Research Project Concluded

Dynamic Data for a Better Fit

Few people will not have suffered the painful consequences of seemingly minor shortcomings of shoes – pressure areas on the toes, blisters on the heels, the sensation of the foot slipping in the shoe with every step. The principal cause of such problems is that lasts and footwear are produced mainly on the basis of static foot measurements. However, our feet need more space when walking and performing numerous everyday activities than when standing. Solutions to this problem were sought in a research project entitled "Development of Design Guidelines for Street Shoes Considering Foot Dynamics" conducted by PFI and ISC.

A world of last design knowledge and skill goes into every street shoe last. An atmosphere of secrecy surrounds a footwear manufacturer's collection of lasts. New last designs are created by modifying well-proven lasts. As a rule, changes reflecting the latest fashion trend are made over a limited area, usually the toe region, while the rest remains unchanged. Thus every collection of lasts retains its traditional good fit properties; faithful customers remain loyal to their favourite brand primarily because of the fit. However, fit defects are also perpetuated by the same mechanism. The crucial drawback of traditional last design is that it is based on static foot measurements. The test persons were standing still during measurement, having been asked to stand in a relaxed manner and to distribute their weight uniformly over both feet.

Modern dynamic foot measuring techniques such as gait analysis and foot pressure measurements are developments of the computer age and far younger than any historically evolved collection of lasts. Sports medicine and orthopaedics have pioneered the application of this approach to the design of lasts and footwear when it is necessary to measure sequences and ranges of movement of damaged or highly stressed feet in order to produce properly fitting footwear or aids or appliances incorporating orthopaedic shoemaking technology. In contrast, the design of everyday footwear, in particular high-heeled women's shoes, rarely focuses on optimum fit and functionality. All that usually counts is fashion. And that falls far short of the mark.

A street shoe must have "universal" properties. It must fulfil a variety of functions and look good at the same time. Special purpose shoes have an easier time because the emphasis is placed on specific functions: A hiking boot may look chunky, a sports shoe inelegant. A cycling shoe does not roll over well but is stiff.

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* This research project was funded as IGF Project No. 17172 N by the German Federal Ministry of Economics and Energy through the German Federation of Industrial Research Associations (AiF) within the IGF programme for promoting industrial cooperative research and development.

The foot has to feel comfortable in a street shoe, whether indoors or outdoors, whether the wearer is sitting, standing, climbing stairs, walking, running, or driving a car, and regardless of whether on a carpeted floor, parquet, cobblestones, asphalt, or a natural surface. The foot changes during motion and the shoe should not restrict its movement. In a research project concluded in April 2014, PFI and ISC sought answers to questions concerning the dynamic demands placed on shoes by the foot:

- How does the moving foot change relative to the standing foot?
- In what parts of the foot do these changes occur?
- What is the extent of these changes?
- To what extent do these changes deviate from the statically determined measurements hitherto used for last making?
- What adjustments should be applied in the design of lasts and footwear?

Standing and Walking Barefoot

Standing and walking are our most frequent everyday activities. The dimensions of the shoeless feet of 70 persons (male and female) aged between 20 and 30 were determined. The equipment used was a plantar pressure measuring system and the PFI leg scanner.

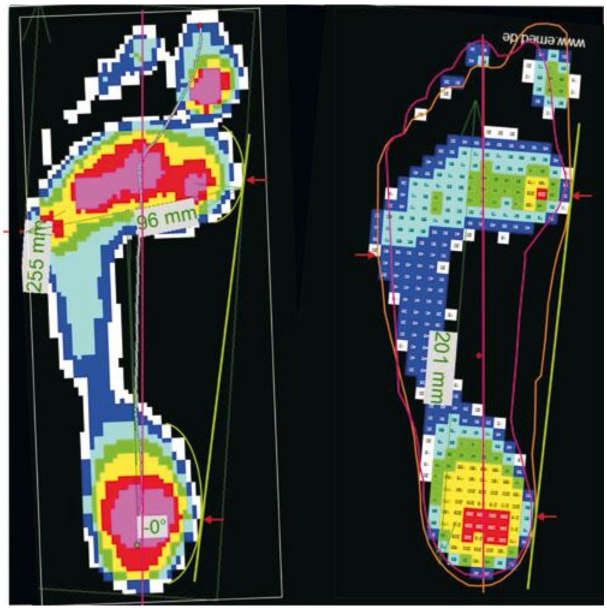

Fig. 1: Comparison of pressure on walking / standing

Comparison of the measurements between the respective plantar pressure images for walking and for standing on one leg expectedly gave larger pressure values for walking than for standing (Fig. 1). That is due on the one hand to the greater forces that act on the foot during walking. In contrast to standing, when only the weight of the body acts on the foot, additional acceleration forces come into play on walking. Bones, joints, ligaments, sinews, and muscles of the foot take up the forces on every step. The foot thus periodically becomes wider and longer. On the other hand, areas of the heel and toes which do not contact the ground on standing are involved in the roll-over process. The differences in dimensions between the plantar pressure images for the two different situations were surprisingly large. Thus the overall length of the plantar pressure images during walking were 18 mm greater for women and 22 mm greater for men than on standing. That corresponds respectively to 8 and 9 percent of foot length. The greatest overall measured length difference was actually 35 mm! The project team initially suspected a measuring error when this length difference was noted but subsequent close examination dispelled such suspicions.

In addition, both the lateral and the medial ball points are displaced forward, compared to their position on standing, by 7 to 8 mm in women's feet and by 10 to 12 mm in men's feet. It could be concluded that the medial ball point of women's lasts should be shifted forward (towards the toes) by an average of 8 mm and that of men's lasts by 12 mm to take account of these results. However, it can be argued that this shift only occurs on walking and that shoes must accommodate the foot both while walking and on standing (and also during other activities). The solution to the challenge of accounting for foot dynamics in the design of footwear and lasts is therefore by no means limited to designing lasts and shoes solely on the basis of dynamically determined measurements. Indeed, the lasts should be designed such that they permit all activities of the foot (according to the intended use of the shoe type). With regard to the ball points, that means that the last should be made in maximum width over a given area. This area of maximum width begins medially at 72 percent of the foot length and laterally at 63 percent of the foot length. This area should extend in the direction of the toes medially and laterally by at least 3 percent of the foot length for women and by at least 4 percent for men.

Apart from these length modifications, the tread area of the foot also becomes broader on walking than during standing. In this context, particular interest attaches to the ball region. Here the width of the tread area or the ball footprint width is measured. It is on average 11 percent wider on walking than on standing, for both women and men.

Comparison with Conventional Lasts

The extent to which standard lasts for women's and men's street shoes meet these needs of the foot was examined for a random sample of 54 women's lasts and 38 men's lasts. Their measurements were compared with the values recorded for the plantar pressure measurement. It was seen that most of the conventionally made lasts already took account of the forward shift of the ball points on walking. However, that did not apply to the width: the lasts had smaller ball footprint widths than the feet actually need during walking. Whereas 89 percent of the men's lasts had sufficient ball footprint widths for the standing foot, the foot widths of the men exceeded the widths of the last soles by an average of 9 mm on walking. The result was even more dramatic for women's lasts because the contribution of the ball footprint width to the ball girth is smaller than for men's lasts. Only 16 percent of the women's lasts had an adequate ball footprint width for the standing foot. On walking the ball footprint widths of the women's feet were on average 14 mm greater that the widths of the last sole; the feet accordingly project over the edge of the sole by 7 mm on both sides.

Foot versus Shoe, Individuality versus Mass Production

Analysis of feet reveals a large variety of different dimensions which defy straightforward categorisation by mere conventional assignment of a particular shoes size. Right at the start (standing) it is seen that no unequivocal relation exists between length and width. The proportion of soft tissues and the flexibility of the feet differ widely. Moreover, both static and dynamic plantar pressure distribution measurements reveal that the stability and functional possibilities, and thus the load bearing properties of the feet, vary enormously from individual to individual (Fig. 2).

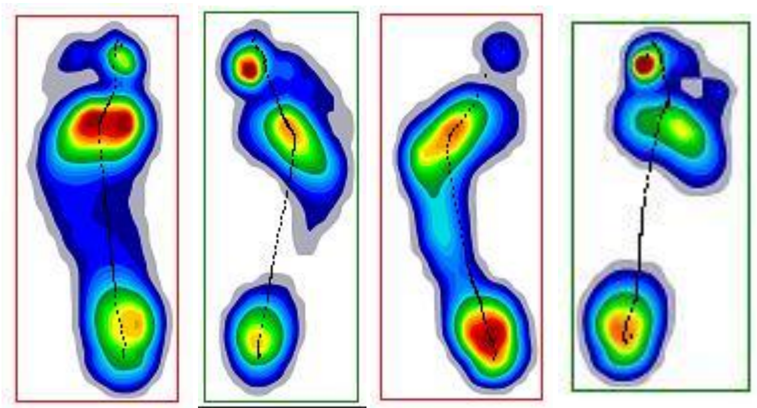

Fig. 2: Individual foot load differences

In contrast to a foot, a shoe is a more or less standardised object. A compromise therefore has to be found to provide good fit for as many feet as possible. A huge variety of opinions and interests abound. The adage “No pain, no gain” is often applied to fashion shoes whereas the opposite view predominates in the case of functional footwear (such as hiking boots).

Fig. 3: This foot has slipped into the toe region of the shoe

Certain problems specifically relating to the wearing of shoes were repeatedly voiced in the course of innumerable interviews with test persons. Slipping of the foot into the toe region of shoes of various heel heights is one such problem. One reason for this is the deviation of the shape of the heel region of the shoe from that of the foot. The joint line and the heel section of the shoe tend to provide a slippery slope for the heel rather than holding it firmly in place. This is clear from the gap seen between the foot and the shoe in the heel region (Fig. 3). This gives rise to a degree of uncertainty of gait and possibly also chafing of the heel. The toes are crowded together in the front part of the shoe.

Solutions Based on Lasts, Footbeds, and Heel Modifications

The goal of the research project was to develop design guidelines for street shoe lasts permitting the production of shoes which better meet the needs of the foot in motion and which no longer suffer from the above-mentioned problems of fit. This meant that for the test phase of the project lasts had to be made for each design variant. Only one pair of women's lasts and one pair of men's lasts were produced for each case in order to save costs and time. The volume was chosen to permit insertion of various footbeds for which the design measures had been implemented. On the basis of the results it was to be decided which of the measures should be implemented on the last itself and which would be better implemented by way of footbeds. Moreover, this approach offers potential users the possibility of also implementing some of the fit-improving measures in existing shoe models. In this way part of the results of the project could be put into practice at short notice without changing the existing lasts but solely by modifying the footbeds. Sufficient internal volume of the respective shoe is clearly a prerequisite. This requirement is frequently met, since many shoe models are currently fitted with removable footbeds.

Women's shoe lasts of size 39 / width 6 and men's lasts of size 43 / width 7 were developed for the production of functional test shoe models. The results of barefoot measurements were taken into account. The lasts had a heel pitch of 10 mm. The fit of the lasts was assessed with the aid of test shoes made from transparent plastic sheet material.

Three pairs of men's shoes and two pairs of women's shoes were produced as test shoes with the developed lasts. The men's shoes had the following types of heels:

a) Normal heel: For use as reference shoe for all other shoes (Fig. 4)

b) Buffer heel: Original heel material on the central-lateral side of the heel was replaced by a wedge-shaped piece of softer material (Fig. 5)

c) Rounded heel: A wedge-shaped piece of original heel material on the central-lateral side of the heel was removed. The place where the material was removed was rounded off (Fig. 6).

The women's shoes had the following types of heels:

a) Normal heel: For use as reference shoe for all other shoes
b) Buffer heel: Original heel material on the central-lateral side of the heel was replaced by a wedge-shaped piece of softer material

Fig. 4: Reference shoe

Fig. 5: Buffer heel

Fig. 6: Rounded heel

Companies represented on the project committee provided two pairs of court shoes for tests with women's shoes having a higher heel pitch.

Footbeds for functional and for fashion shoes were produced as samples to wear on the basis of the plantar pressure images. They are shown in Fig. 7 and Fig. 8.

Fig. 7a and b: Test footbeds for "functional" shoes

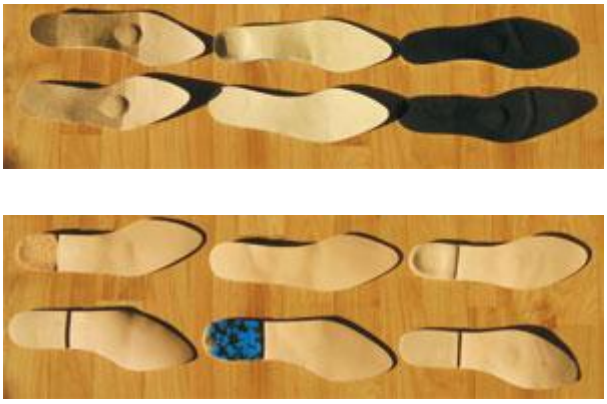

Fig. 8a and b: Test footbeds for "fashion" shoes
Upper row: left – D 4, centre – D 2, right – D 6
Lower row: left – D 3, centre – D 1, right – D 5

The functional test shoes were tested by a total of five men and seven women having the appropriate shoe size. In the tests of the women's fashion shoes there were five test persons for the first shoe model and one test person for the second one. The plantar pressure distribution was recorded and evaluated in all tests. The results of measurements in shoes without footbeds and with footbeds and with normal heels and with buffer or rounded heels were compared.

Results of the "Fashion Test Shoe" Measurements

- All the tested footbeds were suitable for use in fashionable high-heeled court shoes. Although such shoes have a very restricted internal volume, the footbeds had sufficient room and proved to be effective.
- Compared to reference measurements without footbed, all the tested footbeds led to a forward shift of the front boundary of the heel impression. This shift was greatest for footbeds D2 and D4 (see Fig. 8) owing to the action of the heel grip. This demonstrates that they reduce the tendency for the foot to slip forward.
- Footbeds D1 to D4 caused a backward shift of the rear boundary of the ball impression. This also demonstrated that they reduce the tendency for the foot to slip forward.
- There was insufficient evidence for the effectiveness of insole pads and of various covering materials.

Results of the "Functional Test Shoe" Measurements

The effect of the tested footbeds in functional test shoes was apparent from the gait line. Here too, the design of the heel section prevents forward slipping of the foot. This became apparent from the displacement of the highest pressure load to the front edge of the heel. The heel impact nevertheless lay, as desired, at the centre of the heel region. It was not possible to detect any unequivocal effect of the various heel types relative to the reference values. One reason was the particularly favourable design of the shoe bottom of the test shoes. Further comparisons with other shoe bottom designs will be necessary here. Such comparisons would be of interest particularly because subjective assessments of the different heel types showed wide variations.

Details will be found in the final report of Research Project IGF 17172, which is available on request from PFI. Please address your requests to

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