Effect of the shoe on plantar foot pressures

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The bare foot plantar pressures were compared to in-shoe pressure measurements in 11 normal male volunteers using the EMED system. Shoes diminished pressures and forces in most areas under the foot except the medial forefoot. The hallux showed less force, a smaller contact area and a reduced contact time. Therefore a shoe can interfere with the toe-off mechanism. There was no difference between various types of shoes with rubber and leather soles. Heavier subjects tended to put less weight on the medial forefoot.

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Pressure measurements of bare-foot walking using different systems have been well analyzed (Alexander at al. 1990), but little is known about the function of the normal foot in a shoe. Most in-shoe pressure measurements have been done using a small number of discrete pressure transducers (Bauman and Brand 1963, Schwartz et al. 1964, Soames 1985). Recently, more accurate in-shoe measurement has become feasible with the Mikro-EMED system, which has a flexible insole with multiple capacitance transducers and is commercially available (Schaff and Cavanagh 1990).

We evaluated the effect of everyday shoes on the foot pressures during normal gait.

Subjects and methods

11 healthy subjects with clinically normal feet participated in the experiment (Table 1). None of the subjects had significant hyperlaxity of joints and all standing physical evaluations were within normal limits. 6 subjects wore rubber shoes and 5 wore leather shoes. 3 subjects had slip-on shoes and 8 lace-up shoes.

The measurements were performed by the Mikro-EMED insole system on the shod foot and the EMED-SF platform system (Novel, Germany) on the bare foot. This is a commercially available electronic system for recording and evaluating the distribution of pressures on the plantar aspect of the foot.

The method operates with capacitance sensors (Nicol and Henning 1981). The signals are displayed as a conform picture on a monitor, and a hard copy print-out is available from an ink jet color printer. All measurements were taken on the right foot.

The size of the pressure platform was 445 mm × 225 mm, with a sensing area of 2016 mm^2, set flush in a walkway 5 meters long. The pressure plate included 2 sensors per cm^2. The maximal total force that can be applied is 100,000 N.

The Mikro-EMED insole has a homogeneous distribution of 85 sensors, with a local resolution of 1 sensor per 2 cm^2. It is 2 mm thick and flexible enough to adjust to the shape of the shoe. A size 44 insole was used. The sensors were calibrated with homogeneous air pressure ranging from 2 to 150 N/cm^2.

The shod-foot measurements were taken while the patient was walking on a treadmill at a speed of 4 km/h (the normal pace for healthy persons). A metronome was adjusted to the rate of walking on the treadmill. After a minimum of 2 min walking, data concerning the steps was collected for 13 sec (usually 10–12 steps). The data for 3 consecutive representative steps was recorded.

The subjects were requested to walk 3 times across the EMED-SF platform bare-foot at the pace of the metronome, which was set during the shod walk.

Table 1. Physical data of the subjects

Data	Mean	Range
Age	35	25–46
Weight (kg)	73	60–90
Height (cm)	177	170–185
Shoe size	43.5	42–44

Table 2. Results of various variables of plantar foot pressure in the shod foot in relation to the bare foot (percent change)

	Total	Heel	Midfoot	Lat. forefoot	Mid-forefoot	Med. forefoot	Lat. toes (2–5)	Hallux
Contact area	20[a]	15[a]	–14	–16	46[a]	92[a]	37[a]	–10
Max. force	–13[a]	–15[a]	–64[a]	–63[a]	–33[a]	53[a]	–4	–28[a]
Max. pressue	–46[a]	–48[a]	–50[a]	–66[a]	–55[a]	–31	–50[a]	–48[a]
Contact time		100[a]	27[a]	14[a]	15[a]	25[a]	12	10[a]
Pressure-time integral	–41[a]	–17[a]	–41[a]	–50[a]	–54[a]	–28	–48[a]	–49[a]
Force-time integral	–14[a]	2	–60[a]	–60[a]	–30[a]	49[a]	14	–15

[a] Significant change $P < 0.01$.

Altogether 33 steps of 11 subjects of the shod foot and 33 steps of the bare-foot subjects were measured. All data were stored in the EMED analyzing system for further evaluations.

The analysis of the steps consisted of marking 7 areas of interest: heel, midfoot, lateral, intermediate and medial forefoot, toes 2–5 and the hallux. The area of forces, maximal forces, peak pressures, and duration of contact phases were evaluated. The beginning and end of each area of interest, pressure-time and force-time integral, instant of peak pressure and force were obtained, using the EMED software.

Statistics

The mean and standard deviations of the data were calculated using the one-tailed student *t*-test. Statistical significance was determined at the level of 99 percent. To evaluate the effect of body weight on foot pressures it was correlated with all the parameters in the shod foot and bare-foot subjects. The Pearson correlation coefficient was used to correlate the measured variables with respect to the weight.

Results

Differences between groups

The shod foot group showed increased loading of the medial forefoot, decreasing of the lateral forefoot and decreasing forces and pressures in the hallux (Table 2). The step with the shod feet was 43 msec longer (5 percent).

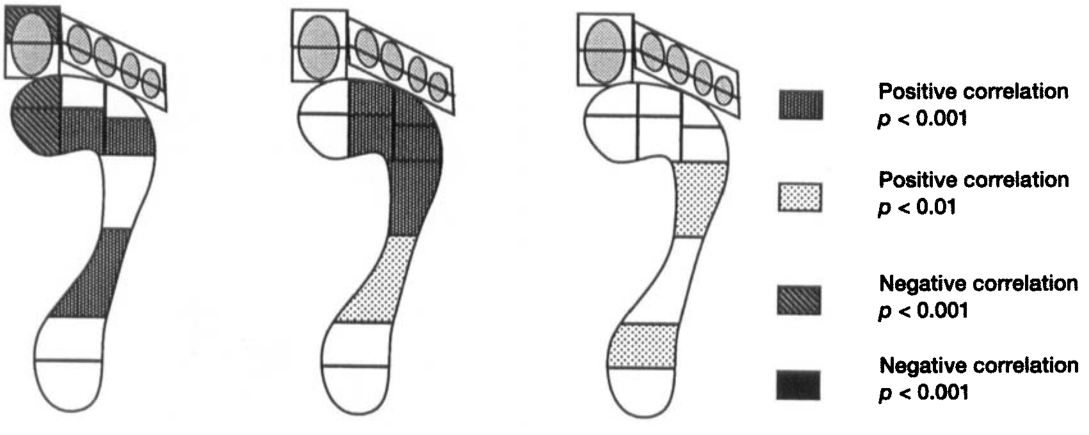
No differences were found between the various sole types, whether rubber or leather.

The group wearing slip-on shoes was too small for statistical analysis, but the individual variables were similar to those in the lace-up group.

Only 3 patients had clinically mild flat-feet while standing. These patients had normal bare foot hard-copy imprints indicating mobile functional flat-feet.

Correlations

There was a positive correlation between most of the parameters in the lateral and central forefoot for the bare and shod feet concerning weight. These correlations were negative in the medial forefoot (Figures 1 and 2).



Peak pressure **Maximal force** **Area**

Figure 1. The maximal force has a positive correlation for both groups in the areas of the midfoot and the lateral and intermediate forefoot. In the medial forefoot, there is a negative correlation for both groups. Anterior part shod foot and posterior part bare foot.

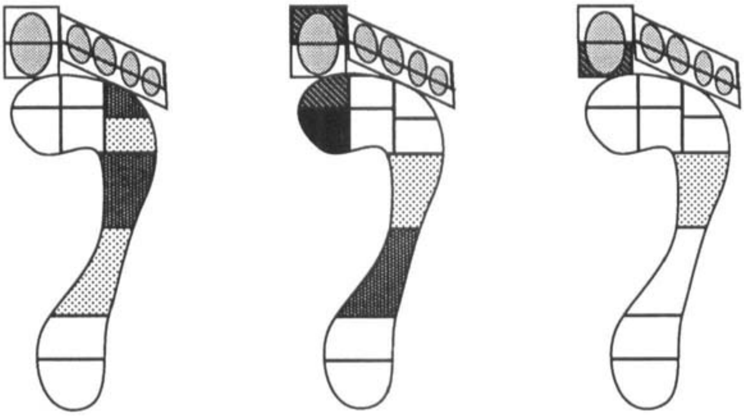


Figure 2. The pressure-time integral correlates inversely in the medial forefoot to body weight. The force-time integral correlates positively in the midfoot and lateral forefoot. Anterior part shod foot and posterior part bare foot. Correlation, see Figure 1.

Discussion

The flexible sole of an ordinary shoe increased the total area of foot contact during the stance phase. This area was mainly increased along an imaginary line of the center of force during the stance phase. This line has been shown to spread from the heel, medially to the midfoot, medial forefoot and than slightly to the lateral toes (Grundy et al. 1975).

Insertion of a thin measuring insole may have altered our results. Therefore, in our study, we considered only the most pronounced differences.

In the shod foot, the maximal force and maximal peak pressures were lower than would be expected. However, in the medial forefoot, the force was greater and there was no change in the peak pressures. The center of force, which passes towards the forefoot close to the designated area of the medial forefoot, was not affected by the shoe. Softer and better cushioning of that area in the everyday shoe may reduce the force and the peak pressures at this site.

The small difference in the step-time between the two groups shows that the method of controlling the rhythm of the pace with a metronome while walking on the treadmill is accurate.

The larger the contact area at a given speed, the more time was needed to complete the roll-over process. Therefore, except for the toes, the duration of the contact phase in all areas of interest was longer in the shod foot than in the bare foot.

The flexibility of the shoe (compared to the rigid pressure plate) resulted in an earlier beginning and a later ending of the stance phase. In the shod foot there was less force, a smaller area and reduced contact time on the hallux. The shoe may interfere with normal great-toe function during the stance phase.

The pressure-time integral and the force-time integral showed a pattern similar to those of Maximal Force and the Peak Pressures, with the same relationships in the shod and the bare feet. These results indicate that, under experimental conditions, the variations in the contact phases were too small to affect the pressure-time or force-time integral. The later instant of peak pressures in the heel may be explained by the shock-absorbing properties of the shoe in the heel.

Substantial differences between the various types of soles were expected. However, the pressure distribution on a rubber-soled shoe during the stance phase was similar to that of the leather sole. After 500 miles, a sports shoe loses 50 percent of its shock-absorption capacity (Cook et al. 1985) and the rubber shoes used by our volunteers were at least 3 months old.

The capacity of the shoe to adjust to weight is observable mainly in the heel and mid-foot; the greater the weight the larger the contact area (Jorgensen and Bojsen-Moller 1989). Most shoes have a thin sole in the area of the forefoot and therefore the possibility of adjustment is small.

During the mid-stance, the foot supinates and the heavier the subject the more force applied on the ground in the mid-foot and lateral forefoot. The wearing of the shoe did not alter this pattern.

Our results are similar to those of Stott et al. (1973), who found that heavier subjects tend to put more weight on the lateral side of the foot. Soames (1985) also found that pressures on the lateral side of the foot increased with weight. An increase in the energy-absorbent properties of the shoe in that area can reduce these forces.

The shoes reduced the peak pressures and were effective enough, even in the heavier subjects. In the bare foot, heavier subjects had higher peak pressures, but in both groups the foot in the heavier subjects tended to apply more force laterally, with lower peak pressures in the area of the first metatarsal heads. Hughes et al. (1991) reported that the best correlation of the weight was found with the fourth metatarsal head. However, they did not distinguish between males and females.

The similar behavior of the foot in both groups with regard to indices of the force-time and pressure-time integral indicates that the shoe did not alter forces in the heavier subjects. Heavier subjects tended to use their medial forefoot less. Soames (1985) found the same phenomena with regard to the pressure-time integral.

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