INCREASING FOOT COMFORT INSIDE THE SHOES BY OPTIMIZING THE LAST SHAPE

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Throughout life, the human foot undergoes permanent transformations. Results of medical studies show that foot size stabilizes at the age of 18, when the ossification process ends. Therefore, special attention should be paid to quantifying constructive parameters of the shoe last so as not to adversely affect the natural development of the foot. To increase foot comfort inside the shoes, lasts will be designed based on anthropometric measurements by 3D imaging capture. For last and footwear prototyping, 17 children, eight girls and nine boys, aged between 3 and 7, were chosen for the study. The following steps were taken: (i) anthropometric data collection from female and male children and statistical processing of these data in order to establish constructive parameters of lasts; (ii) designing and manufacturing the last - average size - according to destination; (iii) designing and manufacturing the footwear model; (iv) creating a batch of shoes - test wearing; (v) analyzing the results of test wearing. As a result of designing and creating the new prototype lasts, and their testing through test wearing, it was concluded that: (a) the back of the last can be standardized in a proportion of 2/3 of the total length; (B) in terms of size, footwear corresponds to the shape of the foot. It follows that the new prototype lasts provide comfort inside the footwear.

Keywords: comfort, anthropometric parameters, last.

INTRODUCTION

The last is one of the most important factors in providing comfort (Zhao *et al*., 2008).

Currently, most footwear producers import last models from different countries (Italy, Turkey, etc.) that do not always comply with dimensional correlations between foot and last (Deselnicu *et al.*, 2014). This leads to footwear being manufactured on lasts whose sizes are not consistent with the foot sizes of Romanian population, with repercussions on comfort in the wearing process.

To determine the correct shape and size of lasts, anthropometric measurements of the lower limb are required, so that there would be a close correspondence between these measurements and those that amount to the internal volume of the shoe (Mihai *et al.*, 2009; Nácher *et al.*, 2006).

The objective of this study is to increase foot comfort inside the shoe by optimizing the shape of the last.

EXPERIMENTAL

To construct the spatial shape of the last, the starting point was scanning the foot and measuring its various total and partial sizes.

Method

Scanning Method Using the INFOOT System – 3D Imaging

The INFOOT USB system, model IFU-S-01 & IFU-H-01, was used for three-dimensional foot scanning (Fig. 1).

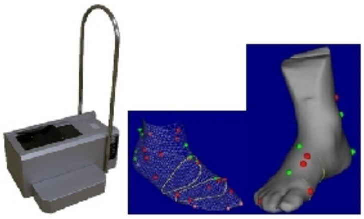


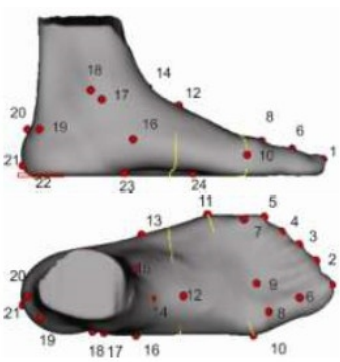
Figure 1. 3D Scanner (INFOOT) - Capturing foot sizes with the 3D Scanner

Data was processed by correctly identifying and positioning anatomical points that define anthropometric parameters of the foot. These points are predefined and are displayed by the scanning software, but they are specific to the spatial conformation of each foot, and therefore can be changed.

Positioning Anatomical Points and Measuring Anthropometric Parameters

Using INFOOT system, the right and then the left foot were scanned in a total of 17 subjects, of which eight girls and nine boys, aged 3-7.

In order to calculate foot anthropometric sizes for the analyzed subjects, 26 significant anatomical points were positioned manually for each foot (right and left). These anatomical points are shown in Figure 2:



Anatomical points of the foot: 1 - Tip of toe 1; 2 - Tip of toe 2; 3 - Tip of toe 3; 4 - Tip of toe 4; 5 - Tip of toe 5; 6 - Toe 1 joint; 7 - Toe 5 joint; 8 - Tip of metatarsal 1; 9 - Tip of metatarsal 2; 10 - Metatarsale tibiale; 11 - Metatarsale fibulare; 12 - Instep point; 13 - Tuberosity of 5th metatarsal; 14 - Tibiotalar joint; 15 - Tentative junction point; 16 - Cuboid; 17 - Sphyrion; 18 - Medial malleolus; 19 - Subtalar joint; 20 - Top of calcaneus point; 21 - Pternion; 22 - Landing point; 23 - Fore point of longitudinal arch; 24 - Rear point of longitudinal arch; 25 - Sphyrion fibulare; 26 - Lateral malleolus.

Figure 2. Positioning anatomical points (Pastina, 2012)

After positioning anatomical points, foot-specific sizes were automatically calculated. Anthropometric measurements were used to determine the shape and contour of the foot by outlining (plantar footprint). Metatarsal joints and toe directions were marked on the footprint and outline.

RESULTS AND DISCUSSIONS

To design the insole of a last, one needs to know: foot length (outline), toe and heel breadth (outline and footprint), heel amplitude length, distance between the pternion and the first and fifth metatarsal joints, the angle between the longitudinal axis (tip of the toes-heel) and the line that defines toe breadth, the angle between the longitudinal axis and the shank axis, foot angle (formed at the intersection of tangents drawn through the first and fifth metatarsal joints and heel contour), the ratio of longitudinal axis dividing toe breadth.

To set these parameters, children's foot scans were processed.

Anthropometric parameter values resulting from processing the imaging capture using 3D scanner (INFOOT) compared to those resulting from processing plantar footprints are given in Table 1.

Table 1. Comparison of average values of anthropometric parameters – INFOOT plantar footprint

Parametri antr. (INFOOT)	Picior stang	Picior drept	Media INFOOT	Media Plantogr.
L (mm)	193.3/190.5/194.7/190.1/162.5/170.6/ 197.6/165.8/190.7/188.5/185.1/163.9/ 184.8/177.6/188.6/184.7/153.7	192.0/192.6/198.0/191.7/162.8/171.8/ 197.2/164.7/190.1/187.6/183.6/162.5/ 187.3/182.2/188.0/184.4/152.3	181.52	181.16
LI (mm)	143.9/136.8/144.4/140.7/117.2/130.8/ 148.7/122.4/143.4/140.1/135.3/121.3/ 127.9/130.6/138.6/133.1/105.6	141.9/142.7/151.6/142.5/118.4/126.9/ 148.7/119.6/145.5/138.2/138.8/120.7/ 133.0/135.9/137.9/135.6/114.9	134.82	133
LV (mm)	120.4/121.2/122.8/116.8/104.6/107.5/ 128.4/102.1/120.4/115.2/116.1/99.0/ 112.4/112.9/118.2/112.8/96.8	123.0/121.1/129.1/126.8/104.2/110.2/ 114.6/101.1/118.9/114.0/115.0/100.8/ 114.9/114.8/117.2/114.9/90.5	113.8	110
ldc (mm)	80.8/71.9/74.1/79.6/66.3/69.7/82.6/75.4 /80.8/73.1/73.4/70.1/78.6/71.2/80.0/ 76.7/62.9	78.1/72.3/72.7/75.4/66.0/66.7/86.9/71.6 /81.2/71.5/74.4/69.3/78.4/72.4/78.8/ 73.4/66.7	74.21	73
Lcc (mm)	53.4/53.2/56.8/54.8/44.1/48.0/54.2/50.2 /54.0/51.9/49.7/51.8/57.5/50.8/55.1/ 55.8/48.6	53.1/52.7/56.9/55.7/43.2/47.1/55.7/51.0 /54.8/54.0/51.1/50.3/58.2/50.9/55.3/ 54.0/47.7	52.4	50
Pd (mm)	194.2/177.6/180.4/191.0/165.9/171.2/ 197.9/181.1/192.0/177.8/178.6/173.8/ 199.7/180.4/192.4/188.1/158.9	192.7/175.3/177.0/183.7/165.6/163.8/ 209.4/177.1/193.0/176.5/180.8/169.9/ 198.6/179.7/191.0/182.3/164.0	181.8	-
Pr (mm)	196.4/183.5/186.8/193.9/169.3/165.5/ 200.8/180.3/192.2/187.3/179.3/172.2/ 199.3/182.9/190.2/186.9/163.0	194.9/180.3/185.7/193.6/168.4/165.7/ 203.4/177.0/190.2/176.5/179.1/168.9/ 199.4/182.1/191.0/183.2/164.1	183.4	-

The analysis of anthropometric parameters shows that the average size is 18 (metric system) or 27 (French system), with the following parameters: α = 13°, β = 5-6°, γ = 74°, ldc = 73 mm, lda = 62 mm, Lcc = 50 mm, Lca = 36 mm, Ace = 6 mm, Aci = 7 mm, ldic = 32 mm, ldia = 41 mm, ldec = 25 mm, ldea = 37 mm, where: α = foot angle (formed at the intersection of tangents drawn through the first and fifth metatarsal joints and heel contour); β = the angle between the longitudinal axis and the shank axis; γ = the angle between the longitudinal axis and the line that defines toe breadth; L = foot length; LI = distance between the pternion and the intersection of the perpendicular from the first metatarsal joint on the longitudinal axis; LV = distance between the pternion and the intersection of the perpendicular from the fifth metatarsal joint on the longitudinal axis; Lc = distance between the pternion and the heel center; ldc = contour toe breadth; lda = footprint toe breadth; ldic = inner contour toe breadth; ldia = inner footprint toe breadth; ldec = outer contour toe breadth; ldea = outer footprint toe breadth; Lcc = heel contour breadth; Lca = heel footprint breadth; ac = heel amplitude; Ade = outer toe amplitude; Adi = inner toe amplitude; Ace = outer heel amplitude exterior; Aci = inner heel amplitude; Pd = ball girth circumference; Pr = instep circumference.

Another element to be considered, in designing both the insole and the last, is the tip of the toes-heel axis. In designing the insole, everything was calculated in relation to the axis that unites the pternion and the head of the second toe (Fig. 3).

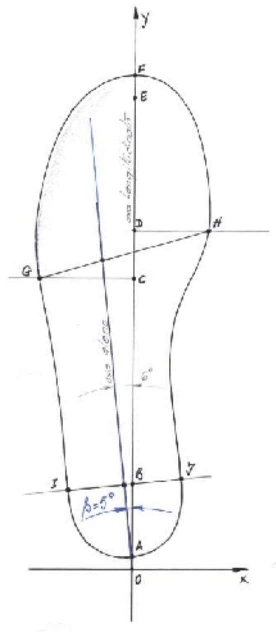


Figure 3. Insole design Nm 18 (Fr 27)

The insole of the last is designed as follows:

First, a system of axes is drawn, XOY. Starting from O, 0.025 Lp are measured (value of heel amplitude) and the rearmost point of the insole is defined, point A. Point B marks the center of the heel (0.18 Lp). Points C and D define on the axis of the first and fifth metatarsal joints, 0.62 Lp and 0.72 Lp, respectively. OE distance is the foot length. EF distance is the tolerance (2-3 mm movement tolerance and 5-15 mm toe tip shape tolerance). The shank axis is drawn through point A, forming an angle of 6° with the longitudinal axis. This angle corresponds to angle β = 5° resulting from plantar footprint processing. On the shank axis, through point B, a perpendicular is drawn, whose intersection is marked K. KI = KJ, where IJ is heel breadth, 42.5 mm. GH is toe breadth, 66.3 mm. This line segment intersects perpendiculars drawn through C and D, so that PH = 44 % ld and HG = 56 % ld. Insole contour is obtained uniting points O, J, H, F, G, I, O, and the appearance of the contour is similar to that of the average contour between the footprint and foot outline. The length of the insole is calculated using equation 1:

$$lb = Lp - ac + am + av \qquad (1)$$

where: lb = insole length;
Lp = foot length;
ac = heel amplitude (0,025 Lp);
am = movement tolerance (2-3 mm);
av = toe tolerance (5-20 mm, depending on fashion).

Starting from the average size insole template, all other sizes were obtained. To check the correctness of these insoles, footprint outlines and insole outlines were overlapped, with positive results.

Making the last requires knowledge regarding anatomical and functional parameters of the foot, elements of biomechanics, method of transposing anthropometric parameters in designing last execution and control templates. In determining the spatial shape of the last, an important part is played by values of ball girth circumference, instep circumference and heel circumference (entry circumference). Another element the last designer should consider is the parallelism of planes in the heel and metatarsals I and V.

Based on the above, two prototype lasts were created using the conventional method, for children's footwear, size 18, breadth 4 and 5, respectively (Fig. 4). Breadth 4 is indicated for girls' shoes, while 5, for boys' shoes.

Figure 4. Prototype lasts

LAST-MAKER software was used to check the position of the foot inside the shoes, i.e. the compatibility between foot and last in terms of size (Fig. 5).

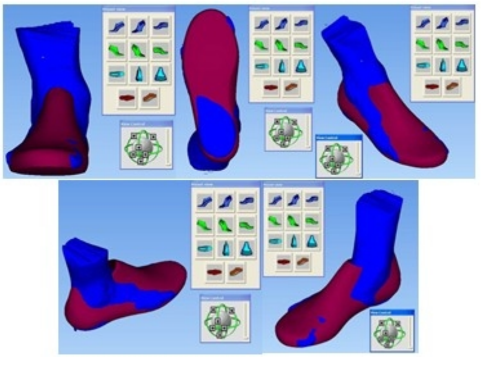


Figure 5. Compatibility between foot and last in terms of size

A correct correspondence is noted between the spatial shape of the foot and that of the last, the accuracy in terms of the method of transposing anthropometric parameters in designing lasts for children's shoes. This sets the premises for the possibility of standardizing (normalizing) the back part of the last. Figure 6 presents this suggestion.

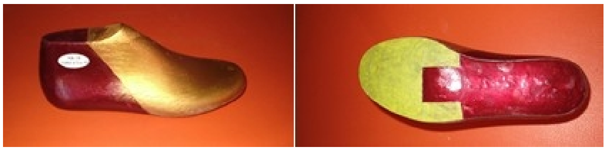


Figure 6. Standardization of the back part of the last

Compared to the 1972 standardization, the new concept is much easier, and does not hinder the act of creation (the fashion factor), but only standardizes certain parts that make up the footwear (metallic shank, counter, insole reinforcement). Prototype lasts were tested in manufacturing and in terms of size fit by test wearing, with very good results.

CONCLUSIONS

Children's footwear is recommended to be manufactured using breadth 4 for girls and 5 for boys, and for boots, breadth 5 and 6, respectively.

When designing the insole of the last, the angle between the tip of the toe-heel axis and the shank axis should be 6°.

Given the results of test wearing and checking the compatibility between foot, last and footwear, the back of the last, a portion of 2/3 of the total length, is considered standardisable.

The lack of abrasions, fatigue, redness of the foot surface in areas of maximum pressure, the walking mobility and safety demonstrates that in terms of size, the shoes conform to the spatial shape of the child's foot (aged 3-7). Therefore, the new prototype lasts provide foot comfort inside the shoes.

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