ISC Germany

Research project completed

Dynamic feet and shoes

Pressure marks on the toes, blisters on the heels, feet slipping in the shoe with every step - who has not experienced it for themselves, the consequences of seemingly minor defects in the shoe that are capable of causing real agony? The main reason for this is that lasts and shoes are constructed on the basis of static foot measurements. Our feet, however, need more space when walking and during the many activities of everyday life than when standing. PFI and ISC have been looking for solutions to this problem in a research project titled "Development of design guidelines for street shoes taking into account the dynamics of the feet "*.

The entire knowledge and skills of the last modeler are in every street shoe last. The last inventory of a shoe manufacturer is well-guarded company know-how. New last models are created by modifying tried and tested lasts. Usually only a limited area, usually the fore part, is designed according to the latest fashion trend, the rest remains unchanged. Traditionally good fit is thus found in every collection; regular customers remain loyal to their favourite brand primarily because of the fit. But fit deficiencies are also carried on. The decisive disadvantage of traditional last construction is namely that they are based on static foot measurements. The test persons stood still during the foot measurement and were asked to stand loosely and distribute their body weight evenly on both feet.

Modern measurement technology for the foot in motion such as gait analysis and foot pressure measurement are developments of the computer age and much younger than historically developed last collections. Pioneers in the use of this technology for last and shoe design were sports medicine and orthopaedics, where the aim is to measure the movement sequences and ranges of motion of highly stressed or damaged feet in order to design suitable footwear or orthopaedic shoe aids. In contrast, everyday shoes, especially high-heel women's shoes, are rarely designed for optimal fit and functionality. Mostly, the only thing that counts is the fashion aspect. And that is just not enough.

A street shoe has to be an "all-rounder". It has to fulfil a multitude of functions and look good at the same time. Special shoes are more simple, because here the focus is on individual functions: a hiking shoe is allowed to look clunky; a sports shoe inelegant. A cycling shoe does not roll well, but is stiff.

The foot must feel comfortable in a street shoe, whether indoors or outdoors, whether the wearer is sitting, standing, climbing stairs, walking, running or driving, and regardless of whether the surface is carpeted, parquet, cobblestones, asphalt or a natural floor. The foot changes as it moves, and the

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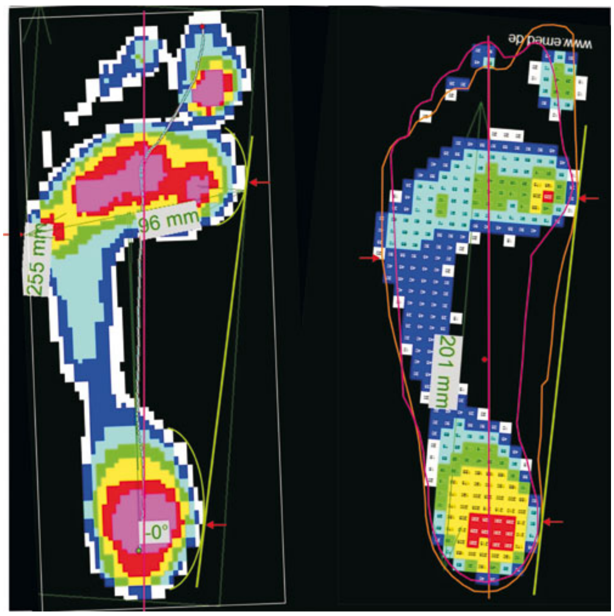
shoe must not hinder the foot motion. In a research project that was completed in April 2014, PFI and ISC investigated questions about the foot's dynamic requirements for shoes:

- What changes occur when the foot is in motion compared to when it is standing?
- In which areas of the foot do they occur?
- What are the dimensions of these changes?
- To what extent do these changes deviate from the statically determined dimensions previously used for the last construction?
- What adjustments must therefore be made in the last and shoe construction?

Standing and walking without shoes

Standing and walking are the most common activities in everyday life. The measurements of the bare feet while standing and walking were recorded on 70 women and men aged 20 to 30 years. A plantar pressure measurement system and the PFI leg scanner were used for this purpose.



Picture 1: Comparison load aisle / stance

The comparison of the measurements between the respective plantar pressure pattern in walking and in single-leg stance resulted in larger values for walking than for stance, as expected (Picture 1). On the one hand, this is due to the higher forces acting on the foot when walking. In contrast to standing, where only the body weight acts, the acceleration forces are added when walking. The

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bones, joints, ligaments, tendons and muscles of the foot absorb these forces with each step. The foot thus periodically becomes wider and longer. On the other hand, areas of the heel and toes that are not in contact with the ground when standing are included in the rolling process. The dimensional differences between the plantar pressure patterns of the two loading situations were surprisingly high. The total length of the plantar pressure patterns was 18 mm longer for women and 22 mm longer for men when walking than when standing. This corresponds to 8 and 9 percent of the foot length respectively. The maximum measured total length difference for men was even 35 mm! When these differences in length became apparent during the measurements, the project team initially suspected a measurement error; however, this was disproved after close examination.

In addition, both the lateral and the medial ball point shift forward when walking compared to standing, by 7 to 8 mm for women's feet and by 10 to 12 mm for men's feet. As a result of these measurement results, it could be concluded that the medial ball point would have to be shifted forward (towards the toes) by an average of 8 mm for women's lasts, and by 12 mm for men's lasts. However, this is contradicted by the fact that this displacement only occurs when walking, but the shoes have to take into account foot proportions for walking as well as for standing (and other activities). The solution to the task of doing justice to the dynamics of the foot in shoe and last construction must therefore in no way be limited to constructing lasts and shoes exclusively based on dynamically recorded dimensions. The last should be designed to accommodate all activities of the foot (according to the purpose of the shoe type). In the case of the ball of the foot, this means constructing the last over an area of maximum width. This area of maximum width starts medially at 72 percent of the foot length and laterally at 63 percent of the foot length. The extension of this area towards the tip of the foot should be at least three percent of the foot length medially and laterally for women and at least four percent of the foot length for men.

Apart from these changes in length, the fore part of the foot also becomes wider when walking than when standing. The ball region was particularly interesting in this context. Here, the width of the contact surface was measured as the so-called ball width. In women and men, it is on average 11 percent wider when walking than when standing.

Comparison with conventional lasts

The extent to which ready-made lasts for women's and men's street shoes meet these foot requirements was investigated using a sample of 54 women's and 38 men's lasts. Their dimensions were compared with the values of the plantar pressure measurement. It turned out that the majority of the conventionally constructed lasts already took into account the forward displacement of the ball of the foot when walking. However, this did not apply to the width: the lasts had smaller ball widths

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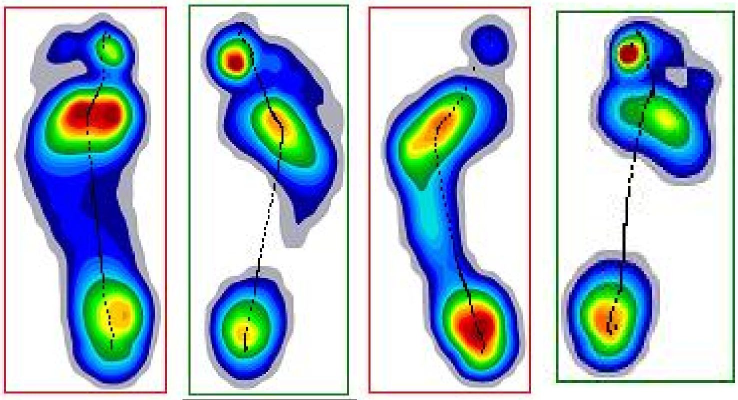
than the feet require when walking. While 89 percent of the men's lasts had sufficient ball widths for the standing foot, the men's foot widths exceeded the last soles by an average of 9 mm when walking. The result was even more dramatic for women's lasts because the proportion of the ball width to the circumference of the ball is smaller than for men's lasts. Only 16 percent of the women's lasts had sufficient ball widths for the standing foot. When walking, the ball widths of the women's feet were on average 14 mm larger than the last soles; the feet therefore protrude on average 7 mm beyond the edge of the sole on both sides.

Foot versus shoe, individuality versus series production

The analysis of the feet shows a great variety of different dimensions that cannot be categorised with the conventional specifications of a corresponding shoe size alone. The initial situation (standing) already shows that there is no clear relation between length and width. The amount of soft tissue and the flexibility (deformability) of the feet are also very different. In addition, the plantar pressure distribution measurements, both in terms of statics and dynamics, show that the stability, the functional possibilities and thus the load on the feet are very individual specific (Picture 2).



Picture 2: individual load differences

In contrast to the foot, the shoe is a more or less standardised object. A compromise must therefore be found that makes a shoe fit as many feet as possible. In some cases, very different opinions and interests are in the foreground. In the case of fashionable shoes, the motto is often "if you want to be beautiful, you have to suffer", whereas in the case of functional shoes (e.g. hiking boots), the opposite is true.

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Picture 3: foot slipped into the toe of the shoe

Countless conversations with test persons revealed certain recurring problems when wearing shoes. This includes the slipping of the foot into the tip of the shoe in shoes with different heel heights. One reason for this is the deviation of the heel area of the shoe from that of the foot. The joint line and heel area of the shoe form more of a slipping path for the foot than holding it in the heel area. This is clearly visible in the heel gap between the foot and the shoe (picture 3). This causes instability when walking and possibly also friction points on the heel of the foot. The toes in the shoe tip area are crammed.

Solutions using lasts, footbeds and heel modifications

In the research project, construction guidelines for street shoe lasts were to be developed in order to enable the production of shoes which better take into account the needs of the foot in motion and in which the aforementioned fit problems no longer occur. For the test phase of the project, this meant having to manufacture lasts for each variant of the design measures. In order to minimise costs and time, only one pair each of men's and women's lasts was produced. The volume was chosen in such a way that different footbeds could be inserted on which the different design measures had been implemented. Based on the results of the tests, it was then decided which of the measures should be implemented on the last itself and which could be better realised via footbeds. In addition, this approach opens up the possibility for potential users to implement some of the fit-improving measures on existing shoe models. In this way, some of the results of the project could be put into practice in the short term without changing the existing lasts, but only through the footbeds. The prerequisite is, of course, a sufficient inner volume of the shoe models in question. Since many shoe models are currently equipped with removable footbeds, this applies to many models.

Lasts for women in size 39 / width 6 and for men in size 43 / width 7 were developed for the production of functional test shoe models. The results from the barefoot measurements were taken into

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account. The lasts had a heel drop of 10 mm. The fit of the lasts was evaluated using test shoes made of transparent foil.

Three pairs of men's shoes and two pairs of women's shoes were produced as test shoes using the developed lasts. The men's shoes had the following heel variations:

a) Normal heel: Use as a reference shoe for all other shoes (Picture 4)

b) Buffered heel: On the central-lateral side of the heel, the original heel material has been replaced by a softer material in the form of a wedge (Picture 5)

c) Rolled heel: On the central-lateral side of the heel, the original heel material was removed in a wedge shape. The interface was rounded off (Picture 6)

The women's shoes had the following heel variations:

a) Normal heel: Use as a reference shoe for all other shoes

b) Buffer heel: On the central-lateral side of the heel, the original heel material has been replaced by a softer material in the shape of a wedge

Picture 4: Reference shoe

Picture 5: Buffered heel

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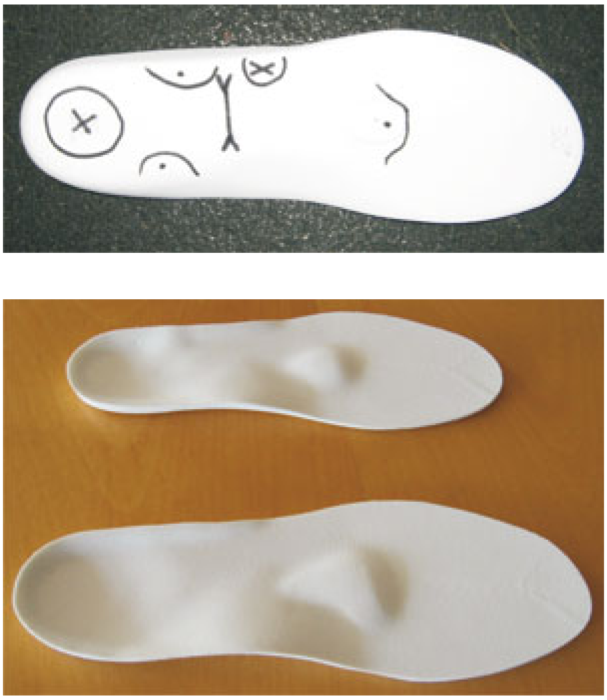
Picture 6: Rolled heel

For the tests with women's shoes with a higher heel drop, companies from the Project Support Committee provided two pairs of pumps.

Based on the plantar print images, footbeds for functional and for fashionable shoes were designed as samples. They are shown in pictures 7 and 8.



Picture 7a und b: Test footbed for "functional" shoes

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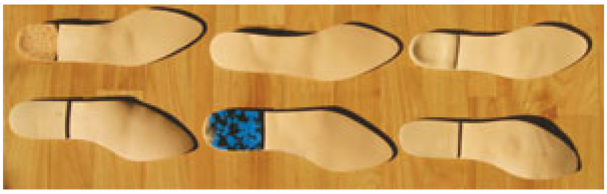

Picture 8a und b: Test footbeds for " fashionable" shoes
Upper row: left – D 4, mid – D 2, right – D 6
Lower row: left – D 3, mid – D 1, right – D 5

The functional test shoes were tested by a total of five men and seven women with matching shoe sizes. For the tests of the fashionable women's shoes, five test persons were available for the first shoe model and one test person for the second shoe model. The plantar pressure distribution was recorded and evaluated for all tests. The results of the measurements in the shoes without footbed and with footbed as well as with normal heel and with buffer or roll heel were compared.

Results of the "fashionable test shoes" measurements

- All footbeds tested were suitable for use in fashionable, heel-spring pumps. Although these shoe models had very limited internal volume, the footbeds were accommodated and were effective.
- Compared to the reference measurement without foot support, all tested foot supports caused a forward shift of the front limits of the heel print. This shift was greatest in the D2 and D4 footbeds (see picture 8) as a result of the heel stops. This proved that they reduce the forward sliding of the foot in the shoe.
- The footbeds D1 to D4 caused a rearward shift of the rear boundaries of the ball. This also proved that they reduce the forward sliding of the foot in the shoe.
- The effectiveness of the Support-pads (Pelotten) and the different cover materials could not be proven.

Results of the "functional test shoes" measurements

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The effect of the tested footbeds in the functional test shoes was reflected in the gait line. Here, too, the heel design prevented the foot from sliding forward. This was evident in the shift of the highest pressure load to the front edge of the heel. The heel strike was nevertheless centrally located in the heel area as desired. A clear effect of the different heel shapes compared to the reference measurement could not be proven with these shoes. One reason was the design of the shoe bottom of the test shoes, which already provided favourable conditions. Further comparisons with other design variants of shoe bottoms are necessary. This appears to be particularly interesting because the subjective assessment of the heel variants showed clear differences in evaluation.

The details can be found in the final report of the research project IGF 17172, which can be requested from PFI, from

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