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PEDOBAROGRAPHIC ANALYSIS OF JUNIOR SWIMMERS

Original research

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ABSTRACT
Introduction: Children of school age are in a slow phase of growth and development in which the skeleton grows slowly, and due to the still unfinished process of ossification, the skeleton of the children is still subject to various deviations. Nowadays, the practical application of new possibilities of objective qualitative as well as quantitative determination of foot deformation in children and youth is becoming more and more widespread. Pedobarography is a special technical discipline that developed within podiatry, an orthopedic subspecialty that deals with the foot.
Research objective: To determine the effect of swimming on the transverse arch of junior sports swimmers compared to the control groups.
Methods: The research was carried out in the private practice of the physiatrist "Sporticus" - dr. Edin Buljugić and the "Otoka Olympic pool" in Sarajevo. The research method is retrospective-prospective, and the type of research is cross-sectional-observational.
Results: The analysis revealed that the average age of the total sample was 10.85±2.50 years. Our results showed that swimming does not significantly change the longitudinal and transverse arch of the foot. Research findings show that swimmers had a better transmission of forces and pressure, especially on the lateral part of the foot, while subjects who did not swim had more pressure on the medial part. The research also showed that the status of the feet is significantly better in children who started swimming in early childhood, compared to the feet of children who started swimming after the age of 10.
Conclusion: Swimming does not change the transversal arch of the foot.

Keywords: pedobarography, arches of the foot, swimming, junior swimmers

INTRODUCTION

Swimming represents the coordinated and harmonious movement of the human body within a liquid medium by the combined movement of the upper and lower extremities, which requires energy both for the floating process and for anterograde progression, with different and variable osteo-arthro-muscular involvement according to different styles (Stanković, S., & Delibašić, Z., 2020).
Success in any sporting activity, including swimming, depends on a large number of anthropological characteristics and abilities, as well as their mutual connection (Bukvić, T. 2017).
It is necessary to separate sports swimming from recreation, although they have many similarities. The basic feature of sports swimming is the competitive nature. Athletes can compete against time, natural and atmospheric obstacles and against other opponents (Pest, T. 2016). The speed of a swimmer through the water represents the result of two forces. One force attempts to hold them back, which is the resistance caused by the water that they must either displace or pull along. The other force pushes them forward and is called propulsion, generated by the swimmer's arms and legs (Dimitrić, G. 2010).
Nowdays, there is a growing practical application of new capabilities for objective qualitative and quantitative determination of foot deformities in children and adolescents, primarily through pedobarography, a specialized technical discipline developed within podiatry, an orthopedic subspecialty focused on the foot (Bukvić, T. 2017). Pedobarography is a safe non-invasive method useful for examining foot

biomechanics. Pedobarographic examination provides insight into gait disorders, their credible association with systemic pathology, and monitoring of treatment and rehabilitation progress (Miguel Andrés et al., 2020).

The function of the foot is diverse and can be divided into two main groups: dynamic and static function. In dynamic function of the foot, it adapts to the surface, enables standing and movement, and absorbs impacts on the ground during movement (Novoselec, N. 2021). The most common foot deformities in children include: pes calcaneus - where the foot assumes a position of dorsal flexion, with the child mainly leaning on the heel; pes equinus - where the foot is fixed in plantar extension, relying on the toes; pes equinovarus - fixation of the foot in extension and inversion, with the foot adducted and rotated outward; pes varus - a foot deformity where walking relies on the tip and outer edge of the foot, causing inversion; and pes valgus - the most common form of children's flat feet is the valgus of the heel - turning the heel outward (Uzelac, A. 2015).

Many studies and analyses confirm levels of flat foot arches, but pedobarography specifically determines the lowering of the transverse arch. Pedobarography is electronic measurement of foot load, and pedobarographic analysis shows distribution of plantar pressures (Bukvić, T. 2017). Under static foot deformations, flat feet are most considered as a comprehensive term for all foot anomalies defined by physiological collapse of arches, or disruption of static-dynamic balance leading to clinically definitive pathological changes (Rota Čeprnja et al., 2022).

The aim of the research is to determine the effect of swimming on the transverse arch of children in sports swimming groups compared to the control groups.

METHODS

Participants and procedure

The research method employed in this study is retrospective-prospective, and the type of study is cross-sectional observational. The investigation consisted of static, balance, and dynamic analysis of the feet on a pedobarographic plate, as well as measurement of anthropometric data and completion of a questionnaire. The study was conducted at the Private Practice of the physiatrist specialist 'Sporticus' - Dr. Edin Buljugić, at the Olympic pool on Otoka in Sarajevo - in swimming clubs PK Bosna, PK Sharks, and PK Sport time, from May 18, 2022, to November 17, 2022. The study involved school-aged children from 6 to 16 years old.

Inclusion and Exclusion Criteria for the Study

The inclusion criteria for the study included school-aged participants who had flat foot problems and were not actively involved in swimming, participants without flat foot problems who were not actively involved in swimming, participants engaged in competitive swimming regardless of foot issues diagnosed earlier, and participants whose parents/guardians provided consent for the study.

The exclusion criteria for the study included participants older than the age range determined by the study, participants younger than the age range determined by the study, participants whose parents did not provide written consent for participation in the study, and participants who did not participate in the study.

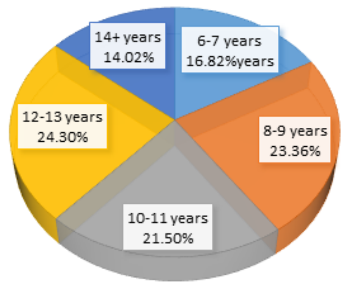
Statistical analysis

Following the study, the collected data were entered into an electronic database created using Microsoft Office Excel 365. IBM SPSS Statistics 26.00 (IBM Corporation, Armonk, New York) was used for statistical data analysis. Statistical significance was set at a p-value less than 0.05 ($p < 0.05$). Pearson's χ^2-test was used for the analysis of categorical variables, and if more than 20% of cells had values <5 or contained zeros, Fisher's exact test was employed. Mann-Whitney U test was used to compare quantitative scalar values between the two study groups.

RESULTS

In the research "Pedobarographic analysis of children's swimmers' feet", the anthropometric characteristics and dynamics of movements and pressures of the feet were analyzed in 107 subjects, divided into two groups. One group is the control group, which included 67 subjects who are not in the swimming training process - children who do not actively swim - non-swimmers and 40 subjects who actively swam. Detailed analyzes of respondents are presented in the following graphs and tables. Analysis of graph 1 found that there were 18 (16.8%) respondents aged 6 to 7 years, 25 (23.4%) respondents aged 8 to 9 years, 23

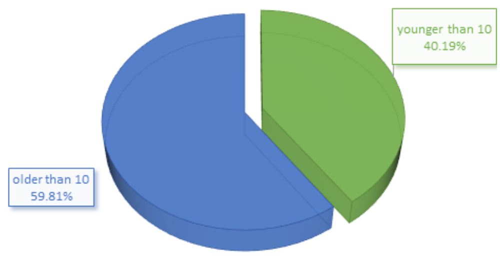
Graph 1. Distribution of respondents in relation to age groups



respondents aged 10 to 11 years (21.5%) respondents, 26 (24.3%) respondents aged 12 to 13, and 15 (14%) respondents aged 14 and over.

For the purpose of the research, the respondents were divided in relation to their age into two groups, one group consisted of respondents up to 10 years of age, and the other group consisted of respondents over 10 years of age. The distribution of respondents in relation to 2 age groups is presented in graph 2.

Graph 2. Distribution of respondents in relation to two age groups



The analysis revealed that 43 (40.2%) subjects under the age of 10 took part in the research, while 64 (59.8%) were 10 and older.
The analysis determined that out of 67 non-swimmers, 26 (38.8%) were female, and 41 (61.2%) were male. Of the total number of swimmers, 15 (37.5%) were female and 25 (62.5%) were male. No significant statistical difference was found in the distribution of respondents in relation to gender and groups (x2=0.018; p=0.893) (Table 1).

Table 1. Distribution of respondents in relation to gender and examined groups

SPOL	Non-swimmers		Swimmers		x^2	p
	N	%	N	%		
Female	26	38.8%	15	37.5%	0.018	0.893
Male	41	61.2%	25	62.5%		
Overall	67	100.0%	40	100.0%		

Children who did not swim had an average body mass of 39.3±15.3 kg, while in the group of children who swam, the average weight was 36.1±10.3 years. No significant statistical difference was found (t=1.170; p=0.244). Foot size, based on EU numbers, averaged 35.8±3.8 in the group of children who did not swim and 35.7±3.2 in the group of swimmers. No significant statistical difference was found (t=0.207; p=0.836). Foot size, based on length in mm, averaged 238.9±25.1 mm among non-swimmers, and 238.0±21.6 mm in the group of children who swam. No significant statistical difference was found (t=0.198; p=0.844) (Table 2).

At the age of up to 10 years, on the left foot, it was determined that the changed foot was present in 10 (47.6%) non-swimmers and 17 (77.3%) subjects who engaged in sports swimming. A significant statistical difference was found in the frequency of foot changes (x2=4.044; p=0.044). On the right foot under the age of 10, the foot was changed in 11 (52.4%) non-swimmers and 17 (77.3%) subjects who were involved in sports swimming. No significant statistical difference was found (x2=2.931; p=0.087).
At the age of 10 years and older, on the left foot, it was found to be altered in 21 (45.7%) non-swimmers and 9 (50%) swimmer children. No significant statistical difference was found (x2=0.098; p=0.754). On the right foot, it was determined that it was changed in 27 (58.7%) non-swimmers and 8 (44.4%) subjects who engaged in sports swimming. No significant statistical difference was found (x2=1.06; p=0.303) (Table 3).

Table 2. Analysis of anthropometric characteristics in relation to the examined groups

Variable	Non-swimmers		Swimmers		t	p
	Mean	SD	Mean	SD		
Body mass (kg)	39.3	15.3	36.1	10.3	1.170	0.244
Foot size EU	35.8	3.8	35.7	3.2	0.207	0.836
Foot length (mm)	238.9	25.1	238.0	21.6	0.198	0.844

Table 3. Analysis of feet in relation to age and examined groups

Age	Foot	Status	Control group N (%)	Experimental group N (%)	x^2	p
> 10	Left	Changes in foot morphology	10 (47.6%)	17 (77.3%)	4.044	0.044
		Normal foot	11 (52.4%)	5 (22.7%)		
	Right	Changes in foot morphology	11 (52.4%)	17 (77.3%)	2.931	0.087
		Normal foot	10 (47.6%)	5 (22.7%)		
< 10	Left	Changes in foot morphology	21 (45.7%)	9 (50.0%)	0.098	0.754
		Normal foot	25 (54.3%)	9 (50.0%)		
	Right	Changes in foot morphology	27 (58.7%)	8 (44.4%)	1.06	0.303
		Normal foot	19 (41.3%)	10 (55.6%)		

By analyzing the feet of subjects aged 10 years and older, on the left foot it was determined that there is no significant difference in the force with which it rests on the big toe area (p=0.825). In the zone from the second to the fifth finger in non-swimmer children, a median value of 2.2 N/cm2 was determined with an interquartile range of 1.5 to 3.5 N/cm2, while in swimmers the median value was 3.3 N/ cm2 with an interquartile range of 2.3 to 4.1 N/cm2. A significant statistical difference was found (p=0.019).
No significant statistical differences were found in the area of the first metatarsal bone in the force with which it rests in the mentioned area (p=0.80). On the zone of the second metatarsal bone, it was determined that the force was significantly higher in children who were

engaged in sports swimming (p=0.032), and the third metatarsal bone (p=0.012). No significant differences were found in the area of the zone of the fourth metatarsal bone (p=0.141). In the area of the fifth metatarsal bone on the left foot, a greater force was found in the swimmer subjects (p=0.002). Also, a greater force in children who practiced swimming was observed in the zone of the medial part of the heel (p=0.045) and the lateral part of the heel (p=0.046).

On the right foot, in the area of the toe zones, including the thumb and the zones from the 2nd to the 5th toe, no significant statistical differences were found in the intensity of the forces with which the subject leans (p>0.05). On the zones of the metatarsal bones, it can be observed that the median force values are slightly higher in non-swimmers, but without significant statistical difference (p>0.05). In the area of the lateral part of the heel, it can be observed that the force in non-swimmers had a median of 9.9 N/cm2 with an interquartile range of 7.8 to 11.45 N/cm2, while the median value in swimmers was 8.3 N/cm2 with an interquartile range of 7.5 to 9.5 N/cm2. A significant statistical difference was observed (p=0.036) (Table 4).

Table 4. Analysis of pressure per examined zone at the age of 10 years and older

Foot	Section	Non-swimmers		Swimmers		MW test	Z	p
		Median	IQ range	Median	IQ range			
Left	Toe Max	6.5	4.9-9	6.8	4.2-9	373.00	-0.222	0.825
	Toe 2-5	**2.2**	**1.5-3.5**	**3.3**	**2.3-4.1**	**239.50**	**-2.339**	**0.019**
	Meta 1	7.7	5.9-9	7.5	6.2-9	371.00	-0.253	0.800
	Meta 2	**9.5**	**8.5-11.5**	**11.7**	**9.5-12.5**	**251.50**	**-2.145**	**0.032**
	Meta 3	**9.8**	**8.3-11**	**11.1**	**9.9-13.5**	**228.00**	**-2.517**	**0.012**
	Meta 4	7.5	5.9-10	9.5	7.5-10.4	294.00	-1.472	0.141
	Meta 5	**4.5**	**3-5.9**	**6.4**	**4.6-8**	**188.00**	**-3.151**	**0.002**
	Mid foot	4.0	3-5	4.4	3.9-6	325.00	-0.982	0.326
	Medial heel	**10.5**	**8.5-11.9**	**11.5**	**10-13**	**267.00**	**-2.001**	**0.045**
	Lateral heel	**9.2**	**7-10.55**	**10.3**	**9.1-12**	**269.00**	**-2.002**	**0.046**
Right	Toe Max	5.50	4.5-7	5.95	5-9	307.00	-1.266	0.205
	Toe 2-5	2.5	1.9-3.5	2.5	1.8-3.5	364.00	-0.365	0.715
	Meta 1	7.00	5.5-9	6.50	5.2-9	373.00	-0.222	0.825
	Meta 2	9.8	8.5-11.5	9.4	7.9-11	332.50	-0.862	0.389
	Meta 3	9.1	8.4-11.1	8.6	8.1-10.1	287.00	-1.583	0.113
	Meta 4	7.5	6-9.5	6.2	5.8-7.6	266.50	-1.906	0.057
	Meta 5	4.5	3-5.9	4.0	3-7	386.00	-0.016	0.987
	Mid foot	3.5	2.5-5.2	3.5	2-4.1	292.50	-1.497	0.134
	Medial heel	10.50	9-13.1	10.80	9.8-12.5	394.50	-0.023	0.981
	Lateral heel	**9.9**	**7.8-11.45**	**8.3**	**7.5-9.5**	**261.00**	**-2.095**	**0.036**

DISCUSSION

Data collection necessary for the research was obtained based on pedobarographic analysis of the feet and a questionnaire. Based on the results obtained, we will compare them with similar studies conducted worldwide.

In the study by Krmek M., the impact of training activities on morphological characteristics and motor abilities of athlete children and non-athlete children was analyzed. The sample in this study consisted of a total of 57 participants - students from lower grades of elementary school "Stojan Novaković" in Šabac, divided into two groups: 25 athletes (athletics 5, mini-basketball 12, wrestling 4, soccer 3), with an average age of 8.52 ± 1.13 years, and 32 non-athletes with an average age of 8.59 ± 1.14 years. By analyzing body weight values, athletes on average weighed 2.5 kg more than non-athletes, with a mean (M) of 35 kg for athletes and 32.5 kg for non-athletes. The standard deviation (SD) values were equal in both groups of participants, amounting to 6.8 (Krmek, M. 2018).

In our study, the average body weight of non-swimmers was 39.3 ± 15.3 kg, while in the group of children who swam, the average weight was 36.1 ± 10.3 kg. The standard deviation (SD) value for non-swimmers was 15.3, and for swimmers, it was 10.3, indicating that swimmers have a lower body weight than children who do not swim, which correlates with the aforementioned study.

In the study by Miguel-Andrés Israel and colleagues, foot morphology in young athletes was analyzed to determine the prevalence of pathologies using the Chippaux-Smirak index. The study involved 75 athletes aged between nine and twenty years (56% women and 44% men), with an average weight of 62.92 ± 13.46 kg and average height of 1.67 ± 0.11 m. Sports considered in the study included weightlifting, swimming, and rowing. The results clearly show that flat feet among adolescents and young adults are a condition with a low prevalence rate, 10.7% for the right foot and 12% for the left foot. One of the most significant findings in the study is the high prevalence of cavus foot, with women being most affected by this pathology. Furthermore, swimming showed the highest prevalence of cavus foot, 42.1% for the right foot and 52.6% for both right and left feet (Miguel Andrés et al., 2020).

In our study, among swimmers aged over 10 years, on the left foot, significantly higher force was observed in the zones of the second to fifth toes (p=0.019), second metatarsal bone (p=0.032), third metatarsal bone (p=0.012), fifth metatarsal bone (p=0.002), medial part of the heel (p=0.045), lateral part of the heel (p=0.046), indicating cavus foot, which corresponds to the aforementioned study.

The purpose of Alvarez C. and colleagues' study was to describe pedobarographic profiles of normal children of all ages, with a specific focus on young children, and to investigate age differences in foot pressure patterns. The Tekscan HR Mat pedobarographic system for pressure measurement was used in a protocol that included dynamic testing at walking speed for 146 normal children (age range 1.6-14.9 years), 79 boys and 67 girls. Data on relative force and timing were obtained for five foot segments (heel, lateral midfoot, medial midfoot, lateral forefoot, and medial forefoot). Analysis of variance (ANOVA) techniques were applied to determine if there were any age-related differences in foot pressure profiles in children across four a priori variables of the pedobarograph: % initial stance on the heel, % stance at midfoot onset, maximum % force on the heel, maximum % force at midfoot. Differences in foot pressure profiles varied across three age groups: (1) Group 1: <2 years; (2) Group 2: 2-5 years; and (3) Group 3: >5 years. Age-related differences in initiation patterns, force transmission, and amount of time spent on each foot segment provide evidence for the maturation of foot pressure profiles from a flat foot pattern in young children to a curvilinear pattern in older children influenced by foot arch activity (Alvarez et al., 2008).

In our study, changes in pressure and force transmission during dynamic measurement in the middle third of the foot in swimmers were directly correlated with the age of the subjects, with subjects aged over 10 years showing a higher risk (rho=0.215; p=0.026). The risk in the heel region had a direct negative correlation with the frequency of swimming participation (rho=-0.452; p=0.003). A lower risk was found in subjects who participated more frequently and for longer durations in swimming, correlating with the study of the aforementioned authors.

In the study by Müller S. and colleagues, 7788 children participated, 48% male and 52% female. For static foot geometry, foot length and width were quantified in a standing position. Dynamic foot geometry and loading were assessed during walking on a path at self-selected speed (Novel Emed X, 100 Hz, 4 sensors/cm2). Contact area (CA), peak pressure (PP), force-time integral (FTI), and arch index were calculated for the total, forefoot, midfoot, and rearfoot. The results show that most static and dynamic foot characteristics continuously change during growth and maturation. Static foot length and width increase with age from 13.1 ± 0.8 cm (length) and 5.7 ± 0.4 cm (width) in the youngest to 24.4 ± 1.5 cm (length) and 8.9 ± 0.6 cm (width) in the oldest. The mean walking speed was observed as 0.94 ± 0.25 m/s. Static and dynamic foot measures change differently during growth and maturation (Müller et al., 2012).

Comparing with our study, foot length and width increase with age, while swimmers had longer and wider feet, but without significant statistical difference, correlating with the mentioned study.

The study by Wang J. was the first to use a three-dimensional laser surface scanner to measure parameters of the medial longitudinal arch (MLA) in children aged 3-12 years in China. The study involved 1744 children (871 girls, 873 boys). Height and weight were within normal range according to Chinese growth standards from 2005. Gender composition among groups was not statistically significant (p = 0.387). Due to the absence of significant differences between left and right foot data, mean values of both feet were used for further analysis. Foot length (FL) and navicular height (NH), arch index (AI), and arch volume (AV) significantly varied with age in weight-bearing and non-weight-bearing positions. Age-related distribution characteristics of these parameters indicate that MLA improves with age (Wang et al., 2022).

In our study, participants aged 6 to 16 years were involved. There was no statistically significant difference in participant distribution by gender ($\chi 2$=1.122; p=0.289). There was no statistically significant difference in foot size (p=0.836), and therefore, the study partially correlates with ours where we found that medial arch height improves with growth, development, and duration of engagement in competitive swimming.

Dynamic pedobarography assessed foot impulses in 102 participants across five predetermined age groups (2-3, 4-6, 7-10, 11-14, 15-17 years). Each pressure map (3 per foot per child) was divided into anatomical foot regions: hallux, heel, medial forefoot, lateral forefoot, lesser toes, and midfoot. Impulse was calculated for each region and used to generate regional percentage impulses and impulse ratios to assess anteroposterior and mediolateral balance within the foot. The impulse through the midfoot was highest in the youngest age group, with correspondingly lower impulse through the medial forefoot. As age advanced, midfoot impulse decreased, and forefoot balance shifted slightly more medially (Dulai et al., 2021). In our study, dynamic analysis of impulse described altered or normal foot. The analysis showed that with aging and participation in competitive swimming, foot condition improved. The foot was altered in children in the youngest age group and in children not engaged in competitive swimming.

Our study included a comparison with 6 studies conducted by various authors worldwide. It is based on research investigating foot arch analysis in children engaged in competitive swimming. Consistent with the results of these studies, during growth and development, competitive swimming positively influenced foot arch development, thus recommended as a sport from the school period to prevent the risk of musculoskeletal changes.

CONCLUSION

Swimming does not significantly alter the transverse arch of the foot. Research findings suggest that swimmers had better force transmission and pressure distribution, especially on the lateral part of the foot, whereas non-swimmers had higher pressure on the medial (inner) part of the foot arch.

By analyzing the length of time spent swimming, it was determined that children who started swimming at a younger age had better foot status compared to those who began their training process after the age of 10. This leads to the conclusion that the duration of swimming significantly influences foot development.

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Conflict of Interest

The authors do not have any conflicts of interest to disclose. All co-authors have reviewed and concurred with the manuscript's content, and no financial interests need to be reported.