RUNNING SHOE STIFFNESS: THE EFFECT ON WALKING GAIT

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INTRODUCTION

A primary purpose of running shoes is to protect the individual from the possible injuries that can occur from repetitive loading. This can be done in a variety of ways, for instance by reducing the peak acceleration experienced, by increasing the time to peak acceleration, by absorbing a larger proportion of the impact energy, or by altering the motion of the foot (McNair 1994). A wide variety of materials and design concepts are used by many shoe companies to achieve these aims. Its now at a stage where the recreational athlete is often overwhelmed by the selection of running shoes available to them. One of the variables the buyer may take into consideration is the flexibility or stiffness of the shoe or the amount of force required to bend the shoe. This is a common technique used by the discerning shoe buyers to get a "feel" for the shoe, but what does it actually tell them about the shoe.

Shoe design is important as the shoe sole has the potential to alter the motion of the foot and lower limbs, and thereby influence the impact forces. In this regard, Shorten and Coworkers (1988) have shown that when compared to barefoot walking, a stiff soled shoe led to different foot placement, decreased range of motion and decreased speed of motion in the forefoot region.

Watson (1992) commented that running shoes need to flex through about 30 degrees in a line just posterior to the metatarsal heads. If the shoe is too stiff in this area, the windlass action of the plantar fascia wrapping around the flexing toes is inhibited. Changes in metatarsal joint kinematics have been suggested as a mechanism for injury. For instance Nordin and Frankel (1989) have commented that stiff soled shoes may alter the lever arm of the foot in the propulsion phase and place greater stresses on structures such as the plantar flexors, thus predisposing the wearer to injuries, such as Achilles tendon problems. Therefore the purpose of this study was to assess shoe sole stiffness characteristics by a materials testing procedure, and then relate these findings to sagittal plane kinematics measured during walking.

METHODOLOGY

Six pairs of running shoes with different sole design and shock attenuation materials were examined. All the shoes has a curved, slip lasted construction, and carbon rubber outsole. The primary material used in the midsole construction of all the shoes was ethylene vinyl acetate (EVA). However, some of the manufactures had supplemented this shock absorbing material with other elements and features which may effect the forefoot stiffness of the shoe.

Oscillation theory and stiffness calculations

When perturbed from an equilibrium position by a transient force, a single degree of freedom mass spring system such as that pictured in Figure 1A will oscillate at its resonant (natural) frequency. This frequency is a function of the stiffness of the spring and the magnitude of the mass. If a viscous damping component is added to this system the resulting oscillations will decay at an exponential rate governed by the amount of damping present (see Figure 1B). The stiffness of the forefoot of the shoe may then be calculated from a knowledge of the damping frequency of oscillation and the coefficient of damping. (For a detailed explanation of the coefficient of damping see McNair et. al. 1992)

Materials Testing

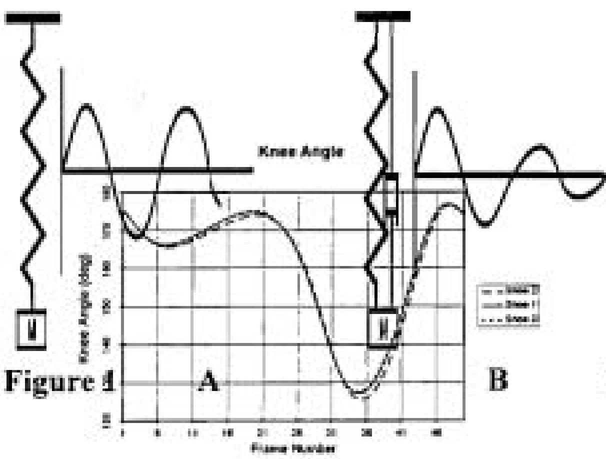
The front of each shoe was positioned under weights to prevent motion When fixed in position, a brief gentle manual perturbation was applied to the posterior aspect of the shoe. An accelerometer (Kyowa, Tokyo, Japan) was firmly secured to the posterior aspect of the shoe with tape. The accelerometer recorded the oscillations associated with the perturbation, the signal was amplified 100 times and transmitted to a computer controlled data collection programme sampling at 200 Hz. We collected 30 trials of data for each shoe. From this testing three shoes representing the range of stiffnesses were identified for use in subsequent gait analysis.

Gait analysis

Nine males ranging in age from 25 to 45 years (mean=36.4, SD=9.5) participated in the experiment. Their heights ranged from 176cm to 186cm (mean=182, SD=3.2) and weights from 72kg to 89kg (mean=81.3, SD=5.4) . No subjects had any musculoskeletal problems and all were familiar with treadmill walking.

Subjects walked on a motor driven treadmill at 5.1 km/hr in each of the three pairs of shoes in a randomised order. Three stride cycles were collected after the subjects had walked on the treadmill for two minutes in each of the three pairs of shoes. Two dimensional video data were collected on the right leg using an Ariel Video Analysis system sampling at 50 Hz Adhesive retroreflective markers were placed either on the skin or on the shoe on the following anatomical landmarks; the greater trochanter, the lateral condyle of the femur, the lateral malleolus of the fibular, the heel of the shoe and on the shoe at the level of the fifth metatarsal head.

The data were digitised using the automatic digitising procedure on the Ariel Video Analysis system. The X and Y co-ordinates for each marker were then downloaded to FMAP software for calculation of the kinematic variables. Segment angle data were then determined for the foot, leg and thigh, then ankle angle (Figure 2) and knee angle (Figure 3) data were calculated from these. As the subjects had different stride lengths, they consequently had different stride cycle times, so the data was normalised to 50 points using a five point interpolation routine. The normalised time-series data for 27 trials (nine subjects x three strides) was averaged and plotted for each of the three shoes. One standard deviation of the mean was also included for each shoe. Three t-tests, with Bonferroni adjustments, were made at the points of maximum difference between traces.



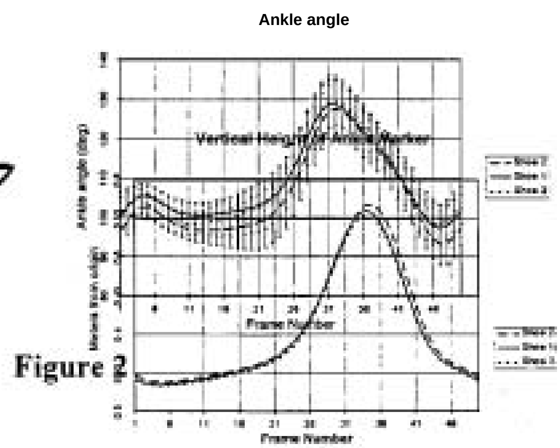


Figure 3

Figure 4

RESULTS

The stiffest shoe (Shoe 1) was brand new and was constructed of double density EVA, and reinforced with a kevlar belt running through the sole of the shoe. This belt is advertised as a propulsion plate, and the shoe is promoted for heavy people who want increased wear from their shoes. The shoe had a straight shape and a combination of slip and cement lasting and had a stiffness rating of 3708 N/m. The least stiff shoe (Shoe 3) had a single density EVA midsole and carbon rubber outersole and had been used for running for 12 months, it had a stiffness rating of 1273 N/m. A shoe (Shoe 2) with a stiffness rating in the mid-range between these shoes (2465 N/m) was also used in subsequent gait analysis. It was a new shoe with a carbon runner outersole and a double density EVA midsole.

The mean for the ankle angle during the stride cycle is presented in Figure 2. The cycle is heel strike to heel strike, the error bars are Standard deviation bars. The stance phase of the gait cycle is from point 0 to 32, swing phase from 33-50. There was no statistical difference ($p>0.05$) between the shoes at the points of maximum difference on the traces, indicating no difference in ankle angle between the three types of shoes anywhere in the stride cycle.

Figure 3 is the mean knee angle for each of the three pairs of shoes for one stride cycle from heel strike to heel strike. Standard deviation bars were large as in figure 2 and are not presented for clarity. There was no statistical difference ($p>0.05$) between the shoes at the points of maximum difference on the traces, again indicating no differences between the three types of shoes.

It was initially thought that a stiff shoe may lift the ankle higher than a more flexible shoe during the end of stance phase. Figure 4 indicates the Y displacement of the ankle marker. There was no difference ($p>0.05$) in ankle height between the three types of shoes at the end of stance phase which occurred at the 32nd point.

DISCUSSION

Differences in ankle kinematics were observed by Shorten and colleagues (1988) when comparing barefoot walking to walking in stiff soled shoes, however, our data demonstrated no differences in ankle or knee kinematics when walking in the range of shoes we tested. In this regard, even though we tested a full range of shoe stiffnesses, including one that uses a stiff kevlar plate, perhaps the shoes we tested were too similar and could not be differentiated by the gait analysis techniques we used. Further, the 70-80kg mass of a person may be too much to be affected by the stiffness of running shoes.

An alternative suggestion is that there are probably numerous combinations of joint and muscle activity, of which the individual parameters need only alter slightly to accommodate the different shoe stiffnesses in an attempt to maintain an invariant walking pattern, changes so small we cannot measure them. Although we found no differences in the way we walk when wearing either stiff or flexible running shoes, people will still go into running shops and give the shoe the forefoot bend test, perhaps its psychological or perhaps it is a part of getting the "feel" for a shoe that we can't measure yet.

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