Current Trends in Athletic Shoe Design

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The characteristics of athletic shoes have been described with terms like cushioning, stability, and guidance.1,2 Despite many years of effort to optimize athletic shoe construction, the prevalence of running-related lower extremity injuries has not significantly declined; however, athletic performance has reached new heights.3-5 Criteria for optimal athletic shoe construction have been proposed, but no clear consensus has emerged.6-8 Given the unique demands of various sports, sport-specific shoe designs may simultaneously increase performance and decrease injury incidence.9-11 The purpose of this report is to provide an overview of current concepts in athletic shoe design, with emphasis on running shoes, so that athletic trainers and therapists (ATs) can assist their patients in selection of an appropriate shoe design.

Basic Construction of an Athletic Shoe

An athletic shoe consists of two primary components: (a) the sole and (b) the upper. The upper covers the dorsal, medial, and lateral aspects of the foot, and the sole provides stability and cushioning at the interface between the ground and the plantar surface of the foot. The shoe upper consists of toe box, heel counter, entry opening, tongue, and quarter. The sole is divided into components that are designated as anterior sole, mid sole/or brand sole, and outer sole. A foot model, made of wood or plastic, which is used for production of the shoe in the desired size and form, is referred to as a last. Lasts are created to match average measurements from a population. The last used for construction of a shoe produced for North America can differ from the one used for the Asian market. Lasts are designated as straight, half-bend, or full bend. The bend form is generally considered to produce a shoe that is more comfortable because most feet are slightly inverted. Straight-last shoes offer more stability, which can be beneficial for an athlete who has flexible feet.

Cushioning

The relationship between impact force at heel strike and musculoskeletal injury was originally based on animal models and theoretical calculations. To date, this relationship has not been established in human models.2,12-14 New biomechanical techniques allow for calculation of stress within biologic structures. Stress on cartilage, ligaments, bones, and tendons of the lower extremity...
are independent of, or only minimally affected by, the cushioning property of the shoe sole.\textsuperscript{15-17} Stress is determined by joint geometry, muscle tension, and external forces.\textsuperscript{18} The contribution of soft tissue vibration related to heel strike is also being investigated. Soft tissue vibration creates an unpleasant sensation that is reduced by muscle activation.\textsuperscript{19,20} Changes in soft tissue vibration and muscle activation could explain the differing sensations experienced when running on soft versus hard ground or running in cushioned versus firm shoes. Electromyography (EMG) changes support this theorized relationship.\textsuperscript{21,22} Research evidence suggests that the impact forces generated during “normal” athletic activity have no significant role in the development of injuries. Shoe cushioning does appear to have a significant influence on comfort, muscle activation, performance, and exhaustion, however.\textsuperscript{8,18}

How much cushioning is sensible? Throughout most of history, humans walked barefoot on natural ground. Anthropologists estimate that early humans averaged a daily walking distance of up to 40 km,\textsuperscript{23} and the ability to run fast may have provided a selection advantage. Current shoe cushioning rationale reflects an effort to diminish the differences between natural terrain and artificial surfaces. Excessive cushioning appears to be as problematic as insufficient cushioning.\textsuperscript{24,25}

\section*{Motion Control}

Excessive foot pronation and associated internal leg rotation has been linked to development of overuse syndromes of the knee (e.g., patellofemoral pain syndrome, ilioltibial band syndrome).\textsuperscript{26-30} Medial tibial stress syndrome, Achilles’ tendinopathy, plantar fasciitis, and stress fractures have also been related to excessive foot pronation and internal leg rotation.\textsuperscript{13,31} As a result of this relationship, restraint of excessive motion has been viewed as a paramount requirement of running shoes and orthotics. Despite widespread belief that support of the medial longitudinal arch is important for correction of over-pronation, the effects of orthotics on foot and leg motion have been found to be minor and inconsistent.\textsuperscript{32-37} In addition, integration of stiff medial components into the shoe sole (“second density”) to provide a increased mechanical resistance to foot pronation was unsuccessful in significantly restraining over-pronation of the foot.\textsuperscript{38,39} The findings of a prospective study of 131 runners who averaged 30 km per week of running over a 6-months period demonstrated that axial orientation of foot and ankle joints did not predict running-related injuries.\textsuperscript{40} Measurements of the bone displacements during running have failed to demonstrate any consistent relationship with medial support.\textsuperscript{41,42} Inverse dynamic analysis, which uses kinematic and kinetic measurements to calculate stress levels within biologic structures, has demonstrated a relationship between foot pronation and high levels of tissue stress. Analysis of simultaneous multisegmental displacements appears to be important for identification of the causes of overuse injury syndromes in the lower extremity. Medial tibial stress syndrome, ilioltibial band syndrome, and patellofemoral pain syndrome have been related to forces created by a combination of excessive foot pronation, leg internal rotation, and leg abduction.\textsuperscript{43} Maximum foot pronation and pronation velocity appear to play a greater role in development of overuse injury than the magnitude of the ground reaction force that is generated at heel impact.\textsuperscript{30} The peak vertical ground reaction force generated by barefoot walking be can be as much as two times greater than that which is generated while wearing a cushioned athletic shoe\textsuperscript{44} (Figure 1).

\section*{Fit}

The term “comfort” is associated with both the fit of a shoe and the extent to which the shoe supports the “natural motion” of the foot.\textsuperscript{45} Athletes view the fit of the shoe as one of its most important characteristics.\textsuperscript{46,47} The mechanical qualities of a shoe’s design can be objectively quantified, but the shoe’s fit involves interaction between shoe’s configuration and

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\caption{Cushioned athletic shoe.}
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the individual athlete’s foot, which extremely difficult to measure. Each of these three factors influences the movement of the foot within the shoe. Runners can subjectively judge the fit of shoe very well.48 There are significant differences in foot shape between male and female runners.22 Research has demonstrated that a runner’s preferred running shoe is always positioned well in relation to the foot structure.45 However, fit in the heel area could not be conclusively correlated with a reduction of pronation velocity.39,49

Athletic Shoe Industry Response to Recent Findings

Based on recent findings, the two biggest trends in athletic shoe design are individualization of fit and force generation that is similar to barefoot walking on a natural ground.50

Various companies make application of these concepts in different ways. An example of the individualization of fit is the availability of various widths from New Balance™. Their four top-selling models are available in 4 different widths for each shoe size. Width individualization is limited to the forefoot; the midfoot and hindfoot are identical in all 4 models. Other companies offer as many as 3 widths for certain models. Due to costs associated with longer shelf time, this fit individualization concept has not been readily accepted by retail stores that sell athletic shoes. Frequently, mid-range widths are the only ones that are available in stores.51

The Biomorphic fit system from Asics™ provides soft elastic areas in the upper of the forefoot. This design feature promises that no pressure points will be created, even with mild hallux valgus or a tailor bunion. Product lines are available that provide adjustments for major differences between the foot structure of male and female athletes, and those of different ethnic backgrounds.22,51,47 Nike™ was the one of the first companies to offer “female” running shoes, which can be found in most major athletic shoe retail stores. In addition to the differences in foot structure, the lower average body weight of female athletes is considered in the degree of sole flexibility. Adidas™ has introduced “mi Adidas,™” individualized shoes, which accommodate a wide variety of different foot types. Foot measurements are utilized to optimize shoe fit for running shoes, soccer shoes, tennis shoes, basketball shoes, and handball shoes.

Differing cushioning needs can be accommodated by shoes having different softness levels. This is made possible through the use of PU-foam and EVA-foam, honeycomb structure (Figure 2), or gel. A new and innovative concept is an electronic cushioning adjustment that involves a servo motor, which alters the pretension level of a cushioning module on the heel. The first shoe of this type (marketed as the Adidas 1™) was too heavy for acceptance by athletes. Its latest version (the “SMART RIDE”) offers greater flexibility and is much lighter in comparison to the original version that was introduced in 2005.

Reduction of pronation moment arm length in the hindfoot can be achieved by specifically designed zones in the sole that readily deform upon heel impact. The “crash pad™” by Nike™ is an example of a shoe design feature that utilizes this concept (Figure 3). Reebok™ created holes in the sole material in the heel area, thereby allowing a few millimeters of movement that reduces pronation-inducing torque during the first few milliseconds of ground contact.

A complete detachment of the hindfoot section is created by the Adidas™ ForMotion™ design. The outer sole slides on a half-cup configuration, thereby reducing for the conversion of vertical ground reaction force into rotational torque. The reduction of pronation torque, which is associated with multiple running injuries, is the primary goal (Figure 4).

The most innovative step toward replication of barefoot walking has been developed by Nike™. The “Nike Free™” shoe is characterized by the complete absence of any stabilizing elements (Figure 5). Its cushioning is designed to mimic forces associated with barefoot contact against natural ground. This shoe requires considerable muscle activation for stabilization of the foot. Many athletes develop muscle soreness after wearing the shoe for the first time. Recently, this shoe has been marketed as a training tool, rather than a running shoe.

Conclusion

The design of athletic shoes has historically reflected emphasis on cushioning, stabilization, and guidance. These concepts have progressively been replaced by emphasis on the individualized considerations, such as sport-specific requirements and the individual athlete’s foot structure. Recently introduced athletic shoe designs incorporate mechanisms to reduce pronation
torque, and cushioning is limited to a sport-specific requirement. Recent athletic shoe design concepts are largely based on the idea that the musculoskeletal system of humans has adapted to barefoot walking on a natural surface for thousands of years.52

**References**


