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# Effect of viscoelastic shoe insoles on vertical impact forces in heel-toe running

B. M. NIGG,* Dr sc nat, W. HERZOG, PhD, AND L. J. READ

*From the Biomechanics Laboratory, The University of Calgary, Calgary, Alberta, Canada*

## ABSTRACT

The purposes of this study were: 1) to compare the impact forces in running using running shoes with conventional insoles to the impact forces using running shoes with four different viscoelastic insoles, 2) to discuss possible effects of the viscoelastic insoles on lower leg kinematics, and 3) to explain the force and kinematic results using a mechanical model. Kinetic and kinematic data were collected for 14 subjects running heel-toe at an average speed of 4 m/s. The results showed that the four tested viscoelastic insoles did not differ in variables describing the vertical impact forces (vertical force peak, time of occurrence of vertical force peak, maximum vertical loading rate) compared to the conventional insoles furnished in running shoes. Furthermore, the viscoelastic insoles did not influence kinematic variables of the lower extremities in a systematic way.

During each contact with the environment, the human locomotor system experiences impact forces[1] that are associated with injury occurrence and frequency. There is evidence that degenerative changes in the locomotor system depend on the magnitude, loading rate, and frequency of repetition of impact forces. Radin and coworkers[19] showed that walking on a hard asphalt surface changed the biochemical and mechanical characteristics of sheep knee cartilage compared with the knee cartilage of sheep walking on a soft wood chip surface. Results by Falsetti and coworkers[6] indicate that increased red blood cell destruction is related to mechanical trauma (impact forces) in running. These quantified changes are supported by various speculations that repeated impact loading can have negative biological effects.[8,9,18,20,21,23]

With the high incidence of injuries in sports, particularly lower leg injuries in running,[9] there has been an effort in research to find strategies for reducing the impact loading on the human locomotor system. Various authors have shown impact loading is of less magnitude on special surfaces such as grass than on asphalt.[4,13,24] Reduced mileage, a new pair of shoes, or a change of running style is sometimes suggested as a possible strategy for reducing the negative effects of excessive impact loading. Additionally, attention has been focused on alterations in shoe construction. Various possibilities have been investigated, such as changing the midsole hardness[2,10,14,17] or thickness[7,10] of running shoes. However, these approaches have been found to have only a small effect on the magnitude of impact forces.[15]

Another strategy to reduce impact loading on the locomotor system has been the insertion of viscoelastic arch supports and/or heel pads. Such insoles are commercially offered for running shoes to reduce the magnitude and/or loading rate of impact forces. However, based on the results that a change in the hardness of midsoles did not influence the magnitude of impact forces in heel-toe running,[10,14,17] the assumption that viscoelastic insoles do affect impact forces must be challenged, even though there seems to be some experimental support for their use.[11,12,25-27]

The purposes of this study were: 1) to compare the impact forces in running using running shoes with conventional insoles to the impact forces using running shoes with four different viscoelastic insoles, 2) to discuss possible effects of the viscoelastic insoles on the lower leg kinematics, and 3) to explain the force and kinematic results using a mechanical model.

## MATERIALS AND METHODS

Sixteen male runners with a mean mass of 76 kg (SD 5 kg) consented to participate in the study. All of the subjects were heel strike runners and injury-free at the time of testing. Two pairs of running shoes (men's size 9) were used in the study. The shoes were of identical construction, except one pair, hereafter referred to as the G2 shoe, included a horseshoe-shaped rearfoot stabilizer, whereas the other pair, hereafter referred to as the G1 shoe, did not include a

* Address correspondence and reprint requests to: B. M. Nigg, Dr sc nat, Biomechanics Laboratory, The University of Calgary, 2500 University Drive NW, Calgary, Alberta, T2N 1N4 Canada.

stabilizer. Five different insoles were used with the two basic shoe models G1 and G2, which resulted in 10 shoe insole combinations. One insole was the regular insole which came with the shoe (EVA material), two insoles were commercially available insoles with viscoelastic properties (two leading models on the insole market), and two other insoles were new developments on an elastomer basis with viscoelastic properties. The insoles were quantified by the hardness and thickness of the material (Table 1). The hardness was determined by a method measuring the resistance of the material against penetration, called the SHORE value.[5] A higher SHORE value indicated a harder material. The thickness of the insole was measured at the point of greatest depth in the heel. An additional shoe, G3, was used as a reference shoe in this study. This shoe was used in several earlier studies and allowed, therefore, an internal comparison of the results. However, the various insoles were not used for this shoe.

Prior to testing, height and weight measurements of the subjects were taken. Markers were then placed on the posterior aspects of the right leg and shoe to quantify rearfoot movement (Fig. 1). Two markers were placed on the lower leg in the barefoot-standing position. Marker B was placed on the Achilles tendon, and marker A was located 15 cm above marker B, in the center of the leg. The third and fourth posterior markers were located on the posterior shoe as follows: marker D in the center of the heel just above the sole, and marker C on the heel cap so that markers C and D were perpendicular to the horizontal in the unloaded shoe. The angle between markers AB and the horizontal on the medial side describe the lower leg angle ($\alpha$), the angle between markers AB and CD on the medial side describe the Achilles tendon angle ($\beta$), and the angle between markers CD and the horizontal line on the medial side describe the rearfoot angle ($\gamma$).[16]

Six markers were placed on the lateral aspects of the right leg and shoe (Fig. 1). Two markers were located on the lateral shoe as follows: marker E at the head of the first metatarsal, and marker F, 5 cm from the back edge of the sole. Markers E and F were on the same horizontal plane in the unloaded shoe. Four markers were placed on the lateral leg on the most prominent point of the following bony landmarks: marker G on the lateral malleolus, marker H on the head of the fibula, marker I on the lateral femoral condyle, and marker K on the greater trochanter. The angle between GH and IK on the posterior side of the knee joint described the knee angle ($\epsilon$) and the angle between EF and the ground described the shoe sole angle ($\delta$).[16]

TABLE 1
Characteristics of the used shoe-insole combinations

| Symbol | SHORE hardness | Insole thickness (mm) | Comments |
|---|---|---|---|
| G1 reg | 24 | 3.8 | Shoe as sold (no heel stabilizer) |
| G1 in1 | 26 | 8.4 | Viscoelastic; commercially available |
| G1 in2 | 28 | 7.4 | Viscoelastic; commercially available |
| G1 in3 | 29 | 5.4 | Viscoelastic; new development |
| G1 in4 | 34 | 7.0 | Viscoelastic; new development |
| G2 reg | 24 | 3.8 | Shoe as sold (with heel stabilizer) |
| G2 in1 | 26 | 8.4 | Viscoelastic; commercially available |
| G2 in2 | 28 | 7.4 | Viscoelastic; commercially available |
| G2 in3 | 29 | 5.4 | Viscoelastic; new development |
| G2 in4 | 34 | 7.0 | Viscoelastic; new development |

The markers were placed on the leg in a standing position with the knee joint fully extended. During running, these markers moved with respect to the bone landmarks due to skin movement. However, we assumed that the change in position of the markers due to skin movement was constant between trials and between subjects.[16]

The subject ran over a force platform (Kistler Type Z4852/C, Switzerland), located in the middle of a runway about 16 meters long. The natural frequency of the force platform was at least 250 Hz in all three channels and the sampling rate was set at 1,020 Hz for each channel. The subjects were filmed from both the lateral and posterior views with two high speed cameras (Locam II) running at a nominal film frequency of 100 frames per second. Each subject performed practice trials for approximately 10 minutes to ensure that he could land consistently with the right foot on the center of the force platform and run at a constant average horizontal velocity of 4 ± 0.3 m/s. Running velocity was checked by photocells mounted at hip height, 1.56 meters apart from each other. The photocells were mounted so that they could not be triggered by arm movement.

The four insoles, as well as the regular insole, were tested in each shoe. Force and film data were collected for a total of 10 trials per subject. The subject performed practice trials with each insole/shoe combination (at least 100 ground contacts) before force and film data were collected. Trials where the subject did not land on the force platform or where the average running velocity was outside the required range were discarded and repeated.

Kinetic data from the force platform was stored directly on a PDP 11/44 computer while kinematic data from the film was digitized and transferred to the computer for analysis. Both force and film data were checked for inconsistent trials. The anterior-posterior force integral was used to detect changes in the horizontal running velocity, and film data was checked to identify irregular footfalls. Two subjects were rejected from the study because one landed flat-footed rather than heel first, and the other changed stride lengths to hit the force platform.

The main variables analyzed and discussed in this study can be defined under the following three categories:

1) Variables describing pronation:

$\Delta\beta_{10}$ = initial joint pronation (change of the Achilles tendon angle in the first 10th of foot contact time).

$\Delta\gamma_{10}$ = initial shoe pronation (change of the rearfoot angle in the first 10th of foot contact time).

$\mathring{\beta}_{10}$ = initial joint pronation velocity (mean angular velocity of the Achilles tendon angle in the first 10th of foot contact time).

$\mathring{\gamma}_{10}$ = initial shoe pronation velocity (mean angular velocity of the rearfoot angle in the first 10th of foot contact time).

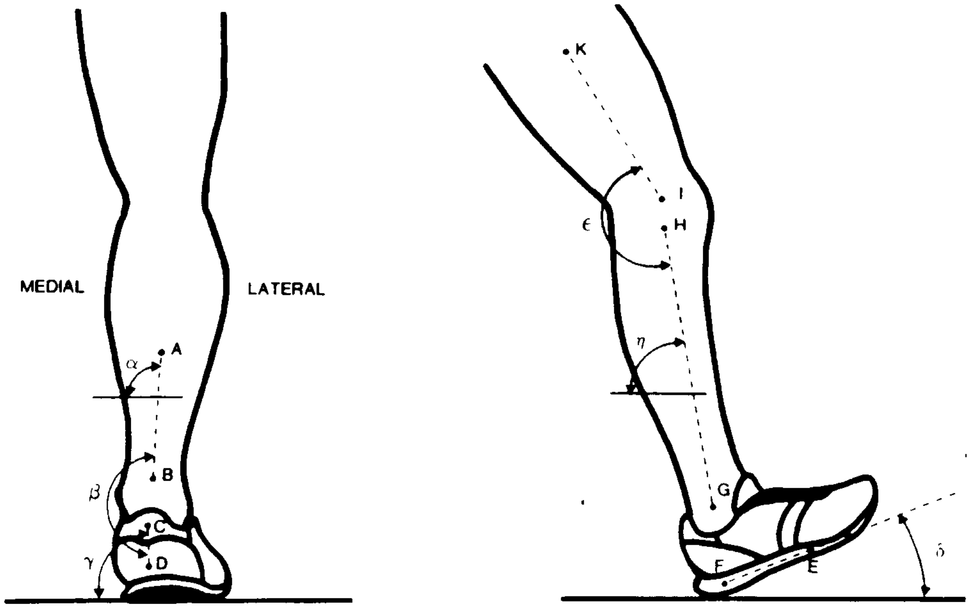


**Figure 1.** Illustration of the markers and angles used in the film analysis for the posterior and lateral view.

$\Delta\beta_{pro}$ = total joint pronation (total change of the Achilles tendon angle from first contact to its maximal value).

$\Delta\gamma_{pro}$ = total shoe pronation (total change of the rearfoot angle from first contact to its maximal value).

2) Variables describing initial conditions:

$\alpha_o$ = initial lower leg angle (all initial variables are determined from the last film frame before ground contact).

$\beta_o$ = initial Achilles tendon angle.

$\gamma_0$ = initial rearfoot angle.

$\delta_0$ = initial sole angle (angle between the horizontal and the shoe sole immediately before ground contact, lateral view).

$\epsilon_0$ = initial knee angle (angle between the lower leg and the thigh immediately before ground contact, lateral view).

$v_{oz}$ = mean vertical touch down velocity of heel.

$v_{oy}$ = mean anterior-posterior touch down velocity of heel.

3) Variables describing ground reaction forces:

$F_{zi}$ = vertical impact force peak (relative maximum of the vertical ground reaction force in the first 50 ms after touch down).

$t_{zi}$ = time of occurrence of vertical impact force peak.

$G_{zi}$ = maximal vertical loading rate (maximum average slope in the vertical direction of Fz(t) before reaching the impact peak).

Multiple comparison, nonparametric statistical tests were used to determine the differences among insoles for each variable analyzed. The level of significance chosen was 0.05 in all cases.

The repeatability of the results depends on the possible digitizing errors of the person analyzing the film and the consistency of movement performed by the test subjects. The short-term repeatability of the variables used in this study was assessed. The subjects were asked to perform the same test again at the end of the first 10 insole-shoe combinations with 3 different shoes, G1, G2, and a control shoe, G3. A different person analyzed the second set of trials and the results were compared to the results of the first measurements. These differences $|\Delta x|$ are listed in Table 2 and are examined in the discussion.

## RESULTS

The measured kinetic and kinematic results are reported in two categories: 1) variables describing the impact forces and 2) variables describing effects relating to pronation and

TABLE 2
Short-term repeatability of the variables used in this study for three different shoes (G1, G2, and G3 all with regular insole) for 14 subjects

| Symbol | Unit | $\|\Delta x_1\|$ | $\|\Delta x_2\|$ | $\|\Delta x_3\|$ | $\|\overline{\Delta x}\|$ | $\|\Delta x\|_{max}$ |
|---|---|---|---|---|---|---|
| $\Delta\beta_{10}$ | deg | 0.3 | 0.6 | 0.8 | 0.6 | 0.8 |
| $\Delta\beta_{pro}$ | deg | 1.5 | 1.3 | 1.0 | 1.3 | 1.5 |
| $\dot{\beta}_{10}$ | deg/s | 9.7 | 31.8 | 4.1 | 15.2 | 31.8 |
| $\Delta\gamma_{10}$ | deg | 0.3 | 0.7 | 0.5 | 0.5 | 0.7 |
| $\Delta\gamma_{pro}$ | deg | 1.3 | 0.9 | 0.5 | 0.9 | 1.3 |
| $\dot{\gamma}_{10}$ | deg/s | 10.2 | 14.2 | 2.5 | 9.0 | 14.2 |
| $\beta_o$ | deg | 1.7 | 1.6 | 0.4 | 1.2 | 1.7 |
| $\gamma_o$ | deg | 1.1 | 0.8 | 0.5 | 0.8 | 1.1 |
| $\delta_o$ | deg | 0.7 | 1.9 | 0.1 | 0.9 | 1.9 |
| $\epsilon_o$ | deg | 3.0 | 0.3 | 0.1 | 1.1 | 3.0 |
| $v_{oz}$ | m/s | 0.5 | 0.5 | 0.8 | 0.6 | 0.8 |
| $v_{oy}$ | m/s | 0.1 | 0.2 | 0.5 | 0.3 | 0.5 |
| $F_{zi}$ | N | 52.0 | 121.0 | 91.0 | 88.0 | 121.0 |
| $t_{zi}$ | ms | 1.0 | 0.0 | 3.0 | 1.3 | 3.0 |
| $G_{zi}$ | kN/s | 5.1 | 12.2 | 1.0 | 6.1 | 12.2 |

initial conditions. A summary of the means and standard deviations for each shoe/insole combination is presented in Tables 3 and 4.

### Variables describing impact forces

The mean values of the vertical impact force ($F_{zi}$) and time of impact force peak ($t_{zi}$) did not change significantly for the different insoles (Fig. 2). Additionally, the loading rate ($G_{zi}$) for the regular insole was significantly lower in the G2 shoe (85.02 kN/s) than for insole 1 (95.41 kN/s) and insole 2 (97.99 kN/s). The time of maximal loading rate ($t_{G_{zi}}$) for the regular insole in the G1 shoe was significantly later (20 ms) than for both insole 2 (17 ms) and insole 4 (17 ms). However, there was no characteristic pattern in the results describing impact forces indicating a consistent behavior of the regular and viscoelastic insoles used for both the G1 and G2 shoes. The ranges of vertical impact force peaks overlapped (1255 N to 1373 N for the G1 shoe with no heel stabilizer, and 1247 N to 1299 N for the G2 shoe). The time of occurrence of these peaks was consistently later for the G1 shoe (27 to 29 ms) than for the G2 shoe (22 to 25 ms). The maximum vertical loading rate was consistently lower for the G1 shoe (77.6 to 83.8 kN/s) than the G2 shoe (85.0 to 98.0 kN/s). The time of occurrence of the maximum vertical loading rate was consistently later for the G1 shoe (17 to 20 ms) compared to the G2 shoe (13 to 14 ms).

TABLE 3
Summary table with mean and SD for variables describing impact forces, pronation, and initial conditions for the shoe-insole combinations without heel stabilizer (G1)[a]

| Symbol | Unit | G1 reg | G1 in1 | G1 in2 | G1 in3 | G1 in4 |
|---|---|---|---|---|---|---|
| $F_{zi}$ | (N) | 1373 | 1255 | 1281 | 1285 | 1310 |
| | | (285) | (209) | (174) | (250) | (206) |
| $t_{zi}$ | (ms) | 29 | 28 | 27 | 29 | 29 |
| | | (3) | (4) | (3) | (3) | (4) |
| $G_{zi}$ | (kN/s) | 83.82 | 80.90 | 83.73 | 77.55 | 81.34 |
| | | (23.76) | 17.54 | (16.18) | (18.03) | (13.25) |
| $t_{G_{zi}}$ | (ms) | 20[b] | 17 | 17[b] | 18 | 17[b] |
| | | (2) | (3) | (3) | (3) | (3) |
| $\Delta\beta_{10}$ | deg | 11.3 | 13.4 | 12.5 | 12.8 | 12.0 |
| | | (5.0) | (3.4) | (3.6) | (3.9) | (3.6) |
| $\Delta\beta_{pro}$ | deg | 20.3 | 21.1 | 20.6 | 21.2 | 21.0 |
| | | (4.3) | (3.4) | (3.8) | (2.9) | (3.3) |
| $\dot{\beta}_{10}$ | deg/s | 424.5 | 476.8 | 465.4 | 453.6 | 442.8 |
| | | (17.95) | (98.5) | (126.3) | (137.4) | (116.6) |
| $\Delta\gamma_{10}$ | deg | −9.5[b] | −11.8[b] | −10.9 | −11.1 | −10.1 |
| | | (4.4) | (3.4) | (3.3) | (3.7) | (3.2) |
| $\Delta\gamma_{pro}$ | deg | −17.0 | −17.9 | −17.4 | −18.0 | −17.3 |
| | | (3.6) | (3.4) | (3.7) | (3.4) | (2.5) |
| $\dot{\gamma}_{10}$ | deg/s | −346.7 | −407.4 | −387.7 | −390.5 | −360.6 |
| | | (158.9) | (90.8) | (108.5) | (122.5) | (114.7) |
| $\alpha_o$ | deg | 100.0 | 100.4 | 100.0 | 100.0 | 100.2 |
| | | (2.8) | (3.4) | (3.4) | (3.6) | (3.4) |
| $\beta_o$ | deg | 175.8 | 175.7 | 176.1 | 175.4 | 175.8 |
| | | (4.0) | (3.9) | (4.2) | (4.4) | (4.5) |
| $\gamma_o$ | deg | 104.1 | 104.7 | 104.0 | 104.6 | 104.4 |
| | | (3.7) | (3.7) | (4.4) | (4.3) | (3.4) |
| $\delta_o$ | deg | 23.8 | 24.0 | 24.4 | 25.5[b] | 23.7[b] |
| | | (4.9) | (3.8) | (4.1) | (3.7) | (3.9) |
| $\epsilon_o$ | deg | 165.5 | 166.0 | 165.7 | 166.7 | 166.5 |
| | | (5.2) | (4.4) | (4.6) | (5.0) | (5.6) |
| $v_{oz}$ | m/s | −1.0 | −1.0 | −1.0 | −1.0 | −1.0 |
| | | (0.4) | (0.2) | (0.7) | (0.3) | (0.3) |
| $v_{oy}$ | m/s | 2.4 | 2.4 | 2.5 | 2.7 | 2.6 |
| | | (0.7) | (0.5) | (0.6) | (0.6) | (0.8) |

[a] Fourteen subjects; v = 4 m/s.
[b] Significant difference.

TABLE 4
Summary table with mean and SD for the variables describing impact forces, pronation, and initial conditions for the shoe-insole combinations with heel stabilizer (G2)[a]

| Symbol | Unit | G2 reg | G2 in1 | G2 in2 | G2 in3 | G2 in4 |
|---|---|---|---|---|---|---|
| $F_{zi}$ | (N) | 1299 | 1247 | 1267 | 1259 | 1247 |
| | | (240) | (159) | (183) | (155) | (192) |
| $t_{zi}$ | (ms) | 25 | 22 | 22 | 24 | 23 |
| | | (4) | (4) | (2) | (4) | (4) |
| $G_{zi}$ | (kN/m) | 85.02[a] | 95.41[a] | 97.99[a] | 90.24 | 89.09 |
| | | (25.03) | (17.75) | (19.53) | (17.35) | (19.52) |
| $t_{G_{zi}}$ | (ms) | 14 | 13 | 14 | 14 | 14 |
| | | (2) | (2) | (2) | (2) | (5) |
| $\Delta\beta_{10}$ | deg | 15.1 | 15.6 | 15.1 | 16.5 | 16.9 |
| | | (2.7) | (3.1) | (3.6) | (3.7) | (4.1) |
| $\Delta\beta_{pro}$ | deg | 19.8 | 21.4 | 20.0 | 21.4 | 21.6 |
| | | (2.8) | (4.4) | (4.9) | (4.3) | (4.0) |
| $\dot{\beta}_{10}$ | deg/s | 566.8 | 609.2 | 570.2 | 631.5 | 618.9 |
| | | (84.9) | (107.4) | (117.5) | (145.6) | (122.8) |
| $\Delta\gamma_{10}$ | deg | −12.0 | −12.8 | −11.9[a] | −13.1 | −13.7[a] |
| | | (2.4) | (3.2) | (3.7) | (3.2) | (3.5) |
| $\Delta\gamma_{pro}$ | deg | −15.9 | −17.8 | −16.3 | −17.8 | −17.5 |
| | | (1.8) | (3.9) | (4.7) | (3.5) | (3.2) |
| $\dot{\gamma}_{10}$ | deg/s | 438.9 | −491.9 | −442.0 | −488.4 | −490.3 |
| | | (72.1) | (96.0) | (109.3) | (119.6) | (102.8) |
| $\alpha_o$ | deg | 100.0 | 100.0 | 100.2 | 100.2 | 100.3 |
| | | (2.7) | (3.3) | (2.8) | (2.9) | (3.3) |
| $\beta_o$ | deg | 176.8 | 175.2 | 176.6 | 175.3 | 175.7 |
| | | (3.5) | (3.9) | (5.1) | (4.6) | (4.9) |
| $\gamma_o$ | deg | 103.2 | 104.8 | 103.7 | 104.9 | 104.6 |
| | | (3.0) | (4.0) | (5.0) | (4.2) | (3.9) |
| $\delta_o$ | deg | 25.7 | 24.7 | 26.4 | 24.7 | 24.0 |
| | | (4.3) | (4.4) | (3.6) | (3.8) | (3.8) |
| $\epsilon_o$ | deg | 165.7 | 165.6 | 166.3 | 165.2 | 164.7 |
| | | (5.4) | (6.3) | (4.9) | (6.2) | (5.3) |
| $v_{oz}$ | m/s | −1.0 | −0.9 | −0.9 | −0.9 | −1.1 |
| | | (0.3) | (0.3) | (0.2) | (0.3) | (0.4) |
| $v_{oy}$ | m/s | 2.5 | 2.7 | 2.6 | 2.6 | 2.5 |
| | | (0.8) | (0.8) | (0.5) | (0.7) | (0.6) |

[a] Fourteen subjects; v = 4 m/s.
[b] Significant difference.

### Variables describing pronation and initial conditions

The initial change in rearfoot angle ($\Delta\gamma_{10}$) was the only rearfoot variable analyzed that showed a significant difference (Fig. 3). In the G1 shoe, the regular insole (−9.5°) had a significantly lower change in rearfoot angle than insole 1 (−11.8°). In the G2 shoe, insole 2 had a lower value of change (−11.9°) than insole 4 (−13.7°). The maximum difference in the repeatability test was 0.7° for $\Delta\gamma_{10}$. There were no significant differences among insoles for any of the variables describing the Achilles tendon angle. The regular insole had the lowest value for all variables describing pronation ($\Delta\beta_{11}$, $\dot{\beta}_{10}$, $\Delta\beta_{pro}$, $\Delta\gamma_{10}$, $\dot{\gamma}_{10}$, $\Delta\gamma_{pro}$) in the G1 shoe and all but one of the variables ($\Delta\gamma_{10}$) in the G2 shoe.

The ranges of initial pronation variables, $\Delta\beta_{10}$ and $\Delta\gamma_{10}$, were consistently higher for the G2 shoe with the heel

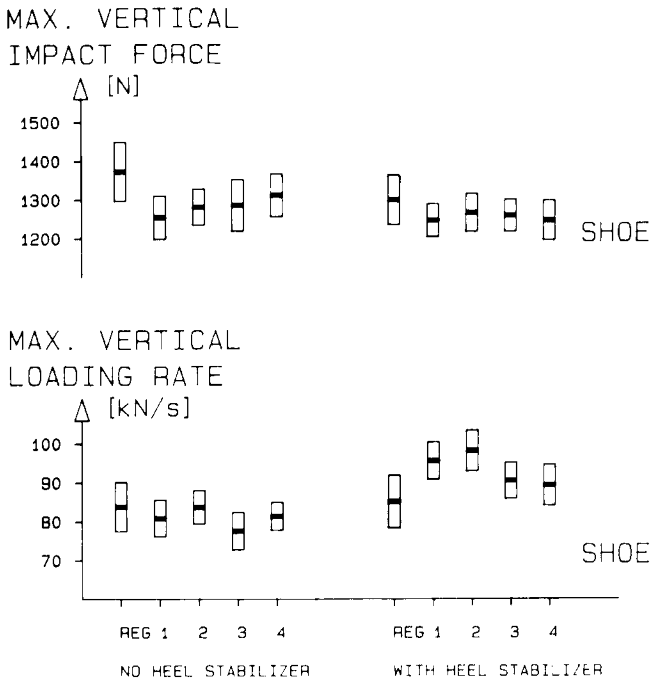


**Figure 2.** Maximum vertical impact forces, $F_{zi}$, and maximum vertical loading rates, $G_{zi}$, for the 10 shoe-insole combinations used in this study. Mean and standard error for 14 subjects running heel-toe with 4 m/s.

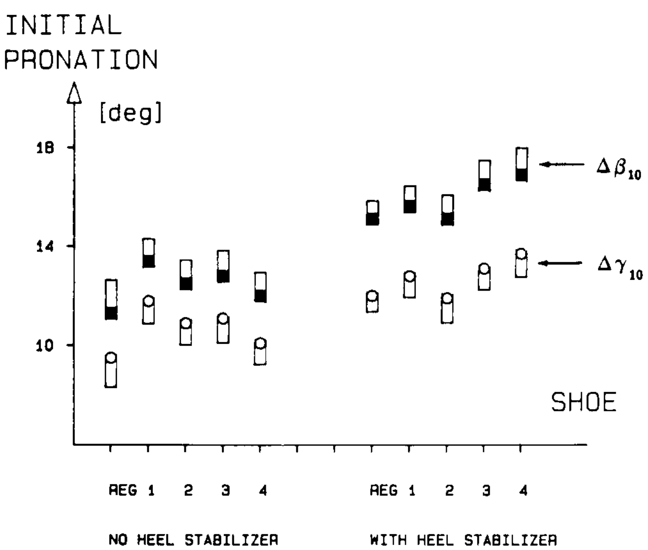


**Figure 3.** Initial shoe and joint pronation for the 10 shoe-insole combinations used in this study. Mean and standard error for 14 subjects running heel-toe with 4 m/s.

stabilizer (15.1° to 16.9° for the joint pronation $\Delta\beta_{10}$ and −11.9° to −13.7° for the heel pronation $\Delta\gamma_{10}$) compared to the G1 shoe without a heel stabilizer (11.3° to 13.4° for $\Delta\beta_{10}$ and −9.5° to −11.8° for $\Delta\gamma_{10}$). However, the ranges for total pronation overlap for the two shoe groups.

The initial sole angle ($\delta_o$) was significantly lower for insole 4 (23.7°) than for insole 3 (25.5°) in the G1 shoe. The maximum difference in the repeatability test was 1.9° for the initial sole angle $\delta_o$. The mean values for the initial lower leg angle ($\alpha_o$), the initial Achilles tendon angle ($\beta_o$), the initial rearfoot angle ($\Delta\gamma_{10}$), and initial knee angle ($\epsilon_o$) did not change for any of the insole-shoe combinations. Additionally, there was no difference in the touch down velocity of the heel in either the vertical ($v_{oz}$) or anterior-posterior ($v_{oy}$) directions. The ranges for the initial conditions overlapped for the two shoe groups.

## DISCUSSION

Studies in running shoe research often use the variables used in this study to assess the performance of running shoes,[1,2,7,10,14] assuming that running injuries are connected with these variables. Injuries at the anterior part of the tibia ("shin splints") are speculated to be connected with the variables describing impact force ($F_{zi}$, $t_{zi}$, $G_{zi}$) and initial pronation ($\Delta\beta_{10}$, $\Delta\gamma_{10}$, $\dot{\beta}_{10}$, $\dot{\gamma}_{10}$). Injuries at the medial and lateral side of the ankle and knee joint are speculated to be connected with excessive values of variables describing pronation ($\Delta\beta_{pro}$, $\Delta\gamma_{pro}$). The following discussion is based on these assumptions.

Viscoelastic insoles in running shoes are commonly assumed to reduce impact force peaks for runners. However, the results of this study do not support this assumption. This may seem surprising since previous studies have presented strong support for the use of viscoelastic inserts, claiming that acceleration amplitudes were reduced.[11,12,25–27] The results of this study show no significant difference in the maximum vertical impact forces and their time of occurrence when comparing the viscoelastic insoles with the regular insole. The only difference found in the kinetic results is a lower maximal vertical loading rate for the regular insole in the G2 shoe (with heel stabilizer). However, there is no systematic pattern, and based on the short-term repeatability results (Table 2), these differences are not relevant. The results of previous studies headed by Light et al.,[11] MacLellan et al.,[12] Voloshin,[25] and Voloshin and Wosk[26,27] seem, therefore, to be in disagreement with the results of this study. Various possibilities for these different results follow:

1) One source for differences may be that the results of this study are collected from running whereas most of the other studies[11,12,26,27] have dealt with walking. These studies claim that the tested viscoelastic insoles provide better attenuation of the maximum vertical impact force.

2) A second possibility for the contrary findings of this study may be that the insoles used in the earlier studies were extremely different from the insoles used in this study. This point cannot be checked because data like that presented in Table 1 are not available for the other studies.[11,12,25–27] The results in this study are based on the comparison of conventional running shoe insoles with special viscoelastic insoles.

3) A third possibility for the differences found in this

study compared to earlier studies may lie in the methodologies used in the various studies. Light et al.[11] MacLellan et al.,[12] Voloshin[25] and Voloshin and Wosk[26,27] all used accelerometers mounted at the tibia. These accelerometers were screwed into the tibia[11,12] or were strapped to the lower leg.[25-27] Denoth's[5] model replacing the human body by an effective mass (m*) may be used to discuss the relationship between the two methodologies. Denoth defined the effective mass as the ratio between the maximum vertical impact force measured using a force platform ($F_{zi}$) and the maximum axial acceleration at the tibia measured using an accelerometer:

$$F_{zi} = m^* \bullet a_{tibia}$$

The measured vertical ground reaction force peak corresponds to $F_{zi}$ measured in our experiments, and the measured axial acceleration peak corresponds to the acceleration maxima measured by Light et al.,[11] MacLellan et al.[12], Voloshin,[25] and Voloshin and Wosk.[26,27] Based on our experimental results, $F_{zi}$ did not change. Based on their experimental results, $a_{tibia}$ did change. According to Denoth's[5] model this is only possible when the effective mass, m*, changes. Denoth could show that the effective mass depends mainly on the initial knee angle $\epsilon_o$ and the time of occurrence of the vertical impact force peak. Both of these variables were measured in our experiment and did not show a change for the different insoles. Therefore, assuming that the effective mass model is appropriate, and using the kinetic and kinematic results obtained in this study, the acceleration at the tibia is believed to be constant in this experiment.

Kinetic and kinematic variables obtained using a force platform and high speed cinematography are, from the point of view of measuring technique, not critical. The natural frequency of the force platform used is high enough to measure the true input signals[1] accurately, and the film data for the initial knee angle, $\epsilon_o$, showed a maximum deviation of 3° (Table 2). However, acceleration measurements are difficult because of the mounting of the accelerometer on the underlying soft tissue. The mounting system may have a natural frequency as low as 10 Hz. For such a natural frequency of the measuring system, the frequency spectrum of the input signal (impact force) may overlap the natural frequency or be above or below this natural frequency. Therefore, the acceleration measurements obtained at the tibia and reported earlier[11,12,25-27] must be considered carefully.

The result that impact forces did not change for the different shoe-insole combinations is well in agreement with earlier results showing that the shoe hardness of the total midsole was changed without having an influence on the impact forces.[10,14,17]

Some kinematic variables were measured to study kinematic effects such insoles may produce. Previous studies have reported a higher incidence of pain and injuries to the lower extremities in runners with excessive pronation.[3,9,17] The variables used to describe pronation are the Achilles tendon angle $\beta$ for joint pronation and the rearfoot angle $\gamma$ for shoe pronation. The results show that the regular insole had the lowest values for all of the variables describing pronation in the G1 shoe and for five of the six variables in the G2 shoe, indicating that the regular insole had less initial and total pronation than all the other insoles. This may be due to the slightly lower position of the heel in the shoe with the regular insole, compared to the positions using insoles 1, 2, 3, and 4. Stacoff and Luethi[22] have speculated that by raising the heel, the axis of rotation of the subtalar joint moves further away from the ground. As a result, the moment arm of the ground reaction force about an axis through the subtalar joint increases, thus, the moment produced about this axis increases. This, in turn, may decrease the shoe's control of a runner over the degree of pronation.

Another interesting result is the fact that the differences between the G1 shoe and the G2 shoe are higher for the initial pronation variables and the loading rate variables than the differences due to the insoles. The different heel construction (the G1 shoe has no heel stabilizer whereas the G2 shoe does) affects the variables of interest more than the various insoles used.

The use of viscoelastic insoles in running shoes to replace the conventional insoles does not appear to affect kinetic and kinematic variables during impact in a relevant way. However, it is known that viscoelastic insoles are medically prescribed and that claims are made for their positive preventive and/or treatment effect. If this claim is correct, then aspects that were not covered by this methodologic set-up must have changed. Further investigation into the point of application of the resultant ground reaction forces and into pressure distribution may reveal additional information, but from the results of this study, the use of insoles does not seem to reduce loading of the locomotor system.

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