

# **An Evolutionary Look at Footwear From an Ergonomic Perspective**

A Literature Review

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## Abstract

**Background:** Shoes are an essential part of today's society that protect and support the feet. Research has shown that this statement is not entirely true. The shoe has evolved from the simple sandal to the high tech sport shoe that we are so familiar with today. It has been proven that the invention of the shoe has played a vital role in fashion and athletics but also presents limitations to proper foot biomechanics.

**Objective:** To research the development of the shoe and how it affects foot biomechanics.

**Data Sources:** The data for this literature review were obtained by using EBSCOhost and Pubmed web searches for selected peer reviewed journal articles and standard texts used in undergraduate course work and additionally those found in the LOGAN COLLEGE of Chiropractic Library.

**Conclusion:** Shoe design has advanced immensely since its invention 10000 years ago. Many years ago, the shoe was a device used for protection from the elements, or from the harsh environment. Today, fashion has become the major influence on shoe design enhancing footwear cosmetically but often neglecting proper foot biomechanics

**Key Indexing:** Shoe design, Foot biomechanics, orthotics, foot pain.

# **An Evolutionary Look at Footwear From An Ergonomic Perspective**

## **INTRODUCTION**

Shoes have evolved from very simplistic, protective devices to high-tech performance enhancers. This historical development has brought great benefits, but not without costs. Often times the mechanics of the limbs that the devices are constructed for are not adequately considered. Even today, shoes are commonly purchased as an accessory, rather based on their compatibility between the foot and its intended activity. The exclusivity between fashion and function is an issue that has been attended to in some sectors of the footwear industry, but requires continued advancement in others. The feet bear an enormous amount of force on a daily basis and mobility is essential in modern society therefore foot health and maintenance must be given the careful attention it deserves.

## **DISCUSSION**

### **ARE SHOES NECESSARY?**

For thousands of years the thick-skinned soles of the feet offered our only source of protection against the land. Still today millions of Indians, both American and Asian, as well as Congoids wander their native Savannah's and rainforests without any foot protection, inconvenience or complaint (Stewart, 1972). Shoes evolved in harsh climates where extra protection was sought. With the invention of shoes came increased foot problems. Many studies have indicated that societies who wear constricting shoes have a higher incidence of foot deformities than do unshod societies (Seale, 1995). Some of the most incriminating evidence that foot deformities can be caused by compression comes

from China. For over a thousand years, the process of foot binding was performed on young Chinese girls between the ages of two and seven, in order to compress the foot to a smaller size. This was later attributed to walking deficiencies. The process was eventually reserved for the wealthy, who could afford servants to carry the young women around and wait on them (Coughlin and Thompson, 1995).

Although this procedure sounds obscure, a similar but less severe form occurs in Western society. The desire to make the foot appear smaller, more dainty and narrower is as prevalent today in our society as it was over a thousand years ago in Eastern cultures.

## **HISTORICAL DEVELOPMENT**

The following research presents a brief history outlining how shoes have evolved to their current forms, and the painful lessons that have been learned by many, but continue to plague a great portion of our population.

The oldest evidence of shoes comes from Fort Rock, Oregon, where a pair of sagebrush bark sandals have been carbon dated to between 9 000 and 10 000 years before present (Stewart, 1972). Sandals are known to be the oldest of the seven basic shoe styles that have been identified by the National Shoe Retailers Association.

The next progressive step beyond the sandal was the moccasin. The moccasin was essentially a bag for the foot, developed by the Native American's. Out of the moccasin the loafer evolved, as a simple two piece shoe with a hard sole. The word "loafer" comes from a German word meaning "wanderer of vagabond." The lace up oxford then developed from the loafer.

The first evidence of painfully pointed toes resulted from a hybrid oxford/ boot worn in 6<sup>th</sup> and 7<sup>th</sup> Centuries BC by the Etruscans of ancient Italy. These tightly laced half boots had turned up toes that ran parallel to the midline of the foot. Similarly, at this point in

history shod men in China and Japan were indicative of nobility, the higher the rank, the longer the toes (Stewart, 1972).

The history of the boot is linked to the military. History states that as Roman soldiers marched northward into Europe, they were forced to abandon their Mediterranean sandals for an enclosed shoe to keep warm (Pattison and Cawthorne, 1998).

Prior to the 14<sup>th</sup> Century, European peasants wore clogs, which they carved themselves from a block of wood. A much more refined version of clogs are presented as slippers. Slippers, or mules, were reserved for the wealthy. These slip on shoes, as the name implies, were worn not just with a bathrobe, but for indoor entertaining and dancing. High heels or pumps as they were originally called, were designed for men. The purpose of the heel was to grip the stirrup plate while riding a horse (Pattison and Cawthorne, 1998). The infamous stiletto heels are a rather recent phenomenon engineered in the 1950s and having tremendous implications radiating from the feet through the rest of the body.

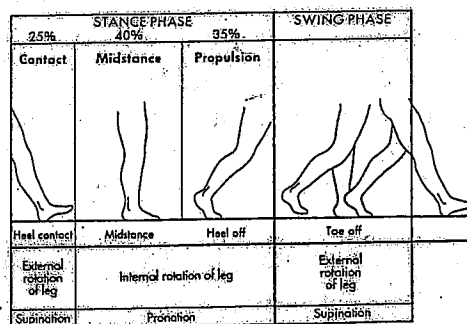
The sports shoe is relatively new in its development, and has therefore not been included in the above classification, but it is definitely noteworthy. This trend began in the 1800s with the development of the sneaker and primsol (an old fashioned tennis shoe). In 1832 Wait Webster of New York patented the first process whereby rubber soles were attached to shoes. Since then, this particular strain of shoes has greatly evolved.

✓ It should be noted that all of the original styles mentioned, were developed by and for men (Seale, 1995). This is interesting as today, men's shoes have evolved into more comfortable styles, yet women's shoes have failed to follow this trend. Evidence

attesting to this can be seen by tracing the foot and its paired shoe. In general, the outline of a man's foot is comparable to the outline of a man's shoe, ie. the shoe conforms to the outer dimension of the foot, resulting in little compression or constriction. In contrast, the typical women's shoe does not mimic the dimensions of a weight bearing foot.

## BIOMECHANICS OF WALKING

In a typical walking stride, as the heel strikes the ground, it begins to pronate, which allows the arch to lower and the heel to evert as the leg internally rotates. This combination acts to absorb shock occurring with the initial heel strike. As the body moves over the planted foot, the arch begins to rise, the heel inverts and the leg externally rotates, allowing the foot to act as a lever, giving an efficient push-off from the ball of the foot (Figure 1). As one takes a step the body weight is transferred from the calcaneus, toward the lateral malleolus, through the ball of the foot and over the big toe (Arnheim and Prentice, 1997).

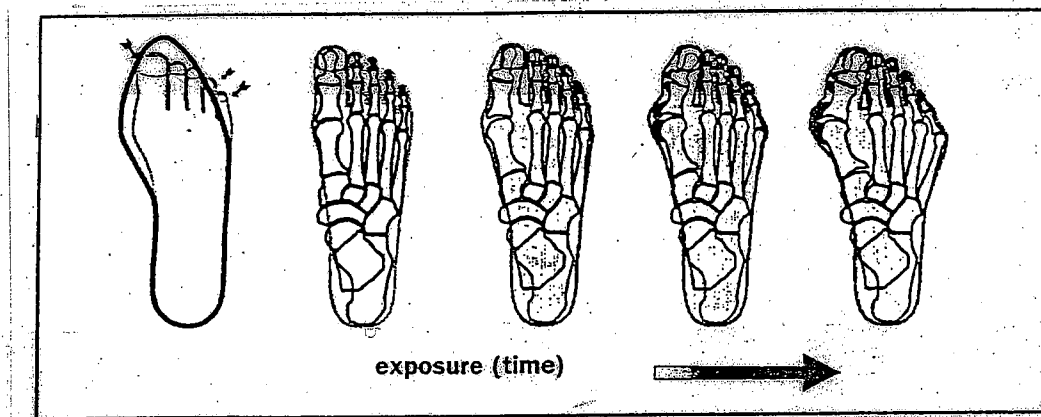


**Figure 1-** Walking gait cycle

Arnheim and Prentice, 1997.

It is important to realize that the foot is a highly mobile structure which has both great flexibility and the ability to withstand extensive weight bearing forces. The foot is also able to adapt to fit a wide variety of footwear shapes. The footwear industry exploits this

flexibility by deliberately altering the natural foot shape. Figure 2 shows that over time the foot will deform to the contours of the shoe. This is very dangerous as a shoe that distorts the natural weight distribution also alters the structural integrity of the foot. An example of this can be seen in a dress shoe, where often the footbed lacks supporting arches, in which case normal pronation is diminished leading to in excessive shock upon heel strike, potentially causing shin splints or stress fractures. Overcompensating by producing a medial arch support within the shoe that is too high can also cause problems resulting in decreased ankle range of motion, increased stiffness and lateral ankle instability (Bartlett, 1998).



**Figure 2-** Foot adaptation and deformity

Brownrigg, 1996.

The American Orthopaedic Foot and Ankle Society have published the results of their women's shoe survey, which illustrates the importance of understanding the biomechanics of the foot as well as the shoe (Figure 4). Of major significance is the finding that 88% of the women surveyed wore shoes that were smaller than their feet. The problems stemming from this are evident in the percentage of respondents experiencing pain and foot deformity. It is obvious that the great majority of women's

foot problems stem from wearing heels. The primary reason for adding heel height to the shoe is cosmetic. Seale (1995) found that three quarters of women who wear heels do so for fashionable reasons rather than comfort. Women often persevere with the pain because heel height creates an optical illusion of shortening of the foot and slenderizing the ankle which contribute to the desirable long legged look. Heels also alter posture by shifting the body weight forward. Aside from altered posture which can lead to back pain, another significant disadvantage is that as heel height increases, the toes become more crowded into an already confined space. A small, one inch heel results in a twenty-two percent increase on forefoot pressure, while a three inch heel, which is the average heel height, produces seventy-six percent more pressure on the forefoot (Coughlin and Thompson, 1995).

Biggest foot		Are your leisure shoes comfortable?	
Right	36%	Yes	87%
Left	30%	No	13%
Equal	34%	Reason	
Change in shoe size since age 20		Yes	89%
Shoe size increased	60%	No	20%
Shoe size not changed	40%	Where is pain?	
Data by age group		Heel	5%
20-29 years	18% increased in size	Arch	10%
30-39 years	43% increased in size	Ball	27%
40-49 years	59% increased in size	Toes	58%
50-59 years	95% increased in size	Foot deformity:	
Last time foot measured		Yes	76%
<5 years	25%	No	24%
5-10 years	39%	Type of foot deformity	
10-20 years	36%	Hallux valgus	67%
Type of work shoe used		Bunions	30%
Sneakers	14%	Bunions	18%
Heels	37%	Prominent metatarsal	13%
Flats	49%	Miscellaneous	4%
Type of leisure shoe used		Foot-shoe size discrepancy	
Sneakers	39%	Foot bigger than shoe	88%
Heels	10%	Foot same size as shoe	5%
Flats	51%	Foot smaller than shoe	6%
Are your work shoes comfortable?		Average discrepancy if foot bigger than shoe	1.2 cm (range 0.1-2.7 cm)
Yes	72%	Those with foot smaller than or equal to shoe had	
Sneakers	19%	Pain	64%
Heels	27%	Deformity	57%
Flats	54%	Those with foot larger than shoe had	
No	28%	Pain	84%
Sneakers	4%	Deformity	79%
Heels	62%		
Flats	34%		

Figure 3- Results of AOFAS women's shoe survey

Frey, 1995.

## PROBLEMS AND SOLUTIONS

One of the main problems with footwear seems to be the mutually exclusive categories of fashion and function, in women's dress shoes. As identified by the results of the



AOFAS shoe survey (Figure 3) women are generally unhappy with the comfort of heels. This problem can be further exemplified by examining Figure 5, which displays the prevalence of women's foot problems over men's. Hallux valgus and hammertoes are the two most common foot problems resulting from under dimensioned footwear (Coughlin and Thompson, 1995). The condition of hallux valgus, commonly called a bunion, results from wearing shoes that are too narrow, too short, too pointed or have high heels. The result is that the first metatarsal is painfully forced outward causing an enlarged joint and malalignment of the big toe. Angulation of the toe progresses, eventually leading to forefoot instability. Similarly, hammer toes result from wearing shoes that are too short, which forces the toes to overlap each other, creating malalignment.

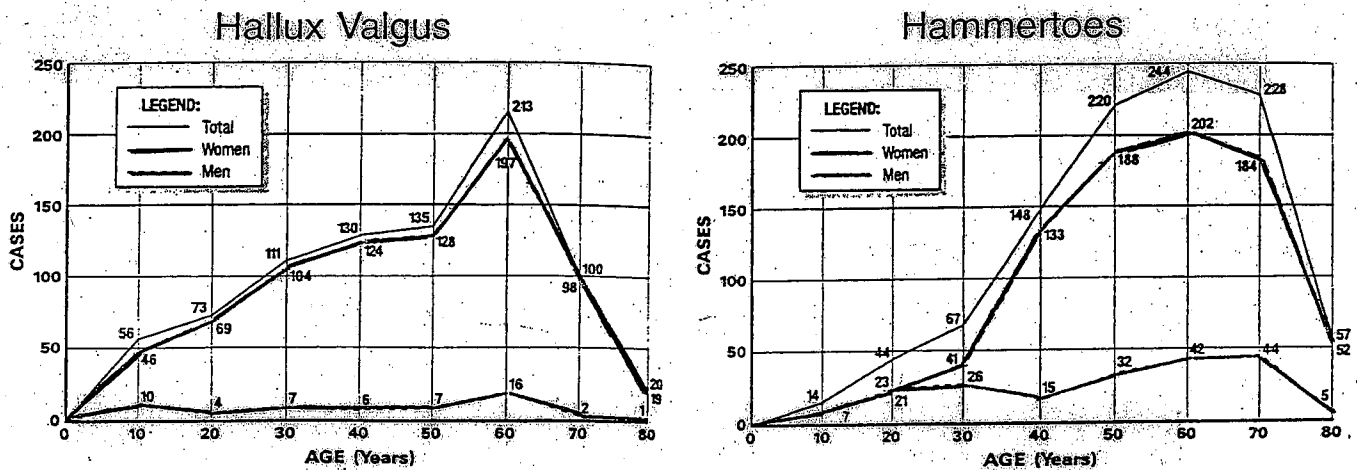


Figure 4- Prevalence of foot problems in women v. men. Coughlin and Thompson, 1995

One simple solution to this would be to trace the outline of the foot, while weight bearing, and find a shoe which matches the dimensions of the foot. Pointed toes should be avoided as they usually taper medially and laterally as if the third toe were the longest.

Overcompensating by wearing shoes that are too large can be equally problematic, as there is an increase in foot-to-shoe movement causing blisters and calluses.

In order to get the best fit, one should try on shoes at the end of the day, as feet are largest after daily weight bearing. Wearing appropriate foot coverings is also important. Shoes should be fitted with the thickness of the sock or stocking that they will be worn with.

There are a number of factors which should be addressed when seeking new shoes. These include; supportive uppers, shoe flexibility and stability, plantar cushioning, shock absorbing heels and medial arch supports (Bartlett, 1998). These features are integral, if any one is absent then functionality is compromised. Serious deformity and possible injury result when footwear is deficient in multiple areas. Sports shoes, where lateral cutting is necessary have evolved to support the ankle, which is statistically the most commonly sustained sports injury. The problem with high top shoes is that ankle mobility and is decreased and therefore performance is limited in an attempt to minimize injury (Lake, 2000). Simple measures can be taken to better any given pair of shoes. For example, companies such as "Spenco" and "Superfeet" produce readily available shoe inserts. These inserts retail for under thirty dollars and come in a variety of widths and lengths. The inserts can be easily switched between pairs of shoes. Slightly different models are made for different purposes, for example superfeet come in three different colours intended specifically for; supportive comfort, endurance or balance (Superfeet, 1998). One should however, already have the inserts when being fitted for new shoes as they do add an additional half size to the foot. Orthotics are often effective in relieving lower extremity ailments which include, but are not limited to ankle pain, plantar fasciitis, posterior tibial syndrome, achilles tendonitis and patellar femoral pain syndrome (Mundermann et. Al, 2001). This option offers a cost efficient alternative to expensive

orthotics. Orthotics do have some benefits over standardized inserts, as they are custom fit to an individual's foot.

Lastly, it is important to have your feet measured regularly as size does slightly change with the season and progressively increase over time.

## **POPULAR CHOICES OF TODAY AND THEIR BENEFITS**

Part of the confusion surrounding shoe technology and therefore, difficulty in deciding which shoe is best suited to your needs can be blamed on marketing strategies. There are an abundance of choices for the consumer, but often limited supporting information, and an uninformed consumer is taking an expensive risk. Many magazines print annual articles on the 'best' new shoes, but keep in mind no two pair of feet are identical.

When looking specifically at sports shoes, there are an overwhelming number of brand names, designs and styles. This strain of shoe has definitely undergone the most significant transformation, in the shortest amount of time. Biomechanically, all athletic shoes are constructed on two interrelated principles; the improvement of performance and the prevention of excessive load and related injuries (Senatore, 1996). The second of these points is the reason that athletic shoes have gained so much popularity. Sport shoes have managed to reduce excessive loads and related injuries by; developing a unique "air" pocket system to reduce impact upon initial heel strike, creating snug heel counters with supportive uppers, crafted of the right combination of nylon, spandex, neoprene, leather and more, and constructing midsoles with contoured footbeds, anatomical flex grooves, and structural footbridges (Nike, 1998). Sport shoes are a very competitive industry, therefore it is difficult to get inside information on any of them. Nike, for example launched a new "Engineered for Women" line in July 1998 and even though the

ads are viewed by thousands of magazine readers, even the shoe managers at “Nike Town” were unable to explain the uniqueness of these products. Currently Nike is the global leader in shoe sales, with an annual revenue of \$9.8 billion; Adidas and Reebok rank second and third, but these are by no means the only major competitors in the industry (www.nike, 2002).

New Balance is a well respected company which has been in existence since 1906. Originally, New Balance was an orthotics company specializing in footbeds. This knowledge was carried over to the sport shoe industry in the 1950s and just recently to line of men’s casual and dress shoes (New Balance, 1998). Ryka was founded in 1987, this company was developed by a woman and prides itself as the only athletic brand committed exclusively to women (Ryka, 1998). Founded on many of the same design principles as the sport shoe, are Dr. Martens. Docs, as they are commonly called, are both practical and fashionable unisex shoes and boots. Docs originated as orthopaedic boots with air cushioned soles, developed for the British WWII military, and were then adopted by industrial Britain (Pattison and Cawthorne, 1998). Docs have diversified from the skinhead image they once were associated with, now coming in many different styles and colours appealing to people of all ages with many different footwear needs. Birkenstock is another respected name in the footwear industry. Mr. Birkenstock began his family business in 1774. At the time these shoes were revolutionary as he had designed a footbed to mirror the structures of the feet (Birkenstock, 1991). These orthopaedic shoes have remained popular, as they provide excellent cushioning and support for the feet. Birkenstocks, are also unisex and come in many styles and colours appealing to all generations.

## **THE FUTURE**

Upcoming models of shoes are rarely displayed before they are available, due to the competitiveness of the market. This makes it difficult to predict where the shoe industry will direct itself in the future. It has been suggested that the ideal shoe of the future will be a "modular shoe", consisting of a personalized "soc" constructed of breathable, stretch material that will fit a variety of exoskeletons designed for specific activities (Fritz, 1994).

There also exists the possibility of reverting back from mass production to individual shoe creation. A cobbler of today could incorporate current technology with individual needs. This option would likely be expensive, but given that a new pair of Nike Air Max retails for \$209.00 it is feasible.

## **CONCLUSION**

In the fashion industry there has been an increasing recognition of natural body shapes and the sort of clothing that is flattering to each type. Few people now deliberately distort themselves with corsets to achieve the illusion of an inherently different body shape, but many still have this conception regarding footwear, as they persist in cramming their feet into undesirable shoes. Given the important role of the feet, more attention should be given to proper shoe fitting, design and construction. Shoe characteristics such as traction, stability, flexibility and weight can all be modified towards attaining this goal.

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