

Preliminary data on foot parameters of Polish boys aged 1-11

Wstępne dane dotyczące parametrów stóp chłopców z Polski w wieku 1-11 lat

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Abstrakt

Wymiary stóp dzieci zależą od płci i wieku. Jednak, ze względu na trend sekularny, a także zmiany demograficzne, wymiary stóp mogą ulec zmianie. W latach 2007-13 IPS przeprowadził pomiary antropometryczne w galeriach handlowych, w miastach Polski. Projekt Akademia Zdrowej Stopy został zrealizowany dzięki inicjatywie firmy BARTEK i jej wsparciu finansowemu. Przebadano 4996 chłopców w wieku 1-11 lat. Zmierzono 7 parametrów mających decydujący wpływ na wymiary kopyt i obuwia. Równolegle wykonano plantogramy, w których wyznaczono kąt Clarke'a oraz kąty alfa, beta i gamma służące jako wskaźniki kształtu stopy.

Abstract

It is an obvious fact, that dimensions of children's feet depend on gender and age. However, due to the secular trend, as well as demographical changes the dimensional parameters of the feet may change. In years 2007-13 IPS carried out anthropometric measurements in malls in cities of Poland. The project called The healthy Foot Academy was realized thanks to the initiative of BARTEK company and its financial support. 4996 boys aged 1-11 were examined. 7 parameters, having a decisive impact on the dimensions of lasts and footwear, were measured. Simultaneously there were made plantograms, in which the Clarke's angle were determined, as well as α, β, γ angles used as indicators of the foot shape.

Słowa kluczowe: pomiary antropometryczne, stopa, chłopcy, wymiary stóp

Keywords: anthropometric measurements, foot, boys, foot dimension

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1. Introduction

Children's feet are vulnerable to deformities because of their delicate structure [1]. Not only skin is open to injuries caused by uncomfortable footwear but also foot skeleton can be damaged by improper dimensions of footwear [2,3,4]. Moreover, improper shoes via static and dynamic interactions can affect other parts of human body like knees, hips, spine.

The most important step in footwear designing - especially in children shoes - is to create a proper solid of last with right dimensions. Information about correct dimensions of footwear design is obtained by anthropometric measurements. In children, these kind of measurements should be repeated periodically ever 10 years. Unfortunately, recent data of children feet from anthropometric studies comes from 1985 (representative cohort of children age 1-15 years old). Therefore, initiative of BARTEK company has got a greater value – organizing the Healthy Foot Academy (known as AZS BARTEK) give the chance to provide data from anthropometric measurements and orthopaedic examination. Measurement were carried out in years 2007-2013.

2.Introduction

2.1.Materials

The research was carried out in malls in specially organized mini-office located in big malls in major cities of Poland (Fig. 1). An imprint of the foot was made using a podograph. The next step was to perform anthropometric measurements directly on the child's foot. Children were standing astride and their feet were evenly loaded. Clarke's as well as alpha, beta, gamma angles were determined on the prints.



Fig. 1. Mini-office, where the research was carried out with logo of Healthy Foot Academy known as AZS BARTEK (Polish: Akademia Zdrowej Stopy Bartek).

The results were statistically analysed, taking into account the age criterion and the size of the foot. As it is shown in Tab. 1, 4996 boys aged 1-11 were examined.

Attribution to the age group was made according to the following rule:

The age was an average value of children's ages in the given group eg. Age group 3 included children which were no younger than 2 years, 6 months, 1 day and no older than 3 years and 6 months.

Tab. 1. The number of children in respective age groups

Age	N
1	689
2	1035
3	836
4	691
5	548
6	370
7	330
8	209
9	145
10	93
11	50
Total:	4996

2.2 Method

The following parameters, having a decisive impact on the dimensions of lasts and footwear, were measured using an anthropometrical calliper, a tape measure and an altimeter [5,6,7,8]. Parameters were measured on the right foot.

- Foot length - determines a shoe size
- Forefoot width – determines the width dimensions of the last and additionally it is one of the parameters of “the last’s width” as well as ball girth
- Ball girth – determines the forepart circumference of the last
- The first metatarsal head height – determines the last forepart height
- Toe height(the first toe height) – determines the last forepart height
- Height of the lateral ankle – are useful to control the quarter’s height in shoes and ankle boots
- Height of the medial ankle - are useful to control the quarter’s height in shoes and ankle boots



Fig. 2. Basic foot measurements.

Simultaneously there were also made plantograms, in which the Clarke’s angles were determined, as well as alpha, beta and gamma angles used as indicators of the foot shape.

The α angle is the angle between the tangent line to the medial edge of the big toe mark and the line perpendicular to the longitudinal axis of the foot, drawn from points mt.t. The angle β , on the other hand, is between the tangent line to the lateral edge of the trace of the fifth toe and the line perpendicular to the longitudinal axis of the foot, drawn from points mt.f. The longitudinal axis of the foot runs through the center of the heel and the center of the forefoot. The γ angle, called the heel angle, is defined by two lines tangent to the outer and inner edges of the footprint. These tangents, intersecting outside the print, create the angle γ [9,10,11]. The last angle – Clarke’s angle (CL) is determined between a line tangential to the medial edge of the footprint and line connecting the point of biggest cavity of the longitudinal arch and point tangential to the medial edge of the forefoot [6,12,13,14,15,16]. Fig. 3 shows the method of determining the alpha, beta, gamma and Clarke’s angles.

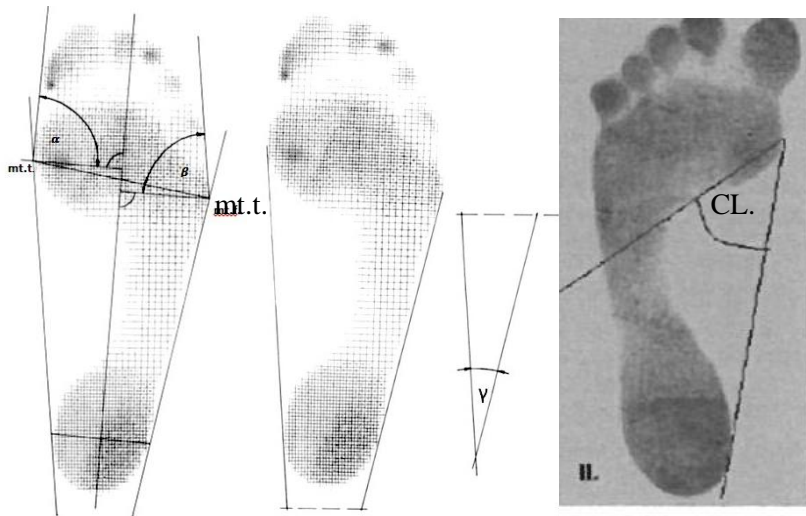


Fig. 3. The method of determining the alpha, beta, gamma and Clarke’s angles [9].

3. Results and discussion

3.1. Age groups

Tab. 2 shows the results of measurement basic parameters: foot length, forefoot width, ball girth, The first metatarsal head height, height at the tip of the big toe, height of the lateral ankle and height of the medial ankle. The analysis was carried out in age group. For each parameter there were calculated average values and range, determined by minimum and maximum value.

Tab. 2. Foot length, ball girth and forefoot width in boys, age 1-11.

Age	Foot length				Ball girth				Forefoot width			
	Aver.	Min	Max	SD	Aver.	Min	Max	SD	Aver.	Min	Max	SD
1	125,4	99	152	8,79	136,8	113	158	9,52	53,1	42	64	4,60
2	143,1	106	169	8,84	147,9	120	180	9,92	58,0	45	70	4,27
3	156,1	126	192	9,11	154,7	124	188	10,39	61,7	49	78	4,43
4	165,7	134	200	9,47	161,4	125	200	10,65	64,5	50	82	4,70
5	174,4	138	207	9,45	169,0	138	213	11,32	67,3	51	86	4,80
6	185,1	140	218	11,19	176,9	140	215	12,23	71,0	56	92	5,70
7	195,8	149	226	11,73	186,4	145	220	12,88	74,8	56	97	5,45
8	204,6	155	242	12,44	193,2	166	227	12,24	77,6	61	97	5,44
9	212,1	165	248	14,31	201,8	166	241	14,01	80,7	65	98	6,40
10	219,9	183	255	12,58	207,5	172	247	14,08	83,1	68	99	6,00
11	233,3	202	265	12,80	217,8	195	251	13,29	87,4	77	103	5,00

Data collected in table 1 show that in younger boys, the annual increase in foot length is about 18mm between 1 and 2 years old. Later the annual increases are smaller, but between 10 and 11 years old it increase till 13,4mm. It can be caused by puberty (known as puberty spike). In girls greater annual increases are earlier because of earlier puberty spike. The same dynamics of changes is observed in case

of ball girth and forefoot width. It means, that foot grow faster in first years of life. Also the puberty period is preceded by a number of changes in the somatics of the body, including an increase in the size of the foot.

The next parameters are also important for correct shoe fitting – heights of the ankles are necessary for designing proper quarter’s height in shoes and ankle boots. The last one – height at the place of ball and the tip of the big toe (toe height) determine the height of the last forepart.

Tab. 3. Height parameters of the foot in boys, age 1-11.

Age	Height of the lateral ankle				Height of the medial ankle			
	Aver.	Min	Max	SD	Aver.	Min	Max	SD
1	35,5	25	56	4,83	39,5	29	53	4,78
2	40,1	27	90	5,03	44,3	28	58	4,82
3	43,0	30	60	4,86	47,3	30	65	4,95
4	46,1	32	64	4,85	51,3	35	66	5,38
5	48,5	32	67	5,52	53,8	35	70	6,17
6	51,7	36	70	5,76	57,7	35	77	6,34
7	54,6	40	72	6,45	60,5	40	80	6,92
8	56,9	43	75	6,54	63,8	43	82	6,29
9	59,5	38	84	6,84	66,0	47	84	6,43
10	60,7	46	78	7,02	67,9	54	86	6,21
11	66,5	50	83	7,44	71,7	54	87	7,70

Age	The first metatarsal head height				Toe height			
	Aver.	Min	Max	SD	Aver.	Min	Max	SD
1	21,4	16	30	2,30	11,3	7	16	1,50
2	22,4	14	34	2,25	12,1	6	18	1,71
3	23,3	18	37	2,16	12,6	8	21	1,65
4	24,2	17	34	2,20	13,2	8	20	1,64
5	25,0	19	33	2,29	13,7	9	20	1,64

6	26,1	20	34	2,39	14,5	10	20	1,79
7	27,5	19	35	2,41	15,2	10	21	1,76
8	28,3	22	34	2,48	15,8	10	21	1,95
9	29,6	17	35	2,65	16,3	10	22	2,20
10	30,1	23	35	2,44	16,4	12	22	2,07
11	31,7	24	37	2,62	17,2	14	23	2,01

Compared to the foot length and ball girth, annual increases of ankle height and toe height are comparative smaller. In case of the toe height it is about 0,1-0,8mm annually, whereas in case of the first metatarsal head height it is about 1-1,6mm per one year. These parameters should be taken into account when designing the tip of the last. Throughout the entire period 1 – 11 years, height of both ankles increased about 31-32 mm. Lateral ankle is situated lower than medial. Difference in height is about 4-7mm. During the ontogenesis process, not only the dimensions but also the proportions of the feet change. At the beginning feet have got a triangular shape with narrow heel and wide forefoot. Then they start to look like adult feet with adult proportion. The proportions of the feet are determined using the different coefficients: ball girth – length, forefoot width – length and forefoot width – ball girth. The average values of the coefficient are shown in Tab. 3.

Tab. 4. The average values of coefficient in boys, age 1-11.

Age	Ball girth – foot length coefficient				Forefoot width – foot length coefficient				Forefoot width – ball girth coefficient			
	Aver.	Min	Max	SD	Aver.	Min	Max	SD	Aver.	Min	Max	SD
1	108,0	85	128	7,16	42,2	35	49	2,73	39,0	32	48	2,75
2	102,9	88	124	5,95	40,4	32	49	2,36	39,4	32	48	2,36
3	99,2	83	115	5,67	39,5	31	49	2,25	39,9	29	48	2,22
4	97,6	79	111	5,25	39,0	26	57	2,26	40,0	29	51	2,32
5	97,0	82	129	5,31	38,6	25	49	2,09	39,9	30	52	2,09

6	95,7	78	116	5,09	38,4	32	51	2,04	40,2	34	52	2,21
7	95,2	76	118	5,19	38,2	29	45	2,16	40,2	29	52	2,02
8	94,6	83	109	4,79	38,0	30	45	2,05	40,2	34	53	1,68
9	94,4	84	108	4,60	37,7	31	45	1,96	40,0	32	53	1,87
10	94,4	83	110	5,07	37,8	32	44	2,13	40,1	37	53	1,67
11	93,1	83	105	5,30	37,3	33	43	2,45	40,2	35	54	2,53

Two of the three presented coefficients inform us about the rate of slimming of the foot. As it is shown in the Tab. 3 during the ontogenesis the foot becomes slender. The value of the coefficients decreases from 108% till 93%. The most visible changes in foot proportions are between 1st and 2nd years old (about 5%). The same dynamic of changes is observed in the second coefficient: forefoot width – foot length. During the 11 years it changes from 42% to 37%. As it was shown at the beginning, also plantograms were made, where α , β and γ angle were determined simultaneously with Clarke’s angle.

Tab. 5. The average value of α , β , γ angle in boys, age 1-11.

Age	α angle				β angle				γ angle			
	Aver.	Min	Max	SD	Aver.	Min	Max	SD	Aver.	Min	Max	SD
1	93,5	73	111	7,33	95,7	73	121	10,06	18,5	10	30	3,81
2	92,4	73	124	6,83	94,9	70	122	8,48	16,9	8	27	3,02
3	93,2	77	118	6,38	92,9	72	124	8,32	16,2	9	29	2,75
4	94,5	75	120	6,20	90,4	73	113	7,49	16,7	8	25	2,61
5	94,7	74	120	6,59	89,9	72	111	7,05	16,5	10	24	2,41
6	94,5	79	118	5,71	88,5	69	111	7,14	16,7	10	24	2,35
7	94,8	76	116	6,11	88,2	70	109	7,21	16,3	11	22	2,35
8	95,0	83	108	5,29	88,4	75	108	6,12	16,3	10	23	2,10
9	95,2	84	107	5,12	86,5	74	105	5,99	16,3	10	25	3,28
10	95,3	83	111	5,97	87,2	70	106	6,90	16,2	12	21	2,21
11	94,6	80	109	6,70	83,8	75	102	5,50	16,7	12	22	2,05

Alpha angle informs us about the deformity of the hallux (it is also called the hallux valgus angle). It of course determines the shape of the toe tip in the last. In boys it increases from 1-10 years old only about 2 degrees. The similar indicator for the fifth toe (beta angle) decreases in the analyzed period. The change is about 12 degrees from 1-11 years old. It is commonly observed that the fifth toe in children is mostly varus shape. The last angle which is shown in the Tab. 4 inform us about the condition of forefoot part of feet (transverse arch). Data collected in Table 4 show a little decrease of gamma angle value between 1st and 2nd years old. The last age groups have the similar result of measurement gamma angle at the level of 16-17 degrees.

Tab. 6. The average value Clarke angle in boys, age 1-11.

Age	Clarke angle RIGHT FOOT				Clarke angle LEFT FOOT			
	Aver.	Min	Max	SD	Aver.	Min	Max	SD
1	14,22	-5	50	8,01	14,92	-6	48	8,22
2	15,93	-6	46	9,19	17,62	-10	71	10,07
3	19,75	-10	43	11,44	20,36	-18	54	10,69
4	26,64	0	57	11,85	24,42	-7	57	11,05
5	25,93	10	52	12,28	28,24	-6	55	11,83
6	28,83	12	53	12,27	30,01	-7	55	11,18
7	32,57	9	53	11,81	32,86	3	86	12,79
8	32,39	12	55	13,20	35,68	5	55	11,55
9	37,14	14	56	11,51	37,20	7	57	11,30
10	48,00	42	56	5,48	40,86	5	59	10,62
11	37,00	20	56	12,57	39,20	7	62	14,58

Tab. 5 summarized the Clarke, angle in boys, aged 1-11. It is commonly known, that Clarke’s angle is one of the most popular indicator of arching the foot (at the longitudinal arch). It is sensitive method which provide the information about medial arch height. Data collected from both feet shows that in the most age groups

left foot was better arched. The values of Clarke’s angle were higher. Based on these data we may conclude that Clarke’s angle increases gradually with age. In youngest group, negative values of the angles were observed. It confirms the presence of physiological flat foot till 6 years old boys.

3.2 Foot size (UE and metric size)

Simultaneously the analysis in metric sizes was carried out. At the beginning, the frequency of occurrence of foot sizes in age group was analyzed. Tab. 6 shows the results.

Tab. 7. Frequency of occurrence of foot sizes in age groups (EU seizes and metric sizes).

nf	nm	Age											
		1	2	3	4	5	6	7	8	9	10	11	
18	11	10,68	0,16										
18,5	11,5	11,87	0,31										
19	12	20,98	1,42										
20	12,5	22,03	3,26	0,07	0,07								
21	13	17,28	10,34	0,45	0,07								
21,5	13,5	10,69	17,06	3,26	0,33								
22	14	5,01	23,95	6,74	0,46	0,35							
23	14,5	0,92	18,90	13,37	2,31	0,43							
24	15	0,53	13,61	19,89	7,79	0,78	0,49						
24,5	15,5		6,90	22,47	12,34	3,55	0,46						
25	16		3,14	15,73	21,19	8,31	1,72	0,14	0,20				
26	16,5		0,74	11,12	20,86	14,63	4,48	0,72	0,40				
27	17		0,25	4,21	17,36	19,05	9,64	3,45	0,40	0,54			
27,5	17,5			1,63	10,23	19,74	12,74	4,60	0,61	0,54			
28	18			0,67	4,09	15,76	20,67	7,34	1,82	2,41			
29	18,5			0,28	1,85	9,44	15,04	14,68	5,47	2,41	1,27		
30	19			0,11	0,79	5,19	14,35	13,81	8,50	7,24	1,69		
30,5	19,5				0,13	1,65	10,22	16,12	13,77	9,38	1,69		
31	20				0,13	1,04	4,94	14,39	19,64	16,62	1,69	3,06	
32	20,5						0,09	3,33	10,36	15,99	13,14	8,05	2,45
33	21							0,80	9,50	12,15	13,40	14,83	9,20
33,5	21,5							0,46	2,73	8,70	12,87	16,95	8,59
34	22							0,23	1,58	6,68	8,04	16,95	11,04
35	22,5							0,22	0,58	3,44	7,24	15,25	14,11
36	23									1,21	2,41	8,47	12,27
36,5	23,5									0,40	1,88	7,63	13,50
37	24									0,61	0,54	4,24	11,04
Above :38	24,5										1,34	1,26	14,72

As it is shown, the the differentiation of the metric sizes in age groups is high and it is about 9-17 metric sizes in one age group. These data shows that not the age but

numeric size should be the most important information about the customer. Therefore, analysis was also performed in numeric size groups. Data collected in Tab. 7 shows that the average growth between numeric sizes is about 1,6mm for the forefoot width and about 3,7mm for the ball girth.

Tab. 8. Forefoot width and ball girth in different sizes group (EU sizes and metric sizes).

nf	nm	Forefoot width				Ball girth			
		Aver.	Min	Max	SD	Aver.	Min	Max	SD
19	12	51,0	47	58	3,09	132,1	115	150	7,26
20	12,5	53,4	45	61	3,64	137,8	123	158	8,46
21	13	53,9	45	61	3,04	137,8	122	162	7,66
21,5	13,5	55,5	46	64	3,53	141,3	120	158	7,89
22	14	57,0	47	67	3,25	145,0	120	188	8,90
23	14,5	58,6	46	70	3,35	148,1	125	171	8,62
24	15	59,7	50	72	3,19	151,3	130	180	8,12
24,5	15,5	60,9	53	70	3,24	154,0	132	178	7,82
25	16	63,0	51	78	3,50	157,3	132	182	8,18
26	16,5	64,3	50	75	3,36	161,0	138	189	8,38
27	17	66,0	50	77	3,58	165,5	134	190	8,80
27,5	17,5	67,6	58	82	3,73	168,7	143	195	8,80
28	18	69,0	60	80	3,25	172,5	143	194	8,92
29	18,5	70,8	57	83	4,05	177,6	154	213	9,48
30	19	73,1	55	88	4,04	180,8	145	204	9,53
30,5	19,5	74,3	65	88	3,89	185,6	166	215	9,10
31	20	75,8	63	88	4,06	189,3	167	215	9,39
32	20,5	77,0	68	88	3,65	192,1	160	217	9,81
33	21	80,2	70	91	3,81	198,3	175	219	9,30
33,5	21,5	71,4	71	93	4,56	202,8	178	224	10,08
34	22	82,7	73	96	3,98	206,2	185	241	9,23
35	22,5	84,1	71	93	4,69	209,4	187	232	10,8
Average „numeric” growth:		1,6				3,7			

3.3. Comparative analysis with previous research

Results of our studies (foot length and ball girth) were compare with data from anthropometric measurements in Czech Republic in 1997-8 [17] as well as Łuba measurement in big cities in Poland 1976 [18,19].

Tab. 9. Comparative analysis of the foot length measurement in boys, aged 1-11.

Age	Czech Republik 1997-98				Poland 1976				AZS BARTEK 2007-13			
	Aver.	Min	Max	SD	Aver.	Min	Max	SD	Aver.	Min	Max	SD
1	-	-	-	-	-	-	-	-	125,4	99	152	8,79
2	-	-	-	-	-	-	-	-	143,1	106	169	8,84
3	160,8	142	187	9,11	150,0	130	182	-	156,1	126	192	9,11
4	169,4	141	198	9,14	160,5	133	202	-	165,7	134	200	9,47
5	174,9	150	227	10,3	171,8	145	207	-	174,4	138	207	9,45
6	187,1	154	222	9,58	192,3	160	212	-	185,1	140	218	11,19
7	192,6	164	225	10,5	190,5	161	225	-	195,8	149	226	11,73
8	207,3	167	245	12,3	201,7	169	234	-	204,6	155	242	12,44
9	216,3	184	248	11,1	206,7	179	244	-	212,1	165	248	14,31
10	225,0	194	265	12,6	216,4	183	257	-	219,9	183	255	12,58
11	234,3	192	300	13,9	225,9	189	272	-	233,3	202	265	12,80

Tab. 10. Comparative analysis of the ball girth measurement in boys, aged 1-11.

Age	Czech Republik 1997-98				Poland 1976				AZS BARTEK 2007-13			
	Aver.	Min	Max	SD	Aver.	Min	Max	SD	Aver.	Min	Max	SD
1	-	-	-	-	-	-	-	-	136,8	113	158	9,52
2	-	-	-	-	-	-	-	-	147,9	120	180	9,92
3	161,2	145	182	9,04	159,5	136	160	-	154,7	124	188	10,39
4	167,6	143	193	9,14	166,0	135	166	-	161,4	125	200	10,65
5	174,9	149	211	10,7	172,1	147	172	-	169,0	138	213	11,32
6	182,2	155	208	9,9	180,1	156	180	-	176,9	140	215	12,23
7	190,4	160	220	11,5	187,5	158	188	-	186,4	145	220	12,88
8	197,7	163	233	12,1	197,0	166	197	-	193,2	166	227	12,24
9	205,9	173	240	11,6	205,9	175	206	-	201,8	166	241	14,01
10	212,5	182	258	12,2	210,4	177	210	-	207,5	172	247	14,08
11	220,2	185	265	13,1	219,7	177	220	-	217,8	195	251	13,29

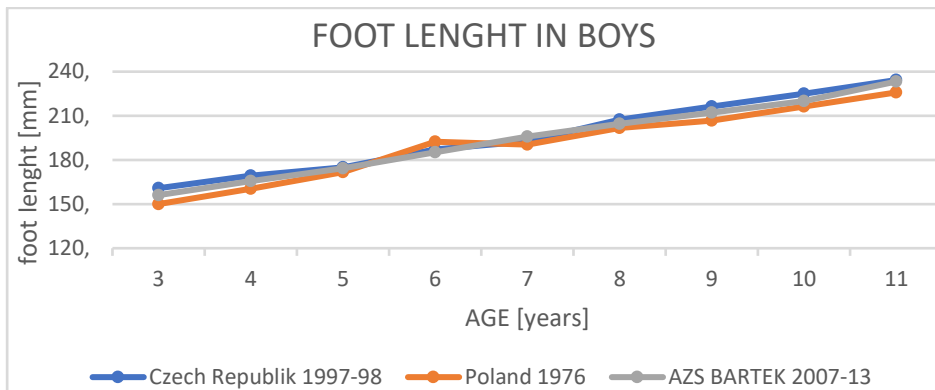


Fig. 4. Comparative analysis of the foot length measurement in boys, aged 3-11.

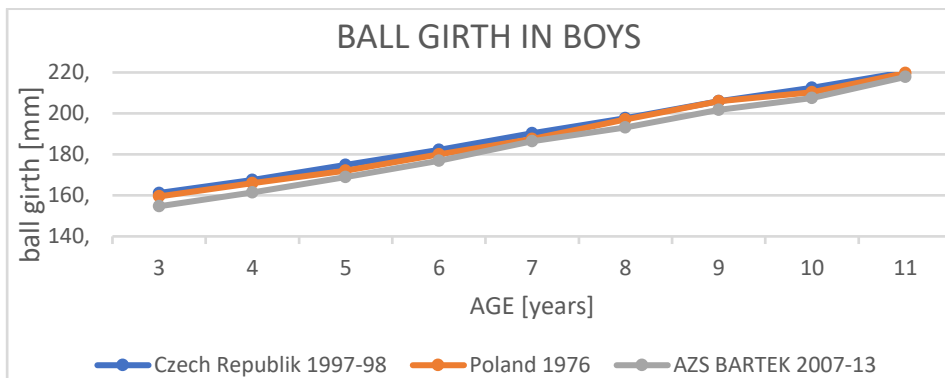


Fig. 5. Comparative analysis of the ball girth measurement in boys, aged 3-11.

The comparative analysis shows that boys from AZS BARTEK have shorter and slimmer feet than it was observed in Czech Republic in 1997-98. The results of comparative analysis between Polish population from 1976 and 2007-13 shows quite different results: boys feet from AZS BARTEK are slimmer to, but they are longer. This analysis allows us to conclude that during 3 decades the process of simmering foot was observed as well as lengthening.

4. CONCLUSION

Comparative analysis of obtained data with data from previous research revealed that the feet are different in different population. In anthropometry some kind of changes, known as secular trend are presented - especially in foot length parameter. Moreover, during the ontogenesis, feet change not only their dimensions but also their proportions, as it was shown by the different coefficients. These results show that the differentiation of last and footwear designing is necessary. Proper fitting of shoes prevent foot deformation in children.

Due to reported a wide range of parameters related to the forefoot width and a ball girth it is difficult to design lasts which would cover the main part of the population. Therefore it is recommended to produce lasts in several widths or produce shoes were width may be accommodated to various dimensions of the feet.

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