 2012). All abnormalities in its shape and function may cause dysfunctions in parts of the upper body: deformities of the spine, asymmetries in the position of the shoulders, shoulder blades, pelvis and joints (Niewiadomska, Makris, & Kotarska, 2018; Rodriguez-Sanz et al., 2018). This is why it is worth paying attention to the proper development of children's feet.

The formation of the feet occurs with great and variable intensity in particular ontogenesis stages. In the structure of the foot of a child in infancy, cartilage elements take precedence over the bones and there is considerable fatty layer forming physiologically flat feet. The foot is malleable due to the low progression of ossification processes and unshaped muscle and ligament systems. When the child begins to adopt a vertical body position, the process of forming the longitudinal and transverse arches of the foot begins (Niewiadomska, Makris, & Kotarska, 2018).

The pre-school and early school ages are considered to be a period of intensive foot development, which, as distal segments, precede the growth in the body's length (Hernandez, Kimura, Laraya, & Favaro, 2007). During this time, the greatest annual increase in the Clarke's angle is observed, one of several degrees (Pauk, Ihnatouski, & Najafi, 2014). In 3- to 4-year-old children, the concave formation of the sole surface of the feet occurs and widely spaced toes provide better stability during locomotion. At the age of 4-5 years, a characteristic flattening of the feet can be observed. However, in 6- to 8-year-old children, the longitudinal arch is already clearly visible. In the years that follow, the foot is formed at a moderate and different rate for each child (Niewiadomska, Makris, & Kotarska, 2018; Waclawek, Drzal-Grabiec, & Truszczynska, 2015).

The formation of the foot arch is influenced by various external and internal factors. While growing, children's feet are more sensitive and susceptible to the influence of these factors. Studies have shown that inappropriate footwear may disturb the proper development of the feet and lead to

defects in adulthood (Medina-Alcantara et al., 2019;Delgado-Abellan, Aguado, Jimenez-Ormeno, Mecerreyes, & Alegre, 2014). Sadeghi-Demneh et al. (2016) observed that being overweight or obese in childhood exerts great pressure on the soles of the feet, which may then result in structural deformities. In addition, flat feet are much more common in children with increased body weight (Halabchi, Mazaheri, Mirshahi, & Abbasian, 2013; Zivkovic, Karaleic, & Andelkovic, 2018; Evans & Rome, 2011). On the other hand, studies by Evans (2011) and Evans and Karimi (2015) indicate that there is no significant relationship between the increased weight index and flat feet. Pauk, Ezerskiy, Raso and Rogalski (2012) report that age, gender, physical activity and place of residence can affect the height of the longitudinal arch, while Pfeiffer, Kotz, Ledl, Hauser and Sluga (2006) observed that age, gender, and weight affect the arches of children's feet.

Scientific reports indicate a relationship between age and the height and dimensions of body parts. During the period of intensive growth in children, an increase in body height, length of lower limbs and length of feet is observed. Tall children generally have longer feet (Bosch, Gerss, & Rosenbaum, 2010; Xu, Hong, Li, & Wang, 2018).

The main aim of this study was to assess the dynamics of changes in the formation of selected parameters of the foot arches in children between 5 and 9 of age. The authors were prompted to undertake the research by numerous cases of adverse changes in the foot arch in pre-school and younger school-age children. It therefore seems justified to conduct such observations in order not to lead to a decrease in health and physical condition. Early detection of any changes enables the appropriate prophylactic and therapeutic measures to be implemented.

Methods

The research comprised 70 children (32 girls and 38 boys). The observations were conducted in 2015 and 2019, as part of two research projects.

The following inclusion criteria were adopted: able-bodied child, born in 2010, participation in both research projects, written consent of parents/legal guardians to their child participating in the study and to the use of the findings for scientific purposes.

The exclusion criteria were: lack of participation in any of the research projects, withdrawal of parents'/legal guardians' consent to their child's participation in the research, a correct foot arch.

The foot tests were performed by means of the plantographic method. Using a podoscope, prints of the soles of the feet were prepared, which were used to assess their arches in a static position. The participant stood on the device and assumed a natural position with an even load distribution on both feet. The device then recorded an image of the sole of the feet. A computer programme recorded the parameters being measured (Dzieciol, Kuryliszyn-Moskal, & Dzieciol, 2015).

On the basis of the resulting plantograms, the length (foot length-mm) and width (foot width-mm) were analyzed. The length of the foot is the distance between the highest point on the foot (tip of the big toe or second toe) and the lowest point, which is located at the back of the heel. The width of the foot is the distance between the most medially extended point on the foot and the most laterally extended point.

Based on Clarke's method (1959), an assessment was made of the longitudinal arch of the feet. The results were then related to the criteria for longitudinal arching: normal feet (42º - 54º), feet with reduced longitudinal arching (31º - 41º), flat feet (< 30º), hollow feet (> 55º) (Clarke, 1959). Flat feet with different degrees of severity of changes were described as asymmetric flat feet. In the study group, there were no single-sided flatfoot cases when one foot was flattened or hollow and the other was flattened or flat.

The transverse arch of the feet was determined on the basis of Wejsflog's length and width index. In the case of a correct transverse arch, the ratio of foot length to width should be 3:1. The standard for a correct transverse arch is between 2.4 and 3.0 (Dzieciol, Kuryliszyn-Moskal, & Dzieciol, 2015). Values closer to "2" are evidence of the transverse flatness of the foot, while a "3" proves a correct transverse arch.

In assessing the foot arch, the big toe position (angle α), the little toe position (angle β) and the back foot position (angle γ) were also considered. Values below 0º, both in the case of big toe and little toe alignment, indicated varus, while values above 7º indicated halux valgus. The normative values for heel alignment are in the 15° - 18° range (Dzieciol, Kuryliszyn-Moskal, & Dzieciol, 2015).

The description of the test results used mean values ($\bar{x}$), standard deviation (SD), minimum and maximum values (min-max) and the median (Me). Using the Kolmogorov-Smirnov test, the normal distribution of these variables was analyzed. In order to determine the relationships between the variables and groups, ANOVA variance analysis was performed. The significance level was taken to be $p < 0.05$.

The research received a positive opinion from the Senate Committee for Scientific Research Ethics at the Jozef Piłsudski University of Physical Education in Warsaw (DM. 74 - SKE 01-30/2018; DS. 246 - SKE 01-01/2014) and was carried out in accordance with the Helsinki Declaration guidelines for research ethics. The observations were carried out on the basis of the DM 74 research project and were a continuation of part of the DS. 246 statutory research project.

Results

Boys aged 5 and 9 generally had longer and wider feet than girls of the same age. There were statistically significantly different values for the length and width of the foot in girls and boys. With age, girls had a significant increase in the length and width of the left foot by 3.53 cm by 1.27 cm, respectively, while the increase for boys was 3.37 cm and 1.29 cm. The right foot also significantly increased by 3.54 cm in length and 1.16 cm in width for girls, and by 3.45 cm and 1.08 cm in length and width for boys (Table 1, Table 2). The levels of significance of these parameter changes are presented in Table 5.

However, the changes in foot parameters over a four-year period in both boys and girls were significant and statistically significant (Table 1, Table 2).

Table 1. Children's feet formation parameters in the first study.

Variables	Foot	I research				p
		Girls		Boys		
		x̄ ± SD	Me	x̄±SD	Me	
Alfa	L	2.76 ± 5.76	2.20	4.79 ± 4.79	3.70	0.112
	P	2.52 ± 5.42	1.60	4.42 ± 5.35	4.60	0.145
Beta	L	9.58 ± 6.00	9.80	8.64 ± 5.90	9.85	0.514
	P	8.76 ± 5.58	7.60	8.62 ± 6.33	7.70	0.922
Gamma	L	15.50 ± 1.81	15.75	16.08 ± 2.76	15.65	0.315
	P	15.90 ± 1.86	16.00	16.75 ± 2.74	16.95	0.140
FootLen	L	14.82 ± 0.73	14.80	15.01 ± 0.84	14.90	0.324
	P	14.80 ± 0.76	14.80	14.94 ± 0.64	14.85	0.378
FootWid	L	7.06 ± 0.55	7.00	6.99 ± 1.04	7.30	0.735
	P	7.10 ± 0.87	7.20	7.27 ± 0.77	7.35	0.384

x̄- average, SD- standard deviation, Me- median, p- statistical significance, ANOVA *p < 0.05, L- left foot, P- right foot, Alpha- big toe angle, Beta- little toe angle, Gamma- heel angle, FootLen- foot length, FootWid- foot width

Table 2. Children's feet formation parameters in the second study.

Variables	Foot	II research				p
		Girls		Boys		
		x̄ ± SD	Me	x̄ ± SD	Me	
Alfa	L	3.44 ± 5.67	2.40	1.59 ± 5.26	1.65	0.193
	P	5.32 ± 4.98	4.00	3.63 ± 4.33	3.40	0.107
Beta	L	9.48 ± 4.41	8.70	11.33 ± 6.28	11.20	0.260
	P	11.47 ± 4.64	12.10	10.97 ± 5.98	12.15	0.490
Gamma	L	15.67 ± 1.93	15.70	16.08 ± 2.61	16.20	0.350
	P	16.48 ± 2.63	16.70	16.37 ± 2.09	16.25	0.807
FootLen	L	18.35 ± 0.92	18.20	18.38 ± 0.89	18.35	0.829
	P	18.34 ± 0.91	18.30	18.39 ± 0.88	18.35	0.726
FootWid	L	8.33 ± 0.67	8.40	8.28 ± 0.65	8.30	0.919
	P	8.26 ± 0.66	8.30	8.35 ± 0.62	8.25	0.513

x̄- average, SD- standard deviation, Me- median, p- statistical significance, ANOVA *p < 0.05, L- left foot, P- right foot, Alpha- toe angle, Beta- small toe angle, Gamma- heel angle, FootLen- foot length, FootWid- foot width

These observations indicated different levels of foot arches in the children examined. Girls and boys differed significantly in terms of the Clarke's angle value determining the longitudinal arching of the feet. Girls aged 5 years were much more likely to have both feet properly arched and hollow, while boys had flat and asymmetrical feet. At the age of 9, gender differences were similar in terms of the longitudinal arch (Table. 3).

Table 3. Description of the longitudinal arch of the children's feet.

	Foot	I research				II research			
		Girls		Boys		Girls		Boys	
		n	%	n	%	n	%	n	%
Flatfoot	L	1	3.1	4	10.5	6	18.8	9	23.7
	P	2	6.3	6	15.8	6	18.8	8	21.1
Feet with fallen arches	L	3	9.4	12	31.6	23	71.9	23	60.5
	P	3	9.4	12	31.6	16	50.0	17	44.7
Correct feet	L	17	53.1	18	47.4	3	9.4	6	15.8
	P	17	53.1	14	36.8	10	31.1	13	34.2
Hollowed feet	L	11	34.4	4	10.5	0	0.0	0	0.0
	P	10	31.3	6	15.8	0	0.0	0	0.0

n- number of groups, %- percentages, L- left foot, P- right foot

With age, the children's longitudinal arching deteriorated. In the second study, a smaller group of girls and boys with properly arched and hollow feet was observed than in the first study, along with an increase in the incidence of flatfoot, with the time and gender changes observed in the arches being statistically significant (Table 3, Table 5). A high degree of flattening was observed in the transverse foot arches of children aged 5 and 9 years. While the vast majority of 5-year-old boys and girls were characterized by a wide forefoot, in 9-year-olds the formation of a better width-length foot ratio was confirmed in girls (Table 4, Table 5).

Table 4. Description of the transverse arching of the children's feet.

	Foot	**I research**				**II research**			
		Girls		**Boys**		**Girls**		**Boys**	
		n	%	n	%	n	%	n	%
Lateral flatfoot	L	31	96.9	28	73.7	23	71.9	27	71.1
	P	26	81.3	32	84.2	24	75.0	32	84.2
Correct transverse foot arch	L	1	3.1	10	26.3	9	28.1	11	28.9
	P	6	18.7	6	15.8	8	25.0	6	15.8

n- number of groups, %- percentages, L- left foot, P- right foot

Table 5. Analysis of variance of individual foot shape parameters in the children's feet.

		L	**P**
Alfa	time	0.100	0.138
	sex	0.896	0.931
	time^sex	0.01**	0.01**
Beta	time	0.092	0.001***
	sex	0.743	0.706
	time^sex	0.117	0.721
Gamma	time	0.801	0.709
	sex	0.307	0.457
	time^sex	0.826	0.08
FootLen	time	< 0.001***	< 0.001***
	sex	0.539	0.545
	time^sex	0.400	0.596
FootWid	time	< 0.001***	< 0.001***
	sex	0.731	0.318
	time^sex	0.858	0.738
Clarke's	time	0.039*	0.01**
	sex	< 0.001***	< 0.001***
	time^sex	< 0.001***	0.021*
Wejsflog length-width index	time	< 0.001***	0.01**
	sex	0.532	0.392
	time^sex	0.847	0.759

p- Statistical significance, ANOVA *p < 0.05, **p < 0.01, ***p < 0. 001, L- left foot, P- right foot, Alpha- angle of the big toe, Beta- angle of the little toe, Gamma- angle of the heel, FootLen- length of the foot, FootWid- width of the foot, Clark- longitudinal foot vaulting, indicator of the length and width of the foot; Gender - whether girls and boys differed in the values of the parameters measured; time - whether the values changed over time; time - whether the rate of change in the values of the parameters measured differed for girls and boys.

With reference to the other parameters of the foot arch, boys aged 5 years had higher average values for the alpha and gamma angles. Girls, on the other hand, were characterized by higher mean values of these variables in relation to boys. In all the 5-year-olds examined, the toe and heel were correctly positioned, while there was varus of the little toe. At the age of 9, girls had higher alpha-angle values for both feet, and the beta and gamma angles of the right foot compared to boys. 9-year-old children were also characterized by the correct toe and heel position and varus of the little toe (Table 1, Table 2).

Furthermore, the rate of change was statistically significantly different for girls and boys in the case of the alpha angle of both feet. Girls aged 9 years and boys aged 5 years had higher alpha angles (Table 5).

Disscusion

Analyzing the length and width parameters of the feet revealed that boys had longer and wider feet compared to girls both at the age of 5 and 9 years. A statistically significant increase in feet dimensions with age was also evident in the children examined. Over a period of 4 years, the girls' feet increased in length on average by 3.53 cm and in width by 1.21 cm, while in boys this increase was 3.41 cm and 1.18 cm, respectively. Therefore, it can be concluded that the rate of change in the length of feet was faster in boys and in width in girls. The same conclusions were reached by Bosch, Onodera, Rosenbaum and Sacco (2015) who observed the development of German children's feet over a period of ten years. Their study showed that boys had wider feet than girls. Furthermore, body height had a significant impact on the length and width of the feet of the children who were examined. Bosch, Onodera, Rosenbaum and Sacco (2015) compared

anthropometric features in the feet of German and Brazilian children aged 3-10 years. The children were characterized by different width values and an arched longitudinal arch. These differences were not statistically significant, although one exception was a significant difference in Brazilian 4-year-olds, who had higher values for the longitudinal arch compared to their German peers.

The results of our own research indicate that a deterioration in the longitudinal arch occurred in children as they became older. A much smaller number of properly arched feet and a lack of hollow feet were noted, with an increase in cases of flatfoot and asymmetric arches. In addition, these changes were significantly different in girls and boys. Our findings are consistent with those presented by Puszczalowska-Lizis and Ciosek (2017), and Pfeiffer, Kotz, Ledl, Hauser and Sluga (2006), who found gender-related differences in longitudinal arches. 8-year-old girls were characterized by better foot arches than boys, while boys were more likely to have flat feet than girls. Studies by other authors also confirm a higher incidence of flatfoot in boys (Pfeiffer, Kotz, Ledl,Hauser, & Sluga, 2006; Chang et al. (2010).

Moreover, our own observations reveal that the longitudinal arching in the children examined varied over the 4-year period. Girls had higher average Clarke's angle values both at the age of 5 and 9 years. The same conclusions were formulated by Vergara-Amador, Serrano Sanchez, Correa Posada, Molano and Guevara (2012) indicating a relationship between age and the occurrence of flatfoot. In the group of children aged 3-5 years, the proportion with flat feet was higher than in children aged 6-7 years. However, studies by Hazzaa, El-Meniawy, Ahmed and Bedier (2015) and Chen et al. (2011) indicate that there is no significant correlation between age and the incidence of flatfoot. Pauk, Ezerskiy, Raso and Rogalski (2012) studied children aged 7-15 years and observed an increase in the height of the longitudinal arch as they grew older. These children were both from rural and urban areas and did not have flat feet. On the other hand, when studying the incidence of the flatfoot in a group of 835 children aged 3-6 years, Pfeiffer, Kotz, Ledl, Hauser and Sluga (2006) observed that the incidence of the flatfoot significantly decreased with age.

With regard to the transverse arch in the children studied, transverse flatfoot was observed in a high percentage of girls and boys, both at the age of 5 and 9. With age, only girls experienced a slight improvement in the transverse arch. There were no significant differences in the transverse arch between girls and boys. The study by Gwani, Asari and Mohd Ismail (2017) also showed a lack of any significant relation between gender and the transverse arch. Different results were obtained by Puszczalowska-Lizis and Ciosek (2017). These authors examined a group of children at the age of 5 and observed normal foot transverse arches in both girls and boys. Moreover, Szczepanowska-Wolowiec, Sztandera and Zbyradowski (2018) observed normal transverse arches in more than half of the children they examined. From the analysis of the authors' own research findings, it was established that children aged 5 and 9 years had a correctly positioned toe and heel but an adducted little toe. With age, an increase in the alpha angle was observed, which may lead to hallux valgus in the big toe in adolescence. Different results were obtained by Pfeiffer, Kotz, Ledl, Hauser and Sluga (2006). In a study group of 835 children, the HV angle was 5.5º. Xu, Hong, Li and Wang (2018) analyzed the shape of Chinese children's feet and observed the effect of gender and age on foot morphology. Significant differences were found in the height and length of the instep and the width of the heel.

Other authors' findings and the present authors' own observations indicate the need for further scientific research on how chlidren's feet develop. It is also worth noting that there is a need to conduct diagnostics of foot deformations in children, because the fast pace of change may have an adverse effect on the locomotor system. Abnormalities in the development and function of the feet due to compensation mechanisms may lead to disorders in other elements of the locomotor system. Thanks to the results of computer examinations of the feet, it is possible to plan the appropriate prophylactic and therapeutic action. Such actions contribute to eliminating a defect, inhibiting its development and restoring proper foot functions. In addition, the irregularities found in the foot shape parameters in girls and boys indicate the necessity of comprehensive foot care. Greater attention should also be paid to the development of feet in children from an early age to prevent the appearance of irregularities.

Conclusion

In the children studied, a significant increase was revealed in the length and width of the feet with age. Boys aged 5 and 9 years had longer and wider feet. Furthermore, it was observed that the rate of change was more intense in the length of boys' feet and in the width of girls'.

A deterioration in the longitudinal arch was found in both girls and boys. Flat and asymmetrically flattened feet were prodominant. Moreover, the rate of changes in the Clarke's angle was different in girls and boys to a statistically significantly degree. The transverse arch also deteriorated, but it improved slightly with age in girls. Differences between girls and boys in terms of the transverse arch were not statistically significant.

The parameters determining the position of the big toe, little toe and heel remained unchanged for 4 years. Varus of the little toe was observed along with correct positions of the toe and heel. However, with age, there was a significant increase in the alpha angle, which may indicate that the toe will be adducted in adolescents.

The analysis of the study findings indicates the need to conduct further observations on the development of foot arches in children, which constitutes a recommendation for further research.

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