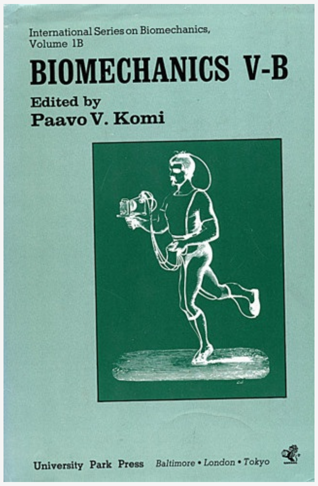
Biomechanics of Athletic Shoe Design

New innovation in designing athletic shoes



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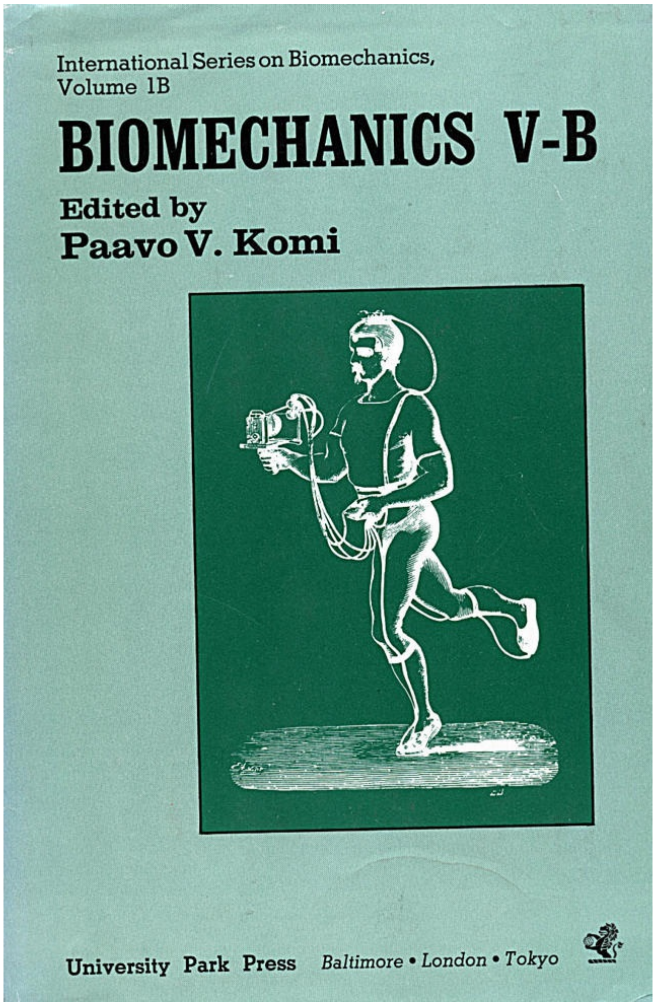

Biomechanics of athletic shoe design

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In all athletic performances, whether team games such as football, soccer, basketball, volleyball, or in individual sports such as running, jumping, throwing, or cycling, where gravitational forces play a major role, the shoes on which the weight bearing athlete plays are probably one of the most important contributing factors in the execution of efficient human performance. The interaction between the uniqueness of each specific activity and the athlete is influenced by factors such as the force of impact, the weight of the athlete, the surface upon which the activity is performed, the individual's stride and gait, etc. Athletic footwear cannot be evaluated separately from the "athlete in the shoe." Therefore, biomechanical factors of the athletic performance must be considered when designing shoes.

For a number of years, repeated attempts have been made by the writer to determine the scientific methods used by various shoe companies in the United States, Germany, Finland, and other countries in the development of their athletic shoes. However, it is evident that shoe design and safety have been the province of both the shoe designer and safety engineer. The engineer has been concerned with the physical components of the shoe such as the coefficient of friction and durability factors influencing the shoe. Often esthetic features receive the greatest consideration. However, it is contended that athletic performance cannot be thoroughly researched without taking into account "the athlete in the shoe." Unfortunately, the shoe designers have overlooked the fact that shoe efficiency, safety, and performance are inextricably tied to the biomechanics of the particular activity and the style of whoever is under scrutiny.

At present, however, there are few reliable approaches for measuring these factors which are essential in athletic shoe design. In the present study, a new approach to athletic shoe design will be discussed.

METHOD

Biomechanical Measurements

A computerized biomechanical analysis system was used in assessing the data. This sophisticated method is described in detail elsewhere (Ariel, 1973). In general, slow motion cinematography is used in conjunction with a force plate to record any desired human motion. This technique permits an undetected recording of an individual's performance under actual conditions. The Model GP-3 Graf-Pen digitizer enables precise determination of the coordinates of the joint centers of the body. A digital processing oscilloscope permits the storage of all forces and moments of force on the contact points between the shoe and the surface. Location of the joint centers provides the measurement of the segment lengths and angles, while determination of the segment masses, centers of gravity, and radii of gyration allows the calculation of forces and moments of force around each body joint center. Appropriate programming (CBA, 1975) results in a segmental breakdown of information of the whole motion, including the total body center of gravity, segment velocities and accelerations, and the timing or coordination of motion among the body segments. The combination of cinematographical data with force-plate data yields the instantaneous forces on the shoe as a function of time.

Shoe Measurements

Vibration testing of the various shoes was performed utilizing the force data obtained from the cinematographical and force-plate data. The force applied to the shoe material at various locations was plotted against the displacement of the material, yielding an elastic hysteresis where the increasing and decreasing forces resulted in curves that did not coincide. The area bounded by this plot determined the energy loss and the slope of the curves determined the energy stored. The sole and inner-sole of the shoe produce a force that is constantly in contact with the test piece and the hysteresis loop takes place during every cycle of vibration. The loop is velocity dependent and yields the damping effect of the materials. The loop also yields the stiffness or restoring force, which is displacement dependent. If the elastic properties are poor, the bottom curve does not return to zero in time for the beginning cycle of the first curve of the next cycle.

RESULTS

The present experiment resulted in two types of data. The first results were the biomechanical behavior of the athlete. The second results were the data obtained from the various athletic shoes based on the dynamic testing of the shoe itself. Figure 1 illustrates the interaction between the surface, shoe, and body joints. A unique approach in this study was that the dynamic characteristics of the shoes were obtained by utilizing the biomechanical data from the athlete as he performed rather than the common trial and error method of observation alone.

Anatomical Consideration

Foot movements are important considerations in the design of the athletic shoe. However, because of the numerous articulations, the foot is quite complex. For example, the foot consists of the following joints: (a) the ankle joint, between the tibia and talus; (b) the talocalcaneal joint, between the talus and calcaneus; (c) the mid-tarsal joints, calcaneus to cuboid, and talus to navicular; (d) the tarsometatarsal and

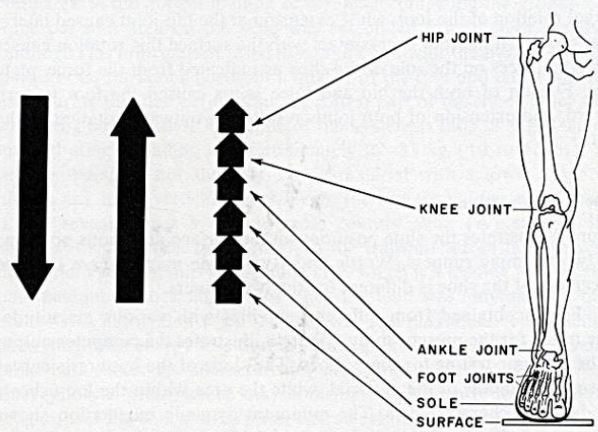

Figure 1. Force interaction between surface, shoe, and body segments.

intermetatarsal joints; and (e) the metatarsophalangeal joints. Cinematographical analyses of 10 athletes running bare-footed yielded the following movements of the foot: (a) the ankle joint allows flexion and extension in the sagittal plane; (b) the talocalcaneal joint permits inversion and adduction combined with foot extension, and eversion and abduction combined with foot flexion; (c) the mid-tarsal joints allow motion in all planes with distinctive supination and pronation of the foot; (d) the tarsometatarsal and intermetatarsal joints permit gliding motion for weight bearing; and (e) the metatarsophalangeal joints permit motions in all planes.

The complexity of foot movements and the specificity of each activity demonstrate the need for biomechanical considerations in designing athletic shoes. A total body analysis is necessary in order to design an athletic shoe that accurately conforms to the needs for the particular event.

Anatomical Factors Relating to Shoe Design

The cinematographical data revealed that the position of the foot is influenced by the mechanical axis of the femur relative to the mechanical axis of the tibia. Normal posture causes the position of the foot to angle outward in a range of 21–30 degrees depending upon individual differences as well as sex differences. The position of the foot was further influenced by motion at the hip joint. Flexion at the hip joint caused medial rotation of the foot, while extension at the hip joint caused lateral rotation. When the foot is in contact with the surface this rotation causes torsional forces on the sole of the shoe as indicated from the force–plate data. Flexion of both the hip and knee joints caused the foot to turn inward, and extension of both joints resulted in outward rotation of the foot.

Shoe Considerations

Figure 2 illustrates the shoe positions on the surface at various positions for two Olympic runners, Wottle and Ryan. One may observe that the placement of the shoe is different for the two runners.

Forces obtained from different activities with various magnitudes were tested for the present study. Figure 3 illustrates the computer output of the dynamic testing for these shoes. The slope of the hysteresis curves shows the firmness of the material, while the area within the loop shows the damping characteristics. The minimum dynamic indentation shows the amount of indentation of the material after a steady-state loop has been attained from a 10-cycle/sec loading. The slope of the curve and the point at which any abrupt changes in the slope take place must be compared to the impact loading of a runner contacting the ground. The force per unit area on the shoe was calculated for different speeds of running. This information, used in conjunction with the hysteresis loops, showed that the shock absorption quality of the foot and ankle was fully used during the time period that the softest part of the shoe (inner sole) was being compressed. The slope of the hysteresis loop changed sharply upward after a loading of approximately 22–33 kg (10 to 15 lb), and neither the shoe, nor the foot, nor a material with a lower slope can absorb any more vertical forces. From the hysteresis loops in Figure 3, it was revealed that a leading cross country shoe (A) showed little shock absorption that might result in the transmission of high forces to the ankle, knee, and hip joints. Shoe (F), which is a leading jogging shoe, had maximum shock absorption when the load was minimal and minimum shock absorption when the load was at a maximum. This phenomenon illustrates energy loss during running. Shoe (C) is a leader among basketball shoes. Its characteristics are opposite to the desired ones. Energy loss is great, which may contribute significantly to the athlete's fatigue, and the shock absorption characteristics are not consistent with those desired in this game.

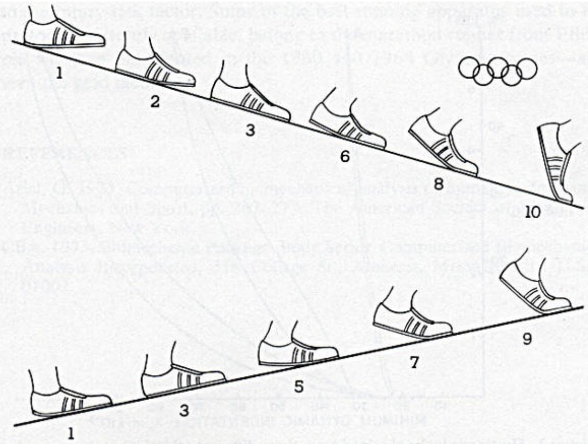

Figure 2. Athletic shoe positions at various contact phases.

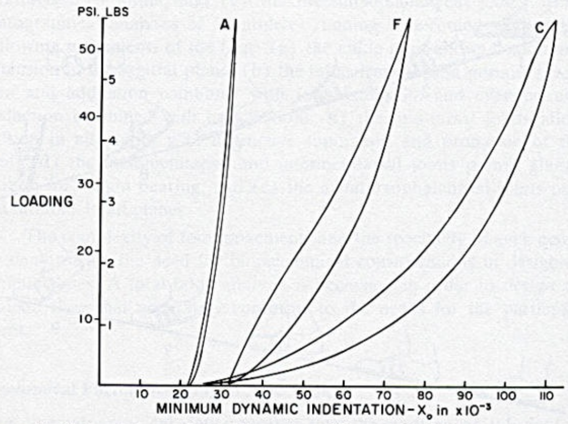

Figure 3. Hysteresis loops obtained from three different athletic shoes.

DISCUSSION

Analyses of more than 35 different running shoes revealed that human factors were not taken into consideration when designing these shoes. The dynamic characteristics of these running shoes yielded results which are opposite to the desired ones. The hysteresis loops obtained demonstrated insufficient shock absorption characteristics or too much absorption at the wrong time. In other words, when the loading was at its minimum the greatest shock absorption occurred while at the point of greatest loading, when the shock absorption is needed, the material does not respond properly. None of the shoes in this study demonstrated results that are considered desirable for the given activity.

From the evaluation of the shoe material and its interaction with the shock absorbing qualities of the foot, it was concluded that the heel and the outside edge of a shoe should have a hysteresis slope of about 45 degrees with no abrupt changes in the slope. The section of the shoe at the ball of the foot should have a hysteresis slope of about 75–80 degrees with no abrupt changes so that the runner or thrower can push off from a solid surface.

At the present time, there are no athletic shoes available which consider the "athlete in the shoe." In fact, some of the shoes may contribute

to the injury-risk factor. Some of the best running apparatus used in the past, and currently available, belong to the marathon runner from Ethiopia who ran bare-footed in the 1960 and 1964 Olympic games—and won the gold medal.

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