Correlations between foot defects and balance reactions among young school-children

Korelacje między wadami stóp a reakcjami równoważnymi u dzieci w młodszym wieku szkolnym

Jacek Wilczyński, Michał Paprocki

Posturology Laboratory, Collegium Medicum, Jan Kochanowski University, Kielce, Poland

Medical Studies/Studia Medyczne 2020; 36 (4): 264–271
DOI: https://doi.org/10.5114/ms.2020.102320

Key words: balance reactions, foot defects, longitudinally flat foot, transversely flat foot, planovalgus foot.

Słowa kluczowe: reakcje równoważne, wady stóp, stopa płaska podłużnie, stopa płaska poprzecznie, stopa płasko-koślawa.

Abstract

Introduction: The shape of the lower limb axis and the foot arch are an integral element of body posture. Therefore, foot defects are wrongly perceived as a local problem.
Aim of the research: To analyse the correlations between foot defects and balance reactions in school-children.
Material and methods: The study included a group of 132 girls aged 9–10 years. There were 103 (73%) children with foot defects, and 29 (27%) without these defects (normal). The foot deformities were examined with the 2D Foot CAD podoscanner, while balance reactions were assessed with the Zebris FDM-S dynamographic platform.
Results: Among girls with foot defects, significant correlations occurred regarding: angle btw. Y and major axis, deg. and width R ($p = 0.022$) and width L (left foot) ($p = 0.039$); heel angle R and path length ($p = 0.019$) and average velocity ($p = 0.020$); Wejsflog index R and path length ($p = 0.021$), and average velocity ($p = 0.023$), and deviation X ($p = 0.038$), and deviation Y ($p = 0.038$). Wejsflog index L was significantly correlated with: path length ($p = 0.003$), average velocity ($p = 0.003$), length of major axis ($p = 0.006$), deviation X ($p = 0.035$), deviation Y ($p = 0.035$), forefoot R ($p = 0.012$), backfoot R ($p = 0.001$), backfoot L ($p = 0.001$).
Conclusions: There were significant correlations between foot defects and balance reactions. Significant differences between the group with foot defects and normal in equivalent reactions occurred for angle between Y and major axis. Girls with foot defects had significantly higher values of this variable.

Streszczenie

Wprowadzenie: Kształt osi kończyn dolnych oraz wysklepienie stóp stanowią integralny element postawy ciała. Wady te niesłusznie postrzega się jako problem o charakterze miejscowym.
Cel pracy: Analiza zależności pomiędzy wadami stóp a reakcjami równoważnymi u dzieci w wieku szkolnym.
Materiał i metody: Badaniami objęto grupę 132 dziewczynek w wieku 9–10 lat. Dzieci z wadami stóp było 103 (73%), a bez tych wad (norma) 29 (27%). Stopy badano podoscanem 2d Foot CAD, natomiast reakcje równoważne oceniono za pomocą platformy dynamograficznej Zebris FDM S.
Wyniki: W grupie z normą stwierdzono istotną korelację między Deviation Y (mm) a wskaźnikiem Wejsfloga P ($r = -0.206$, $p = 0.036$). U dzieci z wadami stóp istotne korelacje wystąpiły między: kątem nachylenia osi Y i głównej osi (mm) a szerokością stopy prawej ($p = 0.022$) i szerokością stopy lewej ($p = 0.039$); kątem piętowym prawym a długością ścieżki (mm) ($p = 0.019$) oraz średnią prędkością ($p = 0.020$); wskaźnikiem Wejsfloga prawej stopy a długością ścieżki ($p = 0.021$), oraz średnią prędkością ($p = 0.023$) oraz odchyleniem X ($p = 0.038$) i odchyleniem Y (mm) ($p = 0.038$). Wskaźnik Wejsfloga lewej stopy istotnie skorelowany był z: długością ścieżki ($p = 0.003$), średnią prędkością ($p = 0.003$), długością większej osi ($p = 0.006$), odchyleniem X ($p = 0.035$), odchyleniem Y ($p = 0.035$), średnim rozkładem obciążenia przodostopia strony prawej ($p = 0.012$), średnim rozkładem obciążenia tyłostopia strony prawej ($p = 0.001$), średnim rozkładem obciążenia tyłostopia strony lewej (%) ($p = 0.001$).
Wnioski: Wystąpiły istotne zależności między wadami stopy a reakcjami równowagi. Znaczne różnice między grupą z wadami stóp i w normie w reakcjach równoważnych obejmowały kąt nachylenia osi Y i głównej osi. Dziewczęta z wadą stóp miały istotnie wyższe wartości tej zmiennej.

Introduction

Foot defects are the result of genetic and environmental factors [1]. The shape of the lower limb axis and the foot arch are an integral element of body posture. Therefore, these defects are wrongly perceived as a local problem [2]. Although their generalised effect on body posture and gait is emphasized, the therapy of foot defects is still limited to local corrections. Therefore, orthopaedic equipment in the form of corrective inserts and kinesiotherapy is used. In severe forms of defects, surgical treatment is required. The effectiveness of therapy understood in this way, focused on local correction, is not satisfactory. The reasons for this situation should be seen in reducing the problem only to the local distorting mechanism [3]. Additionally, in the traditional approach to correcting these defects, slight deviations from the normal development of the feet are considered temporary features, which the child usually grows out of [4]. The reasons for foot defects, however, should be related to disorders of the comprehensive pattern of sensorimotor development. There is a feedback relationship between the shaping of the spatial architecture of the feet and hip joints and their functional development. This development is integrated into the whole sensorimotor functions of the body. It is based on innate, comprehensive movement patterns [5]. Foot defects are a compensatory consequence of disturbances in physiological development in higher body segments or they also initiate compensatory changes [6]. Abnormal foot development relates to disturbed sensorimotor development of the child. Their examination should always be carried out taking the complex movement pattern of the lower limb and the whole body into account [7]. The task of therapy should only be to restore conditions for further physiological development of the entire lower limb. Nothing replaces the undisturbed, physiological development of a child based on genetically conditioned, comprehensive movement patterns [8].

In our opinion, foot defects are the result of the lack of ability to resist gravity. The antigravity system, associated with the function of the central nervous system and balance, plays an important role here [9]. For this system to function properly, it is necessary to develop reflexes, sensory information, muscle tone, postural tension, postural and motor patterns, as well as postural control [10–12]. A properly functioning antigravity system is the basis for developing the ability to adopt and maintain correct body posture and curvatures of the feet. As a result of dysfunction of this system, and especially the reduction of postural tension, children become inefficient in overcoming the force of gravity and develop body posture defects, including those related to the feet. In this situation, the possibility of assuming stable posture is assured by the compensatory system [13, 14].

Children with reduced postural tension, unable to sufficiently stabilise the head, shoulder girdle, trunk, and iliac girdle, compensate for these deficiencies by automatically activating substitute stabilisation. Passive stabilisation takes place, which is obtained by manipulation of the support plane and projection of the centre of gravity or by using passive periarticular elements. The projection of the body's centre of gravity then extends beyond the limits of the support quadrilateral. The consequence of compensation using passive periarticular elements is the shifting of the centre of gravity beyond the axis of a given joint, so that the muscular stabilisation of the joint with passive resistance can be replaced, mainly by that of the ligaments [15, 16]. However, this entails a whole series of irregularities. Moving any segment forward or backward immediately results in the displacement of adjacent sections in opposite directions. Thus, the entire compensatory system is created, in which incorrect settings apply to all body segments, from the pelvis up through the spinal joints to the head position and from the pelvis down through the knee joints to the position of the feet [17, 18]. The second compensation method is excessive proximal or distal stabilisation activated on the basis of reflex tonic activity. The effect of both asymmetrical compensatory mechanisms is pelvic torsion in the flexion mechanism forward on the overloaded side, and in extension towards the back. A similar situation applies to excessive distal stabilisation, which is manifested by irregularities in the positioning of the lower limb joints [19, 20]. Primary protection against triangulation of the lower limb joints in children with a proximal tension deficit is also the manipulation of the centre of gravity projection and distal fixation. A very common manoeuvre here is the tendency to create an additional knee support point, which results in flexion and valgus of the knees, ankles and feet. As a consequence of compensation, hyperextension of the hip, knee and ankle joints also appears, usually accompanied by appropriate foot shape [21]. Their incorrect load is the basic reason for their incorrect shape. Most often, as a result of overloading the forefoot, a flat-valgus foot develops, while overloading the heel, or rather relieving the forefoot, creating a tendency to shape a seemingly hollow foot. Such a shape is acquired due to activation of the tonic grip reflex of the foot [22].

Aim of the research

The aim of the study was to analyse the correlations between foot defects and balance reactions in school-children.

Material and methods

The study included a group of 132 girls aged 9–10 years. There were 103 (73%) children with foot defects, and 29 (27%) without these defects (normal). Research was conducted in 2017 at Primary School No. 3 and 24 in Radom (Poland). All research procedures were carried out in accordance with the applicable 1964 Declaration of Helsinki and with the consent of the University Bioethics Committee of Jan Kochanowski University in Kielce, No. 23/2016.

Foot defects were examined with the 2D Foot CAD. This device is an advanced tool for digital foot analysis. Measurements of many parameters, angles and axis of the foot were performed. The CCD (charge coupled device) transducer was used in the Foot CAD podoscanner, which, in practice, meant that both the part of the foot that adhered to the glass and also the part that was a few cm above were scanned very carefully. This resulted in an accurate (1 : 1 scale) result and foot print. The following parameters were analysed: length R and L (right and left foot) (cm), width R, hallux valgus angle R and L (°), varus angle R and L (°), heel angle R and L (°), Wejsflog index R and L and Clarke angle R and L (°).

Balance reactions were examined via the Zebris FDM-S dynamographic platform. The device recorded the distribution of pressure on the plantar side of the foot (COP). The following parameters were analysed: ellipse area (mm^2) demonstrating the total path length that COP has travelled in both planes during oscillation, COP path length, representing the length of the path (mm), COP average velocity, indicating the average velocity of the subject (mm/s), length of minor axis representing the length of the smaller axis in the balance test on the subject (mm), length of major axis, indicating the length of the larger axis in the balance test on the subject (mm), angle btw. Y and major axis, deg., measuring the inclination angle of the Y and main axis during the test (mm), deviation X representing the average oscillation along the X axis (mm) and mean lateral deflection (mm), i.e. the average distance between extreme deviations of the centre of pressure of the feet in the lateral plane, deviation Y showing average oscillation along the Y axis (mm), forefoot R exhibiting the average load distribution of the forefoot R (%), backfoot R showing the average load distribution (%), total R (%) is the average load distribution of the whole right side, forefoot L is the average forefoot load distribution (%), backfoot L represents the average load distribution (%), total L represents the average load distribution on the left side (%). The tests were non-invasive and completely safe.

Statistical analysis

To determine foot and balance reaction variables, the arithmetic mean, standard deviation and confidence intervals as well as the minimum and maximum values were determined. Before the beginning of the analytical process, the Kolmogorov-Smirnov test, which shows normality of distribution, was performed, with a significance level of $p > 0.05$. This was used to select parametric methods in statistical analysis. To assess whether there were significant differences in foot and balance reaction variables between the group with foot defects and the norm, one-way analysis of variance (ANOVA) was used. The homogeneity of variance was confirmed via Levene's test ($p > 0.05$). Tukey's post hoc test for unequal volume of values was also used to assess significant group-related differences. Pearson's correlation coefficient analysis was applied to assess interdependence of the analysed variables.

Results

The values of location and dispersion measures for foot variables had different distributions (Table 1). The greatest absolute differences in the values occurred for the hallux valgus angle L variable among girls within the norm (S = 4.67). In contrast, among girls with deformities, the largest absolute differences in values occurred for the Clarke angle R variable ($S = 11.67$) (Table 1).

One-way analysis of variance showed significant differences between groups regarding foot variables. This means that the values of the variables significantly differed between the group with foot defects and the norm, and the significance level was less than 0.05 ($p < 0.05$). Homogeneity of variance was met using Levene's test ($p > 0.05$). The foot defect group had a significantly smaller Clarke angle in the right and left foot ($p = 0.001$) (Table 2).

The values of location measures and dispersion of balance reaction variables had different distributions (Table 3). The largest absolute differences in values occurred for the variable ellipse area [mm^2], among girls with foot defects (S = 220.72) and within the norm (S = 438.86) (Table 3).

One-way analysis of variance showed significant intra-group differences in variables for equivalent reactions. This means that the values of the variables significantly differed between the groups of foot defects and in the norm among girls for the variable angle btw. Y and major axis, deg [mm] ($p = 0.047$), which means that girls with foot defects had higher values than girls within the norm. Homogeneity of variance was met using Levene's test ($p > 0.05$) (Table 3).

In the group within the norm, a significant correlation was only found between deviation Y (mm) and the Wejsflog index P ($r = -0.206$, $p = 0.036$) (Table 4), whereas among girls with foot defects, significant correlations occurred between: angle btw. Y and major axis, deg. (mm) and width R ($r = -0.425$, $p = 0.022$) as well as width L ($r = -0.386$, $p = 0.039$); heel angle R and COP path length (mm) ($r = -0.431$, $p = 0.019$) and COP average velocity (mm) ($r = -0.431$, $p = 0.020$); Wejsflog index R and COP path length (mm) ($r = -0.425$, $p = 0.021$), and COP average velocity (mm) ($r = -0.422$,

Table 1. Characteristics of foot defects and balance reactions in the group with deformities and the normal group

Foot variables among girls with defects	Mean	Confidence		Min.	Max.	SD
		–0.95	0.95			
Length R	19.66	19.23	20.10	15.90	24.40	2.22
Length L	19.68	19.25	20.11	16.00	24.40	2.19
Width R	8.00	7.85	8.15	6.70	10.00	0.77
Width L	7.98	7.83	8.13	6.60	10.30	0.75
Hallux valgus angle R	5.16	4.29	6.02	0.00	26.00	4.45
Hallux valgus angle L	4.89	4.13	5.66	0.00	22.00	3.91
Hallux varus angle R	6.04	5.37	6.70	0.00	15.00	3.40
Hallux varus angle L	6.17	5.53	6.82	0.00	16.00	3.31
Heel angle R	14.48	13.79	15.16	10.00	42.00	3.50
Heel angle L	14.40	13.80	15.00	7.00	39.00	3.08
Wejsflog index R	2.46	2.43	2.48	2.12	2.89	0.12
Wejsflog index L	2.46	2.44	2.49	2.15	2.74	0.11
Clarke angle R	36.22	33.94	38.50	4.00	64.00	11.67
Clarke angle L	34.02	32.00	36.04	10.00	63.00	10.34
Foot variables among girls within the norm	**Mean**	**Confidence**		**Min.**	**Max.**	**SD**
		–0.95	**0.95**			
Length R	19.82	18.95	20.70	16.00	24.20	2.29
Length L	19.83	18.98	20.67	16.00	24.20	2.22
Width R	7.90	7.60	8.20	6.50	9.50	0.78
Width L	7.94	7.66	8.22	6.50	9.30	0.74
Hallux valgus angle R	5.59	4.20	6.97	0.00	16.00	3.65
Hallux valgus angle L	4.48	2.71	6.26	0.00	21.00	4.67
Hallux varus angle R	6.52	5.36	7.68	2.00	15.00	3.05
Hallux varus angle L	6.45	5.23	7.67	0.00	15.00	3.20
Heel angle R	14.55	13.76	15.34	11.00	20.00	2.08
Heel angle L	14.28	13.49	15.06	10.00	18.00	2.07
Wejsflog index R	2.51	2.45	2.56	2.29	2.91	0.14
Wejsflog index L	2.50	2.45	2.54	2.30	2.74	0.13
Clarke angle R	47.21	45.71	48.71	42.00	54.00	3.94
Clarke angle L	19.82	18.95	20.70	16.00	24.20	2.29

$p = 0.023$), deviation X (mm) ($r = -0.387$, $p = 0.038$) and deviation Y (mm) ($r = -0.387$, $p = 0.038$). The Wejsflog index L was significantly correlated with COP path length (mm) ($r = -0.531$, $p = 0.003$), COP average velocity (mm) ($r = -0.531$, $p = 0.003$), length of major axis ($r = -0.494$, $p = 0.006$), deviation X (mm) ($r = -0.393$, $p = 0.035$), deviation Y (mm) ($r = -0.393$, $p = 0.035$), forefoot R (%) ($r = 0.458$, $p = 0.012$), backfoot R (%) ($r = 0.571$, $p = 0.001$) and backfoot L (%) ($r = 0.571$, $p = 0.001$) (Table 4).

Discussion

Assuming and maintaining the correct posture determines the efficient functioning of the nervous system, as well as a properly shaped bone and ligament system and a well-developed and efficient muscular system. The nervous system is responsible for the phenomenon of body posture regulation, including balance [23]. Maintaining a vertical position in humans is the result of very precise muscular-neural coordina-

Table 2. Analysis of differences with ANOVA between groups with foot defects and the norm

Foot variables	ANOVA differences	
	F	*P*-value
Length R	0.12	0.73
Length L	0.11	0.75
Width R	0.36	0.55
Width L	0.06	0.81
Hallux valgus angle R	0.23	0.63
Hallux valgus angle L	0.23	0.63
Hallux varus angle R	0.47	0.50
Hallux varus angle L	0.16	0.69
Heel angle R	0.01	0.91
Heel angle R	0.04	0.84
Wejsflog index R	3.68	0.06
Wejsflog index L	1.69	0.20
Clarke angle R	**24.76**	**0.001**
Clarke angle L	**41.93**	**0.001**
Variables of balance reactions	**Differences ANOVA**	
	F	*P*-value
Ellipse area [mm^2]	2.41	0.12
Path length [mm]	0.09	0.76
Average velocity [mm]	0.18	0.67
Length of minor axis [mm]	1.18	0.28
Length of major axis [mm]	0.16	0.69
Angle btw. Y and major axis, deg. [mm]	**3.98**	**0.047**
Deviation X [mm]	0.57	0.45
Deviation Y [mm]	0.27	0.60
Forefoot P (%)	0.27	0.61
Backfoot P (%)	0.15	0.70
Total P (%)	0.16	0.69
Forefoot L (%)	0.01	0.91
Backfoot L (%)	0.00	0.99
Total L (%)	0.16	0.69

tion. Under normal conditions, posture regulation is a dynamic process and is carried out reflexively due to the coordinated action of the balance and vision organ, proprioceptors and the central nervous system. Disorders in the functioning of one of these elements may lead to deterioration of body statics [24].

It is important to understand not only the biomechanical aspect of the problem of these defects, but above all, the neurophysiological mechanisms underlying the improper way of maintaining posture. The essence of the problem of postural regulation is better reflected by the term antigravity system. This system consists of postural tension, organization of opposed innervation and proper coordination of postural and motor patterns [25]. The proper functioning of this system plays a fundamental role in everyday movement, in which it is necessary to be able to move any of the various sections of the body, while maintaining correct body positioning [26]. It is assumed that if there is no reason for disturbing the development of a child, then his/her individual, proper posture develops. It is the result of genetic and environmental factors associated with a child's activity and established habits. A child exists in changing conditions of the external environment and must adapt to them. For proper development of body posture, body balance and stability are necessary. Maintaining balanced posture is a specific movement activity that requires precise cooperation of all body segments as the result of dynamic processes taking place outside of the consciousness. The mediator in this registration and processing of afferent signals as well as the generation of decisions in the efferent ways is the central nervous system. This requires constant cooperation of the proprioceptive, vestibular, visual, auditory and extero- and mechanoreceptor systems [11].

In the authors' research, there was a significant relationship between foot defects and balance reactions. The largest amplitudes of balance reactions were observed in children with longitudinal and transverse flat-valgus. In the group within the norm, the only significant correlation was found between deviation Y (mm) and Wejsflog index R, whereas among girls with foot defects, significant correlations occurred between: angle btw. Y and major axis, deg. (mm) and width R as well as width L; heel angle R and COP path length (mm) and COP average velocity (mm); Wejsflog index R and COP path length (mm) and COP average velocity (mm) and deviation X (mm) and deviation Y (mm). Wejsflog index L was significantly correlated with: COP path length (mm), COP average velocity (mm), length of major axis, deviation X (mm), deviation Y (mm), forefoot R (%), backfoot R (%) and backfoot L (%).

In other studies, it was observed that in children aged 2–6 years with flat feet, the following showed the most correlations: age, somatic features, joint flaccidity and the frequency of knee injuries. Compared to their peers without deformations of this distal part of the musculoskeletal system, children with diagnosed flat foot have greater problems with performing motor tasks and are characterised by poorer locomotion indices, especially in terms of gait velocity. The authors clearly emphasize the deterioration of functional parameters as a consequence of flat feet [27].

Other researchers have observed a relationship between the severity of the symptoms of capsular-lig-

Table 3. Characteristics of balance reactions

Balance reactions among girls with foot defects	Mean	Confidence		Min.	Max.	SD
		–0.95	0.95			
Ellipse area [mm²]	293.98	250.84	337.12	34.00	1486.00	220.72
Path length [mm]	119.07	108.88	129.25	40.00	266.00	52.12
Average velocity [mm]	12.48	11.42	13.53	4.00	28.00	5.42
Length of minor axis [mm]	13.05	12.09	14.00	4.20	25.80	4.88
Length of major axis [mm]	26.29	23.83	28.75	9.00	87.50	12.59
Angle btw. Y and major axis, deg. [mm]	36.09	30.74	41.43	0.20	134.00	27.33
Deviation X [mm]	–7.00	–8.73	–5.26	–51.00	6.60	8.87
Deviation Y [mm]	–17.82	–20.55	–15.09	–48.50	14.90	13.94
Forefoot R (%)	41.91	39.47	44.36	15.00	72.00	12.51
Backfoot R (%)	58.09	55.64	60.53	28.00	85.00	12.51
Total R (%)	49.30	48.15	50.46	25.00	63.00	5.91
Forefoot L (%)	40.15	37.66	42.63	2.00	77.00	12.73
Backfoot L (%)	59.59	57.21	61.98	23.00	80.00	12.20
Total L (%)	50.70	49.54	51.85	37.00	75.00	5.91
Balance reactions among girls within the norm	**Mean**	**Confidence**		**Min.**	**Max.**	**SD**
		–0.95	**0.95**			
Ellipse area [mm²]	386.07	219.14	553.00	55.00	1695.00	438.86
Path length [mm]	122.66	96.45	148.86	43.00	294.00	68.89
Average velocity [mm]	13.00	10.29	15.71	5.00	31.00	7.12
Length of minor axis [mm]	14.37	11.21	17.54	6.60	40.30	8.33
Length of major axis [mm]	27.39	21.50	33.28	10.10	66.90	15.48
Angle btw. Y and major axis, deg. [mm]	24.99	16.19	33.78	0.50	82.60	23.11
Deviation X [mm]	–8.34	–11.08	–5.61	–29.80	4.20	7.18
Deviation Y [mm]	–16.31	–21.24	–11.38	–45.50	10.10	12.96
Forefoot R (%)	40.55	35.75	45.35	14.00	68.00	12.61
Backfoot R (%)	59.10	54.55	63.66	32.00	81.00	11.98
Total R (%)	48.83	46.98	50.67	37.00	58.00	4.85
Forefoot L (%)	40.45	36.49	44.40	24.00	62.00	10.40
Backfoot: (%)	59.55	55.60	63.51	38.00	76.00	10.40
Total L (%)	51.17	49.33	53.02	42.00	63.00	4.85

amentous flaccidity and the reduction of the longitudinal arch of the foot in children aged 3–15 years. The more frequent occurrence of flat foot in children with excessive capsular-ligamentous flaccidity in comparison to subjects with increased body mass suggested that the reduction of the longitudinal arch of the foot is more associated with tissue properties than the mass-dependent load value [28].In other studies, researchers looked at balance among people with transverse flat foot. It was found that balance disorders in this group occur in up to 68% of cases. Only 29% of patients with normal arching experienced balance disorders [29].

In turn, among studies performed among children, it was found that the shape of the feet has a significant impact on postural control parameters. Children with reduced tension of the muscular-ligament apparatus in static conditions had worse proprioceptive control. It has also been noted that receptors located in the

Table 4. Correlations between foot defect variables and balance reactions

Balance reactions	Normal feet	Foot defects				
	Wejsflog index right	Width right foot [cm]	Width left foot [cm]	Heel angle right [°]	Wejsflog index right foot	Wejsflog index left foot
Path length [mm]				*r* = –0.431	*r* = –0.425	*r* = –0.531
				p = 0.019	*p* = 0.021	*p* = 0.003
Average velocity [mm]				*r* = –0.431	*r* = –0.422	*r* = –0.531
				p = 0.020	*p* = 0.023	*p* = 0.003
Length of major axis [mm]						*r* = –0.494
						p = 0.006
Angle btw. Y and major axis, deg. [mm]		*r* = –0.425	*r* = –0.386			
		p = 0.022	*p* = 0.039			
Deviation X [mm]					*r* = –0.387	*r* = –0.393
					p = 0.038	*p* = 0.035
Deviation Y [mm]	*r* = –0.206				*r* = –0.387	*r* = –0.393
	p = 0.036				*p* = 0.038	*p* = 0.035
Forefoot R (%)						*r* = 0.458
						p = 0.012
Backfoot R (%)						*r* = –0.458
						p = 0.012
Forefoot L (%)						*r* = 0.571
						p = 0.001
Backfoot L (%)						*r* = –0.571
						p = 0.001

muscles and tendons play a major role in controlling posture and proprioception when considering the ankle and tarsal joints [30]. Another researcher confirms that the shape of the foot and its defects significantly affect balance parameters [31].

It was also found that parameters of dynamic balance in the frontal and sagittal planes among children with foot deformities were statistically significantly different from all analysed parameters of dynamic balance noted for healthy children. In children with foot defects, values of these parameters were higher than in healthy subjects [32].

Other studies have shown that tarsal valgus may be a compensatory mechanism in response to postural tension deficits. From a neurophysiological point of view, this reasoning is justified. At the beginning of ontogenesis, most children present poor deep muscle performance in the lumbar-pelvic complex. This mainly concerns the transverse and oblique muscles of the abdomen, as well as the multifidus muscle, pelvic floor muscles and the diaphragm. Increased tension in the distal parts and tarsal valgus can improve central stabilisation. Only the gradual development of trunk stabilising muscles allows limb function improvement [33].

As a result of the activation of the compensatory mechanism, a child gradually begins to stiffen or misalign individual body parts (including limbs) in order to achieve distal body stabilisation. It is probable that the development of incorrect adjustment and balance reactions that inhibits the progress in the development of postural tension and postural equalisation in all planes is the cause of foot deformities [34].

Conclusions

There were significant correlations between foot defects and balance reactions. Significant differences between the group with foot defects and the normal group in equivalent reactions occurred for angle btw. Y and major axis. Girls with foot defects had significantly higher values of this variable.

Conflict of interest

The authors declare no conflict of interest.

References

1. Zukunf-Huber B. Trójpłaszczyznowa manualna terapia stóp u dzieci. Urban & Partner, Wrocław 2013.
2. Araújo FA, Martins A, Alegrete N, Howe LD, Lucas R. A shared biomechanical environment for bone and posture development in children. Spine J. 2017; 17: 1426-1434.
3. Anker LC, Weerdesteyn V, Van Nes IJ, Nienhuis B, Straatman H, Geurts AC. The relation between postural stability and weight distribution in healthy subjects. Gait Posture 2008; 27: 471-477.
4. Rampal V, Rohan PY, Assi A, Ghanem I, Rosello O, Simon AL, Gaumetou E, Merzoug V, Skalli W, Wicart P. Lower-limb lengths and angles in children older than six years: reliability and reference values by EOS® stereoradiography. Orthop Traumatol Surg Res 2018; 104: 389-395.
5. Bac A, Woźniacka R, Szaprów T. Ocena ilości i rodzaju wad stóp w stosunku do prawidłowo wysklepionych u dzieci w wieku przedszkolnym i wczesnoszkolnym. Fam Med Prim Care Rev 2008; 10: 1278-1282.
6. Tyagi V, Strom R, Tanweer O, Frempong-Boadu AK. Posterior dynamic stabilization of the lumbar spine review of biomechanical and clinical studies. Bull Hosp Jt Dis 2018; 76: 100-104.
7. Brink Y, Louw QA. A systematic review of the relationship between sitting and upper quadrant musculoskeletal pain in children and adolescents. Man Ther 2013; 18: 281-288.
8. Binkley TL, Specker BL. The negative effect of sitting time on bone is mediated by lean mass in pubertal children. J Musculoskelet Neuronal Interact 2016; 16: 18-23.
9. Szopa A, Domagalska-Szopa M. Postural stability in children with hemiplegia estimated for three postural conditions: standing, sitting and kneeling. Res Dev Disabil 2015; 39: 67-75.
10. Czaprowski D, Stoliński Ł, Tyrakowski M, Kozinoga M, Kotwicki T. Non-structural misalignments of body posture in the sagittal plane. Scoliosis Spinal Disord 2018; 13: 6.
11. Domagalska-Szopa M, Szopa A. Postural orientation and standing postural alignment in ambulant children with bilateral cerebral palsy. Clin Biomech 2017; 16: 22-27.
12. Bobath B. Abnormal postural reflex activity caused by brain lesions. Butterworth-Heineman, Oxford 1991.
13. Sá CDSC, Boffino CC, Ramos RT, Tanaka C. Development of postural control and maturation of sensory systems in children of different ages a cross-sectional study. Braz J Phys Ther 2018; 22: 70-76.
14. Calloni SF, Huisman TA, Poretti A, Soares BP. Back pain and scoliosis in children: when to image, what to consider. Neuroradiol J 2017; 30: 393-404.
15. Drzał-Grabiec J, Rachwał M, Trzaskoma Z, Rykała J, Podgórska-Bednarz J, Cichocka I, Truszczyńska A, Rąpała K. The foot deformity versus postural control in females aged over 65 years. Acta Bioeng Biomech 2014; 16: 75-82.
16. Pfeiffer M, Kotz R, Ledl T, Hauser G, Sluga M. Prevalence of flat foot in preschool-aged children. Pediatrics 2006; 118: 634-639.
17. Hall LM, Brauer S, Horak F, Hodges PW. Adaptive changes in anticipatory postural adjustments with novel and familiar postural supports. J Neurophysiol 2010; 103: 968-976.
18. Hedberg-Oldfors C, Darin N, Olsson Engman M, Orfanos Z, Thomsen C, van der Ven PFM, Oldfors A. A new early-onset neuromuscular disorder associated with kyphoscoliosis peptidase (KY) deficiency. Eur J Hum Genet 2016; 24: 1771-1777.
19. Kim HY, Cha YH, Chun YS, Shin HS. Correlation of the torsion values measured by rotational profile, kinematics, and CT study in CP patients. Gait Posture 2017; 57: 241-245.
20. Derlich M, Kręcisz K, Kuczyński M. Attention demand and postural control in children with hearing deficit. Res Develop Disabil 2011; 32: 1808-1813.
21. Schaffer P, Daraiseh N, Daum L, Mendez E, Lin L, Huth M. Pediatric inpatient falls and injuries: a descriptive analysis of risk faktors. J Spec Pediatr Nurs 2012; 17: 10-18.
22. Ludwig O, Hammes A, Kelm J, Schmitt E. Assessment of the posture of adolescents in everyday clinical practice: intra-rater and inter-rater reliability and validity of a posture index. J Bodyw Mov Ther 2016; 20: 761-766.
23. Bobath K. Neurophysiological basis for the treatment of cerebral palsy clinics in developmental palsy. Mac Keith Press 1980.
24. Czesna S, Raczkowski J. Ocena zachowania równowagi u osób ze stopą poprzecznie płaską i związane z tym upadki. Fizjoter Pol 2015; 15: 90-96.
25. Trzcińska D, Olszewska E. Cechy pantograficzne stóp dzieci i młodzieży w różnych okresach rozwojowych. Postęp Rehabil 2006; 1: 47-53.
26. Puszczałowska-Lizis E, Ciosek J. Shape of the feet and its relationship with body composition in pre-school children. Medical Studies 2017; 33: 214-221.
27. Lin CJ, Lai KA, Kuan TS, Chou YL. Correlating factors and clinical significance of flexible flatfoot in preschool children. J Pediatr Orthop 2001; 21: 378-382.
28. Walczak M, Misterska E. Ocena wpływu wybranych parametrów morfologicznych na występowanie stopy płasko-koślawej u dzieci. Nowiny Lekarskie 2008; 77: 343-346.
29. Czesna S, Raczkowski J. Ocena zachowania równowagi u osób ze stopą poprzecznie płaską i związane z tym upadki. Fizjoter Pol 2015; 15: 90-96.
30. Wiernicka M, Kaczmarek D, Kamińska E, Ciechanowicz-Kowalczyk I, Cywińska-Wasilewska G, Łańczak-Trzaskowska M, Warzecha D. Kontrola postawy ciała w zależności od wydolności stóp u dzieci z bocznym skrzywieniem kręgosłupa. Fizjoter Pol 2008; 8: 299-309.
31. Hertel J, Gay MR, Denegar CR. Differences in postural control during single-leg stance among healthy individuals with different foot types. J Athl Train 2002; 37: 129-132.
32. Szczepanowska-Wołowiec B. Równowaga dynamiczna u dzieci z wadami postawy w wieku 10–12 lat ze środowiska wiejskiego. Praca doktorska. UJK, Kielce 2010; 309-312.
33. Matyja M, Gogola A. Prognozowanie rozwoju postawy dzieci na podstawie analizy jakości napięcia posturalnego w okresie niemowlęcym. Neurol Dziecięca 2007; 16: 49-56.
34. Wilczyński J, Bieniek K. Canonical correlations between somatic features and postural stability in children aged 10-12. Medical Studies 2019; 35: 93-99.

Address for correspondence:

Prof. Jacek Wilczyński
Posturology Laboratory
Collegium Medicum
Jan Kochanowski University
Al. IX Wieków 19
25-317 Kielce, Poland
Phone: +48 603 703 926
E-mail: jwilczynski@onet.pl