

Correlation between the footwear worn by school-age children and morphological structure of the foot

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Abstract

Introduction: Any ill-fitting footwear may contribute to causing foot deformities in children, whilst exposing them to an undue risk of sustaining accidental injuries, and promote incorrect postural development in the long run.

Aim of the research: This study aimed to probe the association between the fit of the footwear actually worn by school-age children and the morphological structure of their feet.

Material and methods: The study group consisted of 1225 school-age children, stratified by gender and age. The morphological structure of the plantar part of the foot in static conditions was assessed with the aid of a 2D podoscope. The key variables determining the foot indicators were considered. The sizes of the footwear actually worn by the subjects were compared against the referential ones, based on the length of the foot.

Results: Linear dependence was established between the size of the footwear actually worn by the children and the referential one, as recommended by the podoscope readout. The assessment of footwear fit revealed to be determined by gender.

Conclusions: Over 50% of children were found to wear the ill-fitting footwear in terms of shoe length. It can be seen that the general trend for children is to wear one size larger footwear than their foot length would suggest. Parents should primarily take into account the actual type of the foot and the fast rate of its lengthwise growth when selecting and purchasing the footwear for their children, with a view to ensuring that their feet would be provided with the right conditions for proper growth and development.

Introduction

The foot, being the supporting, cushioning, and load-bearing part of the musculoskeletal system, is shaped individually throughout one's life. Overall efficacy of its function and structural characteristics depends on complex functionality of its respective constituent parts. Delicate structure of a small child's foot is vulnerable to interaction with various external factors. Numerous studies acknowledge that a human foot is affected by genetic, environmental, and socio-economic factors, as much as by the actual type of footwear regularly worn. Dynamic development of the musculoskeletal system, characteristic for school-age children, requires special attention to be paid to the actual selection of adequately modelled footwear for them [1–4].

Rapid rate of the growth processes occurring within a child's foot, still very much in the midst of its developmental stage, along with obvious financial considerations, frequently causes basic functionality of children's footwear, i.e. effective protection against

accidental injury, shock absorption and stabilizing properties, to be disregarded upon its selection and purchase. Regularly worn footwear should facilitate problem-free interaction with the immediate environment, as well as promote overall development of the foot's key functions. Any ill-fitting footwear may contribute to causing foot deformities, abrasions, promote corns, expose a child to an undue risk of sustaining accidental injuries, whereas in the long run, it may well result in incorrect overall postural development. Selection of footwear suitable for the school-age children should therefore take into account the actual type of foot, and a rather fast rate of its lengthwise growth [5].

Exceptional versatility of children's feet makes it possible to have them squeezed into the shoes that are either too small or too tight. Wearing the tight shoes adversely affects overall development of the joints, muscles, and the circulatory system within the foot. Kinz *et al.* [6] observed in their study that out of 620 participating children, 75.5% wore the outdoor

shoes of insufficient length, whilst 84.6% wore the indoor shoes that were too short. The investigators pointed out that wearing too short footwear becomes significantly instrumental in altering both the anatomical structure and overall functionality of the foot. Poorly fitted footwear contributes to the formation of hallux valgus, with the overall risk increasing by 30%, should the outdoor shoes be two sizes too small.

Another type of adversity consists in regularly wearing oversized shoes as they appreciably hinder proper gait and make children extra prone to tripping over as the shoes have very loose fit. This may force an undue contracture of the foot in order to ensure its necessary stability. In view of all the above, making a well-informed choice of properly sized and modelled footwear for children is absolutely essential [7, 8].

As far back as antiquity, the Greek philosophers asserted that “all ill-fitting sandals make the feet sore and suffering”. Given that 90–99% of children are born with healthy feet and only 3% of adults over 60 years of age happen to have correctly formed feet, a question naturally springs to mind on the very nature of the association between the actual fit of the shoes regularly worn by children and the morphological structure of their feet [7, 8].

Aim of the research

The aim of the study was to investigate the correlations between the fit of the footwear actually worn by school-age children and the morphological structure of their feet.

Material and methods

The study group consisted of 1225 children (aged 10–15 years; 600 (49%) girls and 625 (51%) boys) (Table 1). The study was conducted between 2018 and 2021 in the area of communes from the Świętokrzyskie Voivodeship, Poland.

The inclusion criteria: consent to participate in the study, complete documentation, no diagnosed pathology of the musculoskeletal system.

The exclusion criteria: no consent to participate in the study, incomplete documentation, history of motor organ pathology as established through an interview.

Body height was measured by SECA growth meter (manufactured in Germany, 93/42/EEC, 2007/47/EC;

measurement accuracy 0.01 m). Body weight was assessed using a Tanita BC-418MA scales (manufactured in Japan; 93/42/EEC Annex II; measurement accuracy ± 0.1 kg). The morphological structure of the plantar part of the foot in static conditions was assessed with the aid of a 2D podoscan (Sensor Medica, Rome, Italy).

The following indicators were assessed:

- foot length – the line connecting the furthest points of the forefoot and hindfoot – in mm,
- forefoot width – the line joining the most extreme points on the head of the first (mtt) and the fifth metatarsal bone (mtf) – in mm,
- Clarke’s angle – the angle between the tangent of the medial edge of the foot and the line joining the point of the largest indentation and contact of the medial tangent with the foot edge – in degrees ($^{\circ}$),
- the Wejsflog (W) index – length-to-width ratio,
- the hallux valgus angle (α) – the angle between the tangent to the medial edge of the foot and the tangent of the edge of the hallux, derived from the mtt point – in degrees ($^{\circ}$),
- the angle of the varus deformity of the fifth toe (β) – the angle between the tangent of the lateral edge of the foot and the tangent of the edge of the fifth toe derived from the mtf point – in degrees ($^{\circ}$) [9, 10],
- size of the footwear was calculated against the subject’s foot’s length,
- subsequently, it was verified against the footwear actually worn by the subjects.

Statistical analysis

The results of the study were statistically processed with the aid of the R.4.1.0 software package. Basic measures of descriptive statistics were used to characterize the study material, i.e. arithmetic mean, standard deviation, minimum, maximum. Footwear for the right and left foot was assessed separately. The sizes of the footwear actually worn by the subjects were compared against the referential ones, based on the length of the foot. The χ^2 test, non-parametric Mann-Whitney-Wilcoxon test, was applied to assess the dependence of the shoe fit and gender. On the other hand, when assessing the fit of footwear against the remaining variables, expressed on a continuous scale, Spearman’s rank correlation was used. $P < 0.05$ was assumed as statistically significant.

Table 1. Basic characteristics of the study group

Variable	Girls ($n = 600$) Mean $\pm$ SD	Min.–Max.	Boys ($n = 625$) Mean $\pm$ SD	Min.–Max.	Z	P-value
Body mass [kg]	36.92 $\pm$ 12.44	16–80	37.94 $\pm$ 13.71	17–99	–0.844	0.399
Height [cm]	1.42 $\pm$ 0.14	105–173	1.43 $\pm$ 0.15	107–183	–0.862	0.389
BMI	17.88 $\pm$ 3.29	11.35–31.64	18.06 $\pm$ 3.60	11.61–36.51	–0.186	0.853

Mean – arithmetic mean, SD – standard deviation, Z – statistical values of the Mann-Whitney-Wilcoxon test for two independent samples, BMI – body mass index, p – statistical significance level.

Table 2. Footwear fit

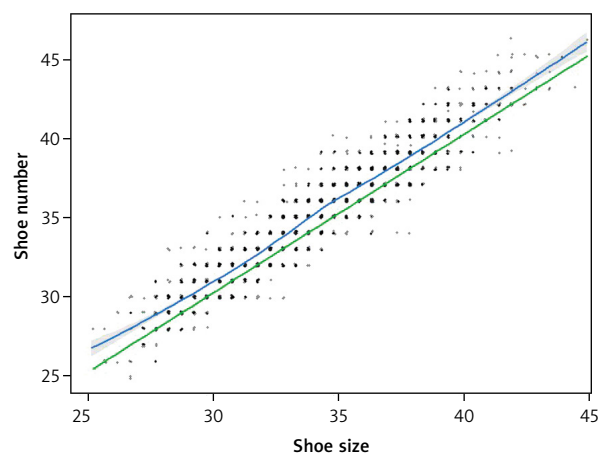
Shoe size	Left foot (n)	Left foot (%)	Right foot (n)	Right foot (%)	Both feet (n)	Both feet (%)
Correct	503	41.1	508	41.5	420	34.3
Oversized	618	50.4	623	50.9	559	45.6
Undersized	104	8.5	94	7.7	75	6.1

Results

The children under study wore oversized shoes, 50.4% of them on the left foot, and 50.9% – on the right one. Undersized shoes (too tight) were also worn, i.e. by 8.5% on the left foot, and by 7.7% of the right one. Properly sized shoes were confirmed with regard to 41.1% of them – on the left foot, and in 41.5% – on the right one (Table 2, Figure 1).

Figure 1 demonstrates a clear linear dependence between the actual footwear size and the one recommended by a podoscope, based on the foot's length ($p < 0.01$; $\rho = 0.94$). Noteworthy is the large scatter of footwear size in relation to the suggested best-fit footwear size. As can be seen from the above, the general trend for children is to wear one size larger footwear than their foot length would suggest.

The assessment of footwear fit revealed to be strongly determined by gender ($\chi^2 = 49.01$; $p < 0.01$). Even though both genders were found to wear the ill-fitting footwear, the boys tended to wear the oversized shoes, whereas the girls – far too tight (undersized) ones (Tables 3–5; Figure 2). In case of boys, 36.6% of them wear footwear according to their foot length, while 57.4% have footwear that is too big, 6.1% have footwear that is too small in relation to their foot length. 46.2% of girls wear footwear in accordance

**Figure 1.** The dependence between the actual footwear size and the one recommended by a podoscope

with their foot length, 43.7% have too big footwear, 10.2% have footwear that is too small in relation to their foot length. This shows that 53.7% of girls and 63.5% of boys have ill-fitting footwear in relation to their foot length.

The data in Tables 4 and 5 indicate that boys are more likely to wear the ill-fitting footwear than girls.

Table 3. Gender-specific footwear fit

Shoe size	Girls (n)	Girls (%)	Boys (n)	Boys (%)	Total (n)	Total (%)
Correct	554	46.2	457	36.6	1011	41.3
Oversized	524	43.7	717	57.4	1241	50.7
Undersized	122	10.2	76	6.1	198	8.1

Table 4. Difference between the shoe size actually worn by the subject and the size recommended by a podoscope readout

Gender	Foot	Mean $\pm$ SD	Min.	Max.	N
Girls	Right	0.59 $\pm$ 1.11	–3.5	4.5	600
	Left	0.58 $\pm$ 1.12	–4.0	4.5	600
Boys	Right	1.03 $\pm$ 1.18	–3.0	5.0	625
	Left	1.00 $\pm$ 1.19	–3.0	5.0	625
Total	Right	0.82 $\pm$ 1.17	–3.5	5.0	1225
	Left	0.79 $\pm$ 1.17	–4.0	5.0	1225
Whole group	Both feet	0.80 $\pm$ 1.17	–4.0	5.0	2450

Table 5. Gender-specific footwear fit

Footwear	Boys	Girls	Statistics W	P-value
Footwear fit	1.01	0.59	600698.5	< 0.01



Figure 2. Gender-specific footwear fit

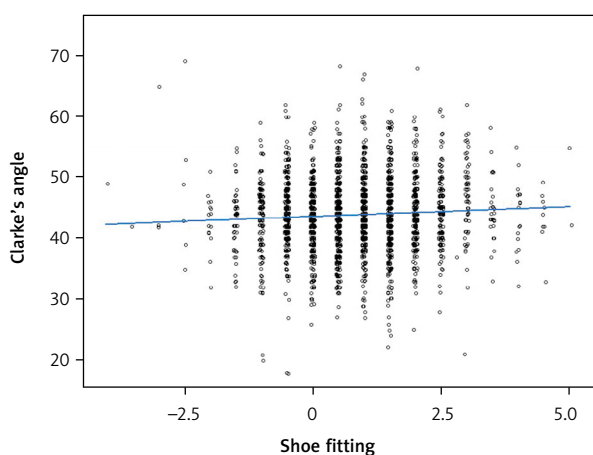


Figure 4. Dependence of Clarke's angle and the footwear fit

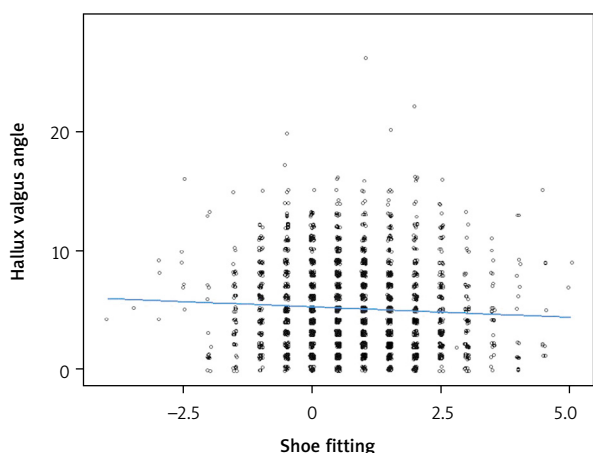


Figure 6. The dependence of the toe valgus angle and the footwear fit

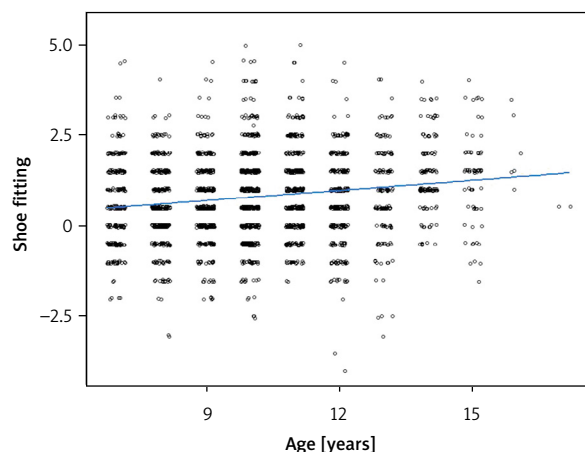


Figure 3. Age-specific footwear fit

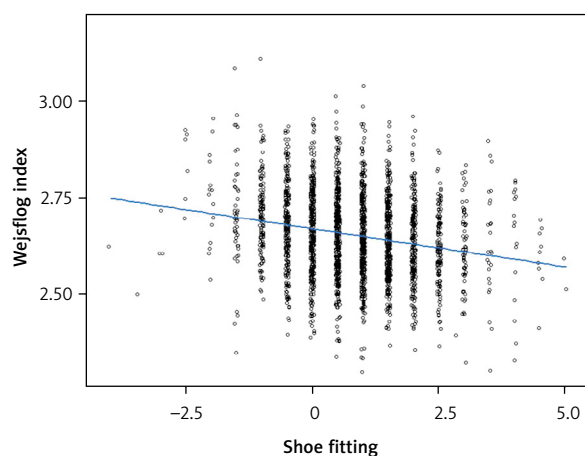


Figure 5. The dependence of Wejsflog index and the footwear fit

The dependence between age and footwear fit was assessed. A statistically significant positive dependence was observed between age and footwear fit ($r = 0.17$; $p < 0.01$) (Figure 3). It was observed that the older the children, the greater the difference between the footwear size calculated by the podoscope and the footwear worn.

Comparison of Clarke's angle and footwear fit indicated a statistically significant dependence ($r = 0.06$; $p < 0.01$) (Figure 4). It was observed that the larger the footwear, the greater the Clarke's angle.

A statistically significant dependence was also established when assessing the Wejsflog index and the footwear fit ($r = -0.21$; $p < 0.01$) (Figure 5). It was observed that the larger the footwear, the smaller the Wejsflog index.

Based on the dependence of the toe valgus angle and the footwear fit, a statistically significant association was established ($r = -0.06$; $p < 0.01$) (Figure 6). It was observed that the larger the footwear, the smaller the toe valgus angle.

Discussion

The essential factor affecting proper development of a child's foot consists in selecting properly fitting footwear. A growing child's foot exhibits different structural and functional characteristics than adult's foot. The childhood period is characterized by disharmony depending on the actual development stage, taking due account of the foot's plasticity, allometry, motor abilities, and its growth rate. The key requirements for children's footwear are grounded in the development of the child's foot and the effect of footwear's adaptation to the foot's morphology [11–13]. One of the essential variables determining the actual fit of the footwear is its length. Other important variables comprise width (metatarsal, hind-foot), joint circumference, shape of the toes [14]. Adequately selected footwear should be characterized by certain "functional allowances", which would allow for the elongation of the longitudinal arch during the foot-loading, whilst also ensuring proper development and operational functionality of the foot.

Quinlan *et al.* during 9-month observation of 9–12-year-old children, randomly selected into two groups – in which standard, or minimalist shoes were worn at school, observed that minimalist footwear affect children's balance and is recommended for children to wear [15].

González *et al.* [16], whilst comparing the length of the feet in 505 Spanish children with the footwear they regularly wore, established that 72.5% of children wore the ill-fitting footwear. We noticed the same relation in our own research as 53.9% of girls and 63.5% of boys used the ill-fitting footwear in terms of shoe length. Inadequate length of footwear disrupts overall functionality of the foot as observed by Matthias *et al.* [17], who examined the children aged 8–12 years, whereby too short a length of a shoe was established to have effectively restricted the foot's mobility. Breet *et al.* [18] examined 698 children aged 6–14 and observed that 59% of children had ill-fitting shoes, taking into account their length, and 98% of the shoes were ill-fitting in width – the shoes were too narrow. Researchers emphasized that footwear manufacturers should especially take into account the width of the produced shoes. Cranage *et al.* [1], whilst comparing the foot's functionality in the pre-school children wearing shoes, and in the pre-school children walking barefoot, noted the effect of the footwear on the alterations in their walking and running patterns. The results yielded by our own study corroborate their observations as wearing the footwear of the adequately fitted length and width may appreciably reduce overall risk of foot deformities resultant from their restricted mobility.

A statistically significant correlation between gender and the size of footwear worn was observed in our own study. The boys were much more likely to wear ill-fitting footwear, usually in terms of length, while

the girls tended to wear the shoes with smaller functional allowances. Similar results were obtained by Puszczalowska-Lizis *et al.* [2]. Kinz *et al.* [6] also reported lesser functional excess in the shoes worn by girls. Girls are more likely to be guided by "fashion" when buying their shoes and therefore they are frequently ill-fitting. Puszczalowska-Lizis *et al.* [2] examined 100 7-year-old children (50 boys, 50 girls), among whom it was observed that 40% of girls and boys wore ill-fitting footwear in relation to their foot length, as many as 74% of girls and 66% of boys wore ill-fitting footwear in terms of the length of the child's foot. In case of both genders, the length of footwear influenced the longitudinal arch of the right and the left foot, and the transverse arch of the right foot. In the case of boys, a correlation with the right and the left toe valgus angle was observed. The authors pointed out that in boys with an increased toe valgus angle, the footwear should be larger in size. The researchers noted that the study should be extended to other age groups as well as other regions of the country.

But in turn, when examining 6-year-old children, Puszczalowska-Lizis *et al.* [19] observed no relationship in the case of wearing too large shoes and the gender of the examined children. The researchers conducted observations based on the group of 100 6-year-old children and observed ill-fitting footwear in 40% of them. Longer shoes are accompanied by a greater transverse arch, and wider ones with a lower transverse arch of the foot. As evidenced by published research, the actual shoe size designation provided on the label, does not correspond to the actual inner length of the shoes [6, 7].

Also in the case of elderly people, researchers emphasize that poorly fitting shoes were worn both in terms of length and width size. It affects a large number of irregularities in the structure of the feet [20]. The type of footwear worn is also important as minimalist footwear can significantly affect the body stability and functional condition of elderly people [21–23]. An interesting study was conducted by Puszczalowska-Lizis *et al.* [24] in which it was observed that even the subjective comfort assessment of the footwear has an impact on the risk of falls in the elderly. A total group of 100 people aged between 65 and 74 years were studied; the subjects were asked to wear footwear selected by the authors of the publication for 7 days for at least 7 h a day. The authors observed that the footwear with a closed heel, Velcro fastening, and a stable sole appear to be comfortable, and wearing them may reduce the risk of falls in elderly people.

Another interesting issue is the effect of the functional allowances (extra room) offered by the footwear on the shape of the foot. The results of our study show that children tend to wear larger shoes than the actual foot length measurement indicates. Ill-fitting footwear affects the longitudinal and transverse arches of the foot. In our own study, there was a slight

tendency for the longitudinal arches to increase with a larger shoe. These results allowed us to conclude that the toe support within the shoes causes excessive longitudinal arching of the foot. Puszczalowska-Lizis *et al.* [2] offers other findings.

We noted in our own research that the more excessive the length, the smaller the transverse arch. It seems likely that the increased forefoot dimension might well be owed to wearing longer shoes. Similar correlations were reported by Puszczalowska-Lizis *et al.* in their study [25]. In the study involving 100 9-year-old girls, the authors observed that girls' footwear was ill-fitting. Footwear that was too short in relation to the length of both the left and the right foot was more common among the girls, and girls also wore footwear that was too wide. It was found that ill-fitting footwear affects the delicate structure of the girls' foot, and it is noteworthy that too wide footwear also does not have a positive influence on the child's foot formation. Too wide footwear affects the longitudinal and transverse arch of the foot, mainly the hollow foot and the appearance of the deformity of the fifth toe. Similar observations were made in our study – the larger the footwear worn by the children, the greater the Clarke's angle.

The results of our own study indicated that there was a statistically significant correlation between the length of the shoe and the angle of the toe valgus. A statistically significant correlation was also observed between a smaller shoe and a higher toe valgus angle. Kinz *et al.* [6] established in a study of 620 Japanese children that 75.5% of shoes worn were too short, and this had an impact on the incidence of the toe valgus. Too short a shoe does not give the child's foot enough space, which is acknowledged to adversely impact its correct development and overall functionality. Investigators highlight that the time actually spent wearing shoes appreciably affects the foot's morphology. In their cross-sectional study, Klein *et al.* [26] indicated a correlation between insufficient shoe length and an increased toe angle in children. Similar conclusions were drawn by González *et al.* [27] when investigating the relationship between footwear and the development of hallux valgus in Andalusian schoolchildren. The authors observed that among 38.5% of the 187 children studied, aged 3–15, the footwear length was incorrect as it was too small in relation to the child's foot, did not allow for proper development of the child's foot and correlated with the appearance of a greater toe valgus angle. These observations are consistent with the results of our own research.

In our own study, we established a correlation between the shoe length and the incidence of hallux valgus toe ($r = -0.06$; $p < 0.01$). The key observations give sufficient grounds to conclude that wearing ill-fitting shoes may be instrumental in causing detrimental changes in the foot's structure, with more adversity

still to occur in the longer perspective. The findings of this study may well prove inspirational for any well-coordinated action, principally aimed at educating the parents in applying effective preventive measures in footwear selection for their children. Insufficient awareness of potential hazards associated with the ill-fitting footwear may adversely impact overall health of their children's feet.

Bearing in mind the design of our study and the multicausality of the deformity analyzed, it is logical to consider the presence of some limitations. The study did not take account of foot deformities in other family members and we are aware that particularly toe valgus may be associated with the inheritance of this deformity [28]. In future studies, we will consider increasing the research tools used in the study, taking account of more accurate parameters of the shoes worn.

Certainly, a strong point of the article is the large number of people studied. To our best knowledge, this is one of the few studies conducted in our region. Among similar studies, the studies conducted by Puszczalowska-Lizis *et al.* [2, 19, 25], in which the authors emphasize the need to extend the research to other regions of Poland, are of great importance and invaluable contribution. Our own research just complements and extends the studies mentioned hereinabove. The studies also emphasize the need to disseminate among parents the impact of the footwear worn on the child's foot structure and its locomotor system and posture, as well as the need for continuous monitoring of children's footwear size. There is still a high percentage of children with ill-fitting footwear, which has an impact on the appearance of deformities in foot structure, and as a consequence, deformities and problems with locomotion, as well as the entire locomotor system of children and adults, can occur.

Conclusions

As over 50% of girls and boys were found to wear the ill-fitting footwear in terms of shoe length. It can be seen that the general trend for children is to wear footwear one size larger than their foot length would suggest. It was observed that the older the children, the greater the difference between the footwear size calculated by the podoscan and the footwear worn. It was observed that the larger the footwear, the greater the Clarke's angle, which may result in a tendency to appear to increase the longitudinal arch of the foot. It was also observed that the larger the footwear, the smaller the Wejsflog index. It was noted that the larger the footwear, the smaller the valgus angle. Properly selected footwear size ensures the correct development of the foot structure.

Parents should primarily take into account the actual type of the foot and the fast rate of its lengthwise growth, when selecting and purchasing appropriate

footwear for their children. This way they would make sure that their feet would be provided with the right conditions for proper growth and development, whilst precluding any potential postural stability issues in the long run.

Obviously enough, the present study findings merely provide an extra impulse to undertake further and more in-depth research into this issue as well-targeted prevention policies always prove far cheaper to introduce and pursue than running a complex and expensive therapeutic management.

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Ethical approval

Approval number: 26/2016.

Conflict of interest

The authors declare no conflict of interest.

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