THE EVOLUTION OF ATHLETIC FOOTWEAR

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The purpose of this presentation is to discuss the evolution of athletic footwear and how biomechanics has influenced this evolution. Footwear has undergone a significant evolution from the Paleolithic period to modern times. The origins of footwear emphasized protection from the environment. During the Egyptian, Greek and Roman eras, the need for military shoes drove the development of footwear. It was not until the 19th century that specific footwear for athletic performance was designed. Footwear were improved significantly during the first half of the 20th century but it was not until the latter portion of this century that biomechanics truly had an influence on footwear design. The intersection of biomechanics, injury risk factors and footwear development paralleled the growth in lower extremity research. More recently, the interest in barefoot running has driven the development of minimalist footwear.

KEY WORDS: biomechanics, footwear, athletic footwear, lower extremity mechanics

THE ORIGINS OF FOOTWEAR: Tool making by ancient humans began approximately one million years ago with clothing and footwear appearing ~50,000 years ago in the mid-Paleolithic period. There is evidence to suggest that *homo erectus* (~50,000 years ago) was involved in locomotion – both walking and running since these activities were necessary for survival (Carrier & Bramble, 2004). However, there is no evidence that these early humans used footwear. In fact, it is doubtful that we will ever know when the first shoes were worn or what they looked like. The development of footwear came much later. When they started to develop footwear, early humans probably did so for protection against the environment. The first shoes were probably bag-like wrappings of animal skins.

The earliest footwear that has been found dates back to approximately 5- 10 thousand years ago. Footwear, found in Fort Rock, Oregon in 1938 by University of Oregon archeologist Luther Cressman has been dated from 13,000 to 9,000 years ago. These shoes were basically sandals made of sagebrush. Other ancient footwear, made of cowhide and shaped like a moccasin, was found in Armenia and dated to ~5,500 year old (Pinhasi et al., 2010). Thus, the development of footwear is relatively recent in human history.

In ancient Egypt (~2000 BC), soldiers wore sandals made of woven reeds, papyrus or thin animal skin. By ~1550 BC, the reed sandal was replaced by one with a thick leather sole that was secured by a leather strap. This structure allowed the soldier to run without losing their sandals. Subsequently, leather side pieces were added to make the sandals look like shoes. At approximately the same time period, ancient Greeks had developed a sandal structure. Interestingly, there is no evidence that Greek athletes wore footwear during races. In fact, they wore no clothes at all. The most famous marathoner from ancient Greece was Pheidippides who ran 26 miles from Marathon to Athens to tell of victory over the Persians. There is no evidence whether he wore shoes or not but as a soldier we can postulate that he did.

In the Roman era, the emphasis on footwear development was on combat sports and the military. Shoe-making was a well-developed art in Roman times with footwear ranging from sandals to nailed boots. Roman soldiers who acted as couriers wore special footwear known as *gallica*. Into the middle ages in Europe, the same theme in footwear followed as footwear was based on the military needs. These footwear were very simple and uncomplicated. However, rounded heels and pointed toes were in evidence. By the Tudor period (~1450-1600) welted shoes were made while later in that period heels were added. In the following years (1600-1800), fashion appeared to rule the development of footwear.

THE MODERN ERA: By the 1800's, running races were quite common although using footwear specific for the races was not common. It was thought that special shoes were not necessary. In 1839, Charles Goodyear developed the process to use rubber in many different contexts including making shoes for athletics. Shortly thereafter (~1850) the first spiked athletic shoes were made for the sports of cricket and croquet. The first known spiked running shoe was developed in Northampton, England in 1865.

Athletic footwear continued to develop throughout the latter portion of the 19th century and up to approximately 1965. At this time, athletic shoes transitioned from leather uppers to a greater reliance on synthetic materials.

THE REVOLUTION IN FOOTWEAR: By the 1970s, jogging became very popular as a form of exercise and the 'running boom' began. Footwear was now deemed to be an integral part of the athlete's equipment and runner's felt a necessity to have footwear for the occasion. It was during this period that biomechanics began to exert a significant influence on footwear design. The explosion of interest in running prompted a comparable growth in research on running. The biomechanics of running became a major focus of researchers and this interest transitioned to the development of running footwear. The influence of biomechanics on footwear design also coincided with the development of biomechanics laboratories. These laboratories around the world studied athletic footwear as it related to the kinematics and kinetics of runners at both the elite and recreational level. The key individuals who promoted and developed most of the research techniques for the investigation of athletic footwear were: 1) Dr. Benno Nigg first at the ETH Zurich in Switzerland and then at the University of Calgary, Canada; 2) Dr. Peter Cavanagh at the Pennsylvania State University, 3) Dr. E.C. Frederick at the Exeter Research Lab and founder of the Nike Sport Research Laboratory; and 4) Dr. Barry Bates at the University of Oregon. The development of footwear design according to biomechanical principles paralleled the development of biomechanics laboratories with the result that, as research programs and technology developed, the research in athletic footwear became more involved.

A further development in athletic shoe research was that research programs began to study the possible link between footwear and overuse injuries, particularly during running. It was demonstrated that incidence of knee, leg and foot injuries was 42%, 27% and 19% respectively of all running injuries (Clement et al., 1980). These results were responsible for directing running related, and by extension, footwear research. In the lay and sports medicine literature, 'excessive' calcaneal eversion was blamed for every conceivable injury of the lower extremity with little evidence to support this notion (Cavanagh, 1987).

The principle biomechanical concerns for protecting runners against injury were the need for: 1) cushioning; 2) rearfoot mediolateral control; and 3) forefoot stability (Winter & Bishop, 1992). Interestingly, the third concern, forefoot stability has not been addressed adequately and so will not be addressed in this paper. In order to study these concerns, biomechanists used force platforms and tibial accelerometry for the former and cine or video motion capture for the latter. Force platform analysis determined that during heel-toe running (the most prominent footfall pattern), there was an initial peak (often referred to as the 'impact or passive peak') and a second peak (often referred to as the 'push-off or active peak') (Figure 1).

The impact peak ranged from 2 to 3 times body weight during running and this shock travelled through the skeletal system to the head. This meant that the body had to attenuate the shock using either passive structures (i.e. bones, cartilage, etc.) or via altering the body geometry (i.e. altering lower extremity joint angles). It was thought that footwear should have some cushioning ability to aid in attenuating the foot-ground collision. Therefore, cushioning materials such as ethyl vinyl acetate (EVA) and polyurethane (PU) were used in the midsole as cushioning materials. Unfortunately, it was discovered that a softer midsole was not functionally different from a harder midsole so there was no immediate effect of the shoe on shock attenuation and no real solution to the cushioning problem.

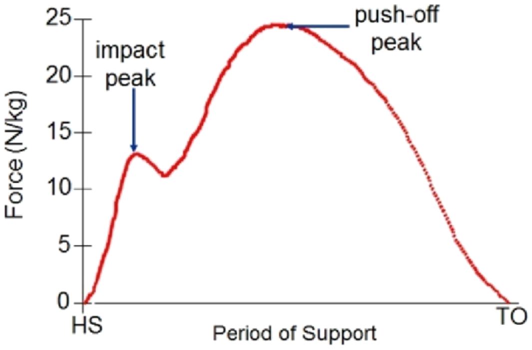

Figure 1. Illustration of the vertical ground reaction force component showing the impact and push-off peaks

The second major biomechanical concern was controlling the medio-lateral motion of the rearfoot. This action is referred to as calcaneal eversion. The foot contacts the ground in an inverted position and rolls medially to an everted position (Figure 2). It was thought that too much eversion or ‘excessive’ eversion caused a running related injury and so footwear were designed to control eversion. However, since there is no clinical definition for ‘excessive’ eversion, it is not known how much eversion is considered excessive. The most common technique used for controlling this motion of the foot was to create a firmer midsole. By altering the midsole density, the medial border of the midsole of the shoe should not collapse thus controlling the amount of foot eversion. Other features of footwear used to accomplish the control of the rearfoot were stiffer heel counters, different lacing systems and midsole plates. The method generally employed to evaluate foot eversion was to place markers directly on the shoe. However, it was later reported that such a technique was not a true evaluation of foot motion. In fact, the foot actually moved less than the shoe did (Reinschmidt et al, 1997).

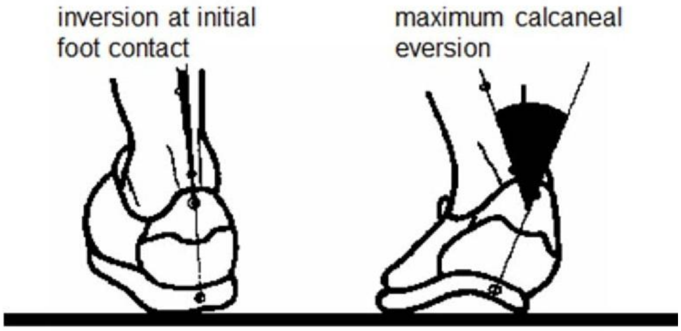

Figure 2. Illustration of the rearfoot positions at initial foot contact (inversion) and at maximal eversion. The shaded area in each position is referred to as the rearfoot angle.

It then became a problem to try to reconcile these two biomechanical concerns. Many techniques such as dual density midsoles (soft on the lateral border and firm on the medial border), materials in combination (e.g. EVA + encapsulated gases), midsoles with structural bars were used to accomplish both tasks and midsoles with mechanical structures.
Other developments in footwear resulting from biomechanical studies involved optimal metatarsophalangeal flex grooves, increasing midsole forefoot stiffness to improve sprint performance (Stefanyshyn & Fusco, 2004), the Adidas computerized shoe and the concept of energy return.

RECENT FOOTWEAR DEVELOPMENTS: Current developments in footwear evolution have centered around the ‘barefoot’ running and minimalist shoe craze. The discussion actually began with a criticism of the existing footwear. Existing footwear were criticized for being 'overbuilt'. That is, they had a thick midsole, particularly in the heel, a firm heel counter and considerable arch support (Robbins et al., 1988; Liebermann et al., 2010). It has been claimed that these shoe characteristics have forced runners to contact the ground initially on the heel thus making them rearfoot runners. It was suggested that this rearfoot footfall pattern limited plantar proprioception and led to 'excessive' eversion and plantar fasciitis. However, there is no research in the literature that has verified these claims.

Barefoot running advocates have made many claims (e.g. strengthen the intrinsic foot muscles) that have accelerated the barefoot running craze. The conclusion is that shoes may not necessary because we have 'natural' means to accomplish what shoes do. It was suggested that ancient *homo* did not wear shoes and habitually ran barefoot (Liebermann et al., 2010) and so barefoot running may be best for modern man. Barefoot running has been adopted by a small but very vocal minority. These advocates have claimed that changing to a forefoot footfall pattern, almost necessary in barefoot running, reduces the risk of injury, is more economical and results in a healthier foot. None of these claims have been substantiated by researchers. In fact, several researchers have reported studies that indicate that barefoot running is not more economical and may not reduce the risk of injury (Gruber, 2012; Hamill et al. 2011).

Footwear manufacturers have responded to this craze by developing 'minimalist' footwear. This category of footwear is theoretically as close to barefoot running as possible while still wearing shoes. At this point in time, research on minimalist shoes is on- going and therefore, there is little definitive research as to the effect of this type of shoe on either performance or injury risk.

THE FUTURE: There are many aspects of the biomechanics of human movement and of footwear that are still poorly understood. In the past, it was thought that designing footwear involved understanding a few simple movement principles based on the mechanics of the lower extremity. However, footwear research has shown that it is not that simple. The paradigms on which athletic footwear were based were clearly flawed. For example, the relationship between injury and calcaneal eversion has never been shown definitively. Biomechanists are now challenging these old paradigms used in developing footwear and are presenting new paradigms based on their research (Nigg, 2010). These newer paradigms include a better understanding of the individual. We do know that there is considerable variability inherent in human movement that confounds group studies indicating that we have to concentrate on the individual. With these new paradigms, biomechanics will definitely continue to influence the development of athletic footwear. However, it is hoped that new paradigms will drive footwear innovation rather than the paradigms of the past.

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