A RESEARCH ON FOOTWEAR AND FOOT INTERACTION THROUGH ANATOMY AND HUMAN ENGINEERING

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Particular Fulfillment of the Requirements for the degree of

MASTER OF SCIENCE

in Industrial Product Design

by
Özgü HAFIZOĞLU ÖZKAN

January 2005
İZMİR

We approve the thesis of **Özgü ÖZKAN**

Date of Signature

………………………………… **09 January 2005**
Assist. Prof. Yavuz SEÇKİN
Supervisor
Department of Industrial Design
İzmir Institute of Technology

………………………………… **09 January 2005**
Assist. Prof. Dr. Önder ERKARSLAN
Department of Industrial Design
İzmir Institute of Technology

………………………………… **09 January 2005**
Prof. Dr. Murat GÜNAYDIN
Department of Architecture
İzmir Institute of Technology

………………………………… **09 January 2005**
Assist. Prof. Yavuz SEÇKİN
Head of Department
İzmir Institute of Technology

…………………………………
Prof. Dr. Semra ÜLKÜ
Head of the Graduate School

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my parents who have shown me and unconditional love and support and continuous encouragement.

My loving spouse Cenk-thank you for your love, patience, tolerance and sacrifice.

To my friends--thank you for your love and encouragement.

I would also like to express my sincere gratitude to Assist. Prof. Yavuz Seçkin and Assist. Prof. Dr. Önder Erkarslan and for their support and labour throughout my graduate studies in the department.

And very special thanks to Advisory Assist. Prof. Yavuz Seçkin whose knowledge, energy, enthusiasm and outstanding thought were critical to this effort. And also I would like to sincere gratitude for his mentoring and guidance throughout my thesis study and providing me with constant inspiration and encouragement.

"The human foot is a masterpiece of engineering and a work of art".

Leonardo da Vinci

ABSTRACT

The main purpose of this thesis is to examine the footwear design from the human engineering point of view. Traditionally, the concern of the designer has mostly concerned to the form in footwear design field, but user and environment-conscious designer should think about the value and compatibility of the footwear to experience comfort, performance, safety and satisfaction during use. To develop the "Footwear Design" in a human centered way, the designer should be able to synthesis the datum of design that had been analyzed from the "Human Engineering" point of view and able to assess or evaluate which design solution is better and compatible for human mobility.

The basic aim of this study is to help designers to comprehend the conceptual infrastructure of footwear and foot interaction such as anatomy, anthropometry, biomechanics, physical characteristics, and ergonomics.

One of the main purposes of chapter 2 is to examine the every aspect of industrial product design from the human engineering point of view and in this context, the definition of footwear design elements.

In chapter 3, the foot structure is analyzed from the anatomical, morphological and biomechanical point of view with respect to foot-footwear interaction and human engineering and the Failings of modern footwear design and its discordant features and detrimental manner for the foot natural characteristics are examined to attract the attention of the designers for perceiving the responsibility that they have.

In chapter 4, there are two main sections which contain fundamental design criteria through foot- footwear interaction and ergonomic considerations. Then the innovative and affirmative characteristic of modern footwear design is analyzed to encourage the designer to design the better products to drive the footwear design to new heights with respect to human nature using appropriate materials and appropriate forms.

Keywords: Foot, footwear design, foot-footwear interaction, human engineering, comfort & performance.

ÖZ

Bu tezin ana amacı, ayakkabı tasarımını insan mühendisliği bakış açısıyla incelemektir. Geleneksel süreçte, tasarımcının ürünle ilişkisi ayakkabı tasarım alanında daha çok form odaklıdır, ancak, kullanıcı ve çevre bilincine sahip tasarımcılar ayakkabının konfor, performans, güvenlilik ve memnuniyet gibi değerler açısından uygunluğunu düşünmesi gereklidir. İnsan odaklı bir yaklaşımla "Ayakkabı Tasarımı" nı geliştirmek için, tasarımcı insan mühendisliği bakış açısı ile analiz ettiği tasarım verilerini sentezleyebilmeli ve insanın hareket kabiliyetine uyumlu en iyi tasarım çözümlerini değerlendirebilmelidir.

Bu çalışmanın asıl hedefi, tasarımcılara, "Ayakkabı Tasarımı" nın anatomi, antropometri, biomekanik, fiziksel karakteristik ve ergonomi gibi ayak ve ayakkabı etkileşiminin kavramsal altyapısını kavramada yardımcı olmaktır.

Bölüm 2'nin asıl amacı, Endüstriyel Ürün Tasarımının temel ilkelerinin insan mühendisliği bağlamında ele alınmasıdır ve bu bağlamda ayakkabı tasarım öğelerinin tanımlanmasıdır.

Bölüm 3'de, ayağın yapısı anatomik, morfolojik ve biomekanik açıdan ayak-ayakkabı etkileşimine ve insan mühendisliğine göre analiz edilmiştir. Tasarımcının sorumluluğunu algılayabilmesi için dikkatini çekmek amacıyla, modern ayakkabı tasarımları ve ayağın doğal karakteristiklerine uygun olmayan biçimleri incelenmiştir.

Bölüm 4'de ayak-ayakkabı etkileşimi doğrultusundaki temel tasarım kriterlerini ve ergonomik değerleri içeren iki ana bölüm bulunmaktadır. Tasarımcıların insan doğasına göre, uygun malzemeler ve formlar kullanarak daha iyi ürünler tasarlamaları ve ayakkabı tasarımını daha üst düzeylere çıkarmaları için, modern ayakkabı tasarımının yenilikçi yada olumlu özellikleri analiz edilmiştir.

Anahtar kelimeler: Ayak, ayakkabı, ayak-ayakkabı etkileşimi, insan mühendisliği, konfor & performans.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1. DEFINITION OF THE PROBLEM

In recent years footwear sales have shown significant growth and the variation of footwear available in the market today is increasing parallel to quantity. In addition to quantity and these variation the perceptions of fashion and style has grown. Product performance on the other hand, should broadly base on its function, form, and fit that mean the interaction with the foot. It is well known that fit or product compatibility is necessary for a person to experience comfort, safety and satisfaction during use and improve the performance. However, compatibility is not so well known for all types of interaction between people and equipment. For example, form and aesthetics has been the dominating factor in the sale of footwear over the last few decades. Even though technology enhancements are thought to improve the functioning of footwear, some of them are simply ornaments to enhance form rather than functional elements that protect people's feet. Given the tremendous flexibility of the foot, it is important that the foot be accommodated in a way that allows a foot to function as "designed". Ergonomics dictates good posture and many other specialized human engineering areas can be reasonably should be well integrated into the design and development of footwear.

The concept of human and product interface becoming increasingly important parameter for designing any product for the reason that the interaction between them may cause some disorders, injury, pain or discomfort. Pressure at the human-product interface is unavoidable, at has received considerable attention over the years. There is wide range of product variety, but among them the footwear has a very special feature. It is a kind of product that;

- Nearly all people use it,
- Nearly all the time except sleeping they wear it.
- It covers the human feet, carry the body and mechanically they work together.

There are various categories of footwear - those made from leather, synthetic material and other fibres. Since all humans are different in size and taste, shoe designers and manufacturers need to keep in mind different needs and wants - shoes for men, women, children, formal shoes, casual shoes, trekking shoes, sports shoes and so on; the list of different styles of shoes is endless. But, footwear is the source of feet disorders if it is not designed well. Major issues such as **structural fatigue, slipper bumps, hammer toes, bunions, blisters, abrasions, ingrown nails, calluses, fungus, hallus valgus, achilles tendon inflammation, back problems, body column chance, knee discomforts, sprains and ligament injuries, heel spur** etc. are all side-effects of footwear on the market designed for the fashion concepts disregarding the **human-footwear interface and interaction.** In recent years designers and consumers have started to look beyond appearance and aesthetical requirements.

As the most of the product, footwear has a social and sexual expressing role. The form and its aesthetical characteristic was the unique factor for self expressing by using its semiotic point of view. In the history, especially women had weared too small, high heeled, pointed or platform shoes which had caused foot disorders.

This indicates that apart from social expressing role of footwear, even thought the functionality is more an important parameter for designing footwear. Footwear design should concentrate; controlling rear-foot movement, shock attention, weight bearing, and body balance and comfort factors (involves several different factors).

Comfort and functionality are features increasingly demanded by the consumers. Footwear comfort is the result of a complex interaction of several factors that affect the foot function during human activity. They are the factors of human engineering which lead to us to find the **footwear design criteria.**

The design strategies have to work for human-footwear interfaces with respect to human engineering for the reason that product and human interaction is the basic factor to design good products. The main factor is to study the **human feet**, **biomechanics** and **the human body in motion**. Trying to understand the design and construction of good shoes would be difficult without the knowledge of what goes inside or above them. Hence the comprehensive knowledge of human anatomy is key for human engineering. So, shoe design requires the efforts of several academic fields.

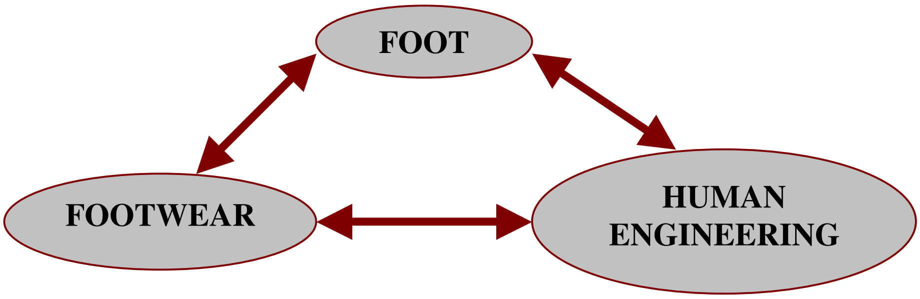


Figure. 1.1. Foot-footwear and human engineering

Footwear design is a complex process that involves the collaboration of a variety of individuals, designers, craftsmen, technicians, scientists and doctors. Designers have a crucial role to develop the footwear and consequently to improve of the human performance.

What should be the designer's role?

Designers are designing something that causes the some disorders which may or may not be their fault. For example, the premise for many product liability cases is that the actions of the person were normal and predictable and that the manufacturer of the product should have foreseen the behavior and provided the appropriate safety features (design and/or warning). This is a human engineering problem and is far more complex than the passive biomechanics problem. It involves knowledge of how the various body systems function along with their contribution to action or activity. Fortunately, all human performance/action patterns are performed using a similar information processing procedure that is dependent upon past experiences of the individuals.

Today, apart from bespoke shoes, shoes do not show much customization (adaptation) in general. Foot length and width are the most common dimensions by which shoes are manufactured and fitted. Yet every foot is so different in size and shape that 'fitting the foot into the shoe is bound to cause painful feet. In addition to the foot shape itself, its change throughout life is equally important, as well as a person's medical condition. Therefore, as a designer I see a necessity for footwear that will be 'fitted on the foot' and that takes account of the individual foot shape, provides the required comfort considering the human engineering. This shoe will be much more customized than one can find today. The objective is to extend the bespoke shoe into a larger user market for the average people while integrating human factors engineering to the footwear design, and at the same time trying to respond to the shoe's social role.

Future work will involve the use of evolutionary computation to aid in the development of footwear segments that articulate to provide the necessary motion for intimate coupling with the foot. Evolutionary computation holds the potential for making significant contributions to product design, particularly in the field of functional products that enhance human performance.

- right shape for human feet
- well constructed
- in the correct size

Finally, when considering the products that interact with the human body and affect the human performance, the industrial design field has a great demand of responsibility to prevent the negative consequences of the products. From this point of view, especially footwear is the most important product because of its characteristics. Thus, designers should concentrate to interface design and aim to create better design solutions based on the comprehensive knowledge of human engineering.

1.2. AIMS OF THE STUDY

The purpose of this research is to analyze the foot and footwear interaction and explore ways of improving the footwear design, the fit of the shoe on the foot from the view point of human factors engineering. Traditionally, the social role of footwear was more important than its function, but in this today's mobile world, designers should think about the comfort factor to increase the human performance.

There are some important questions, such as what are the underlying reasons, medical and sociological, for people's feet to become painful and deformed? How can we avoid the high number of people experiencing problem feet? What are the static and dynamic foot concepts that affect the footwear design? What is the changing criterion of footwear design for the activity performed? What are the design characteristics of footwear for the intended purpose? Is the fit and comfort parameters appropriate to the function? How does the morphological and biomechanical characteristics of human foot and human body influence the foot function and footwear design? Apart from the bespoke shoe, how can we obtain the right fit? What is the effect of interaction between foot and footwear? In other words, how can we ‘fit the shoe on the foot’ (compared to ‘fitting the foot into the shoe’), taking account of;

1. Foot morphology,
2. Foot and body biomechanics,
3. Factors such as age, gender,
4. Activity performed.

And consequently how can we design intelligent shoes to improve the human performance by using the data of human factors and engineering? How can we constitute the design criteria according to human engineering? Using these data and in the conscious of footwear design parameters how can we reach footwear design fundamentals?

Intelligent footwear performs its function successfully for the human biomechanics safely and effectively. The criteria of footwear design and the importance of these criteria will vary for the different activities. But basic human engineering parameters and its importance have to be known by the designers to design good footwear.

The definition of good product will include human factors consideration. In this case, the vital problem is whether the footwear is designed to minimize the impact it has on the human body and human movement or not. If we want to minimize the extent of the human body disorders, design and design process will have to change and the human engineering knowledge will have to improve and the users and consumers will have to have consciousness.

The objectives of this thesis are:

- To attempt to explain scientifically the footwear design parameters according to human engineering.
- To review the effects of footwear design faultiest ant the force on human feet in the published literature,
- Evaluate and improve technical knowledge for designing of footwear by comparing of performance values of various footwear,

- Examine the effect of human motion,
- Improve the basis for an alternative design method instead of the present standard determining the human engineering properties,
- Develop recommendations on footwear use based on the human activity,
- Most importantly, to stimulate ideas for innovative designs and research to minimize discomfort at interfaces footwear.

Designers can make innovative solutions, using the data of different fields and combining their creativity, recognition and precision. **Recognition** is to be passionate about his or her work along with the ability to experiment. **Precision** is to keep the prospective buyer in mind. And the most important one is the **technical knowledge.** For this reason, the aim of this study is to try to improve the knowledge of human engineering for using as a criterion of footwear design in the expectation of leading to designers to make innovative design solutions.

1.2. METHOD OF THE STUDY

Footwear design requires the efforts of several academic fields in knowledge and consequently to constitute a new approach for designers. The design of footwear is a determinant of human performance. Design is the basic discipline to intervene and predict the radical improvements in the human-equipment interface and interaction using the knowledge of the related academic fields to go beyond the visual appearance and aesthetics requirements.

To develop footwear with respect to foot-footwear interaction and its effects to human body, the designer should assess which design approaches or solutions are better for human performance from the human engineering point of view. For this reason designer has a great demand of responsibility in this mobile world. The main purpose of this thesis is to develop designers to comprehend the features of footwear-foot interaction. In other words, this thesis aims to improve mechanical features of footwear considering biomechanics, morphological features considering the anatomy and anthropometry, physical features considering environmental factors, determining the disorders occurring in the foot and body caused by aesthetical but poorly designed footwear.

The study will run through three consecutive sites of investigation that feed into each other. Investigation is currently being done in the field of anatomy and podiatry to establish the most common types of foot problems and their causes, by exploring the chiropodists' podiatrists' and patients' researches. Existing products on the market are being looked at, such as faulty shoes and their effects explained in podiatry. This experience will lead me to the next site, where I want to investigate shoe fitting in general and explore possibilities to obtain a customized fit and the design solutions for the human biomechanics. It is hoped that the work on these subjects will result in new concepts to improve the fit of the shoe on the foot, shoe designs, and fitting concepts in which the human engineering will play an important role.

These are the features which are crucial to create "performance footwear" and improve a technical knowledge based process that are completely considered in this study. One of the main purposes of chapter 2 is to examine the various foot and footwear parameters and human engineering and their connections to each other. Therefore, this chapter based on the three points which are the foot, the footwear and the human engineering. The structure is formed with the definitions of terms related to footwear design. First of all, the morphological and the biomechanical structure of human foot analyzed. Secondly, human engineering is defined and analyzed from the designers' point of view. Because, footwear design is an important humanistic focal point and design can have an impact upon the human body and human performance in many different ways. Traditionally design issues mostly considered to functional, fashionable, aesthetical, financial concerns. For being the decisions made by designers have direct affect on the performance characteristics and foot or body deformation, they have a great responsibility. And for the reason that designers being at the critical point to make judgment for the product development they have to build the knowledge based on the right information.

In chapter 3, of human engineering some cross-sections related to foot-footwear interaction are taken to examine the design issues. This method aims to build a view to analyze the design parameters of footwear for respect to human performance development. In this chapter, the functional elements of footwear design examined from the conceptual point of view and tried to make connections with the human engineering. The disorders which are caused by the modern footwear design faultiest analyzed to indicate the effects of designs, considering the information built in chapter 2 and chapter 3 to find the right method for designers.

Finally, in chapter 4, this information includes the environmental and human based issues are concluded as fundamental design criteria of footwear. Thus, well designed footwear criteria syntheses are made through human engineering in foot-footwear interaction concepts giving innovative modern footwear design examples.

CHAPTER II

HUMAN ENGINEERING AND FOOTWEAR DESIGN

2.1. Definition of Human Engineering

Human Engineering is the application of human performance principles, models, measurements, and techniques to systems design. The goal of human engineering is to optimize systems performance by taking human physical and cognitive capabilities and limitations into consideration during design. DoD Directive 5000.53 (1988). Briefly, human engineering means engineering for human use. More specifically, human engineering is defined as follows: the design of human tasks, man-machine systems, and specific items of man-operated equipment for the most effective accomplishment of the job, including displays for presenting information to the human senses, controls for human operation, and complex man-machine systems. In the design of equipment, human engineering places major emphasis upon efficiency, as measured by speed and accuracy of human performance, in the use and operation of equipment. Allied with efficiency are the safety and comfort of the operator. (Woodson, W. E., 1954, p. 1)

The human engineer is typically the designer who is best suited to perform user reviews and specializes in job and task **design and the interaction of humans** with one another and with automation, and his or her responsibility covers the human subsystems within the system to be designed. (Dugger et al., 1999, p.6)

Human engineer is likely to know more about the **specific capabilities** and limitations of the intended users. (Dugger et al., 1999, p.7)

The human engineer will need to quantify the effects of **environmental characteristics** on human performance and will provide the data to the systems engineers and other design disciplines for use in design decisions. The human engineer is primarily responsible for two types of requirements, **human performance requirements** and **human engineering design requirements.** (Dugger et al., 1999, p. 13) The functional architecture needs to be compared to the human engineering requirements, specifically human performance requirements, to determine whether or not they are satisfied by the functional architecture. (Dugger et al., 1999, p. 13)

Function analysis involves the translation of the system's requirements into a functional architecture that defines **how the system will meet those requirements**.

Interface-specific tasks are those that are created as a function of the interface that is chosen, and are based on **the interface concepts and designs.** (Dugger et al., 1999, p. 17)

The specific human engineering requirements, such as **design requirements and human performance requirements**, must be used to evaluate the designs. One of the major roles of the human engineer is to **determine the requirements and needs of the intended operators and users**. (Dugger et al., 1999, p. 26)

The human engineer must know which human engineering requirements can be traded away to efficiently meet overall system requirements and which requirements cannot be sacrificed. The human engineer should not blindly hold to requirements to **optimize human performance** when the overall performance of the system will suffer (Dugger et al., 1999, p. 27). Through system use scenarios and static or dynamic models of system operation, the human engineer can elicit **feedback** that may be used for changes to designs or requirements. (Dugger et al., 1999, p. 27)

Distinguishing Features of Human Engineering Perspective

In simple terms, engineers apply the laws of science and mathematics to the designing and building of structures, machines, products, systems and processes. Their concern with the nature and characteristics of the human component varies depending upon their background and training. The biomechanist and biomechanical engineer apply the same laws of science and mathematics to human systems. Human engineers specialize in the relationships of human-machine environments from a behavioral perspective. They are conversant with the overall functioning of the human body as it interacts with the environment and typically has a broader background than many of the other experts.

2.1.1. Human Engineering in Design and Modifications

The key in maintaining human engineering and design organization is involvement of the customer or end user in the design, design change or modification process.

Implementing good Human Factors up front will make the transition from design to operation go smoothly and prevent human errors.

Product Quality: The Japanese Industrial Standard JIS Z 8101-1981 defines quality as the totality of the characteristics and performance that can be used to determine whether or not a product or service fulfills its intended application. Product quality is generally evaluated on the basis of whether or not the product carries out its intended functions and the extent to which a product meets the requirements of the user. This is especially the case when human body parts need to match with the product components or characteristics. (Goonetilleke et al., 2000, pp.515)

Product Performance: Product performance can be broadly evaluated based on its **function** (that is the product works as designed), **form** (appealing to the eye), and **fit** ("matches" the purpose) (F 3). In many cases, fit can govern function and is hence an important property. In traditional mechanical engineering applications, there are different types of fit depending on function. (Goonetilleke et al., 2000, p.515).

Product Compatibility: It is about the interaction between people and equipment.

Product Liability:

- Evaluate the efficacy of the design of a product (footwear) relative to functional human anatomy.
- Issues were related to both design and warnings. For example: each factor related to footwear design.
- Product evaluation and design effects on a performance injury. The analysis evaluated the likelihood that the specific injuries were caused by the shoe design even when the slide was properly executed.
- Several instances involving design failures (For example: golf, walking and baseball shoes) should be evaluated to determine their effect on injuries while properly performing the activity.

<u>Industrial Design and Safety/Human Factors</u>

- Determination of contributing factors in several foot disorders. Issues assessed included the adequacy of the design relative to human performance capabilities, expected use patterns and use and effect of warnings.
- Evaluate the disorders and determine how they occurred and possible contributing factors.
- Evaluate the design and design modification of a footwear to personnel safety.
- The evaluation included product examination coupled with an analysis of human perceptions and expectations.

Industrial Design and Environmental Factors

- Evaluation of the factors to determine the contributions of the environmental factors and product's physical features should be examined. (For Example: For the footwear designs the slip, trip and fall accidents or thermal responses, ground or whether conditions).

2.2. Definition of Footwear

Footwear is one of the clothing *accessories* and as such today it is an *indispensable* part of the human outfit. Shoe functions and forms follow and complement the features of the wearing apparel. The value of a pair of shoes depends not only on its functionality (purpose, comfort, aesthetics, material composition, durability etc.) but it is relative to time, social status, economic conditions and individual taste.

Shoes are designed to protect the feet during their primary functions of mobility and support. Over the past century, fashion has frequently interfered with the original purposes of protection from injury and exposure. Footwear is sometimes the cause of, and frequently a contributor to, musculosketal disorders (Charrete, 2002) The Chiropratic Journal.

From the functional point of view; footwear can be defined as "personal protective equipment." It serves as a container designed to cover the foot, providing protection from external forces and debris. The footwear must also provide support to allow the foot to function adequately in both dynamic and static conditions.

But from the aesthetical point of view; form of shoes express different meanings from the antiquity to now. Shoes are a force for change, a means of shedding the past and buying into the future. Because from ancient Egyptian times down through the centuries, footwear has been designed to meet mankind's real and perceived needs—protection, support, comfort, sturdiness, and stylishness. So people will usually select their shoes for one of three reasons: **comfort, appearance, or protection.**

What is the Function of Footwear? Functional footwear should protect the foot from injury and improve performance. To do this Freychat and Bouche (1999) believe that a shoe must be comfortable. They think that matching the dynamic changes in foot shape is the appropriate basis for footwear design. Lee (1997) agrees and says that the design of a comfortable shoe must correlate to the function and dynamic shape of the foot. According to this**,** the footwear has three important functions.

1. Provide protection to the foot and ankle.
2. Help prevent injury by either decreasing the stress on the leg.
3. Enhancement of performance. (The Nicholas Institute of Sports Medicine and Athletic Trauma, 2002)

The apparel and the footwear industry are both industries that are forerunners in the application of mass customization. The reason behind this development can be seen in the fact that clothes and footwear offer the potential to address all three possible dimensions of customization**: fit** (shape, measurements, and size**) functionality** and **aesthetic design** (taste, forms). Products that require the matching of different physical dimensions or functional requirements often engender a higher price premium than products that are customized just by the possibility of changing colors or design patterns. Clothes and footwear are products that must, first of all, exactly fit their user's measurements. Additionally, customer integration into the aesthetic design of a shoe or a piece of clothes and the adaptation of functional requirements (like the profile of a sole, height of a heel; features of a fabric) are further means of increasing the utility of a product (Tseng&Piller, 2003, p.20). "Functional footwear aims to protect the human foot from injury and to facilitate performance. In order to accomplish this, a shoe must be comfortable. One mode of thinking is that matching the dynamic changes in foot shape and dimensions the appropriate construction for a comfortable shoe." (Moeller, 1978, p. 265) It can be possible by evaluating the footwear in order to match the normal function of the foot during motion.

What makes a shoe special? Shoes are responsible for injury prevention, foot health and maximizing performance. People often underestimate the importance of wearing shoes that are in good condition that also suit their own needs. Each component of a shoe, like each part of human foot, has to work to fulfill its role in helping you to increase the human performance without breaking down.

Shoes both protect feet as well as, when incompatible in size and shape, present exciting factors in inflammatory conditions e.g. bunion. Because, feet endure tremendous pressures of daily living. Footwear significantly influences;

- **The frequency of overuse injuries**,
- **The energy expenditure**
- **The comfort level of the users**.

An average day of walking brings a force equal to several hundred tons on them. Since a person takes approximately 5,000-10,000 steps each day, mostly on hard surfaces, their entire musculoskeletal systems are being punished if their shoes do not fit correctly. (Information from the American Podiatric Medical Association) This means, people are subject to more injury than any other part of the body, underscoring the need to protect them with proper footwear. Despite the presence of pain, people are reluctant to change their footwear styles. The main function of modern footwear is to provide feet with protection from hard and rough surfaces, as well as climate and environmental exposure. To the wearer the appearance of their footgear is often more important than its (mis)function. This causes foot injuries. "For example according to a research almost all (95 percent or more) of these physically deprived feet of adults Americans and Europeans begin in childhood with the wearing of faulty designed and constructed footwear, starting in infancy". (Rossi, 2002, pp.84)

- Rehabilitation
- Sport
- Safety
- Fashion
- Daily use

In order for proper function the foot variation must be identified. People tend to have either a flat foot or a high arch foot. Regardless of the variation, the shoe must fit the foot.

2.2.1. The Components and the Structure of Footwear

It is useful to understand some basics of shoe construction to be able to discuss and design a quality shoe. According to McPhoil (1988) the structure of a shoe can be divided in an upper and sole (or bottom part and or lower). Sections of the upper include vamp, quarter, toebox, throat, insole board, and topline. The sections of the sole consist of an outsole, midsole, insole and shank & heel.

1. Sole,

2.Upper.

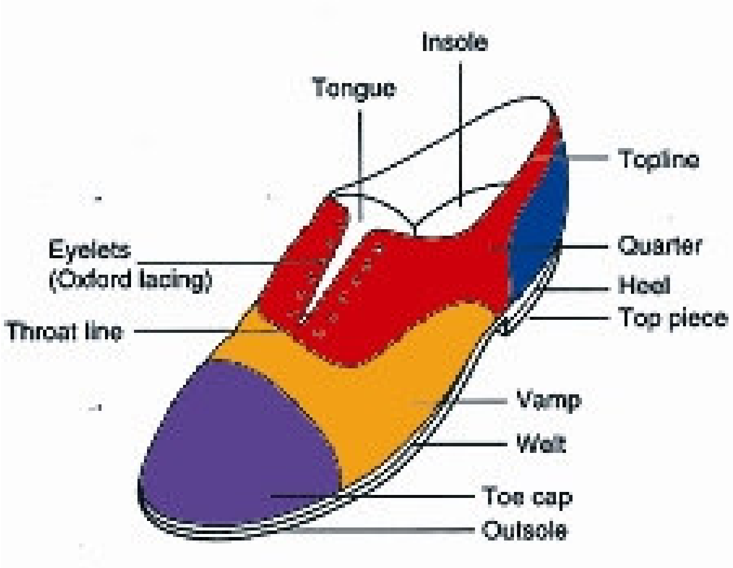


Figure. 2.1. Components of Footwear

2.2.1.1. Sole

It is the part of footwear under the foot that insulates the foot from the ground conditions. Its other aspect is to help the biomechanical characteristic of foot. The sole refers to the heel, heel & shank, insole, midsole and outsole combined. Using of the individual ergonomic sole allows to maximum facilitate human movements as well as to avoid injuries as the form and **configuration of the ergonomic sole allow the foot to work in a natural way.**

Outsole: This is the portion of the shoe in direct contact with the ground and directly exposed to abrasion and wear. Traditionally made from a variety of materials, the outsole is constructed in different thickness and degrees of flexibility. Ideal soling materials must be waterproof, durable and possess a coefficient of friction high enough to prevent slipping. The outsole should be flexible and non-slip.

Midsole: The midsole is the layer that lays between insole and outsole and certainly the heart of the shoe. Most of the technology of shoes is focused on this area. Its function is to provide cushioning, support, stability and guidance.

Insole: A layer of material shaped to the bottom of the last and sandwiched between the outsole (or midsole) and the sole of the foot inside the shoe. The insole covers the join between the upper and the sole in most methods of construction and provides attachment for the upper, toe box linings and welting. This provides a platform upon which the foot can operate and separates the upper from the lower.

Heel: The heel is the raised component under the rear of the shoe. Heels consist of a variety of shapes, heights, and materials and are made of a series of raised platforms or a hollowed section. The part of the heel next to sole is usually shaped to fit the heel; this is called the heel seat or heel base. The heel breast describes front face of the heel. The ground contact section is called the top piece. Heels raise the rear of the shoe above the ground. A shoe without a heel or midsole wedge may be completely flat. When the heel section sits lower than the forefoot the style is called a 'negative heel'.

Heel Shank: The shank is the inner part of the shoe that extends forward from the heel. The shank bridges between the heel breast and the ball. Its purpose is to prevent excessive pressure on the medial longitudinal arch of the foot.

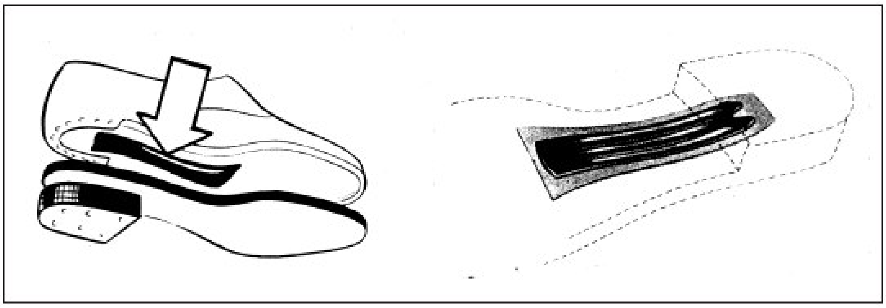


Figure. 2.2. Steel shank for arch support

2.2.1.2. Upper

The upper must comply with the morphology of the foot. It functions to position, support, and protect the foot. It also is the primary influence on fit. The upper consists of four distinct parts, the heel and heel counter, the midfoot saddle, the toe box, and tongue and lacing. Materials and design are wide ranging. Some are functional others are simply aesthetic.

Vamp: The vamp is the material over the instep. The ideal vamp contains laces for an adjustable fit. The vamp must be high enough to prevent pressure on the instep. Pumps and slipons often have little or no vamp, requiring a too-tight fit to prevent the shoe from falling off. A vamp that has been "pushed over" the edge of the sole is a sign of improper shoe fit and probable biomechanical problems in the foot. A too-narrow vamp forms a "cast" crowding bones and impairing circulation and joint mobility (Janisse, 1992).

Heel Counter: The heel counter is a component that wraps around the back of the heel and acts to stabilize (to hold the heel still and in place) the heel (hind foot) in the footwear and provides motion control, stabilizes the foot in the footwear. It supports the calcaneus, prevents shoe slipping, and helps control rear foot motion. It should be stable and constructed to absorb shock / hinder torsion movements injurious to the foot and retains the shape of the posterior portion of the shoe.

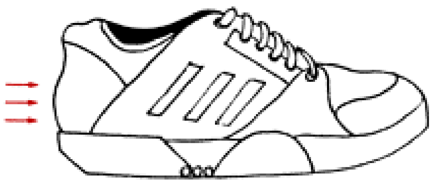


Figure.2.3. Heel Counter

Heel Tab: The heel tab pads the top of the heel counter so that it does not dig into the Achilles. Its main function is comfort and fit rather than stability but the padding can add some extra support. It now often grabs from the sides of the heel rather than the back.

Tongue: Tongues have become thicker to help pad the top of the foot from the pressure of the laces. They are also larger to help make the shoe more easily customizable by allowing a wider lacing system.

The Laces: Innovations in the laces have been the introduction of round laces and a change in the type and number of eyelets. Laces keep the shoe firmly on the midfoot. This is the most important area for the shoe to fit firmly. A firmly fitting shoe in the midfoot can compensate for extra length or width in the forefoot. Parallel lacing is a thing of the past. Current laces are designed to be customized by the individual. Elastic laces are becoming more popular but do not provide adequate support for running.

The Toebox: It is the area in the front of the upper part of shoe either rounded pointed, containing the toes providing spaces. The function of the toe box is to retain the shape of the forefoot and allow room for the movement of the toes for the toes.

The Quarter: The complete upper part of the shoe behind the vamp line covering the sides and backpart. The top edge of the sides and back of the quarter describes the topline of the shoe.

The Linings: The lining is a part of upper which comes into direct contact with the foot and must therefore be particularly supple and able to “breathe.” (Wass&Molnar, 1999, s. 126)

The Throat: The central part of the vamp just proximal to the toe box. The throat is formed by the seam joining the vamp to the quarter i.e. throat-line.

The position of the throat line depends on the construction of the shoe, for example a shorter vamp and longer quarters define a lower throat line. This gives a wider lower opening for the foot to enter the shoe. The throat is defined by the connection of the rear edge of the vamp and the front part of the quarter. The location of the throat will vary with the design of the shoe. Because the vamp and quarter panels are often one piece in the athletic shoe, the throat is at the eye-stay. This refers to the point where the lacing is attached to the vamp. The throat of the shoe dictates the maximum girth permitted by the shoe. (Rossi WA, 2000)

Shoe height: The height of a shoe can be categorized into three types: high, bottine (ankle-high), and low (Fig. 3). High shoes are necessary for the transference of forces: for correction, relieving the pressure on a particular part of the foot, and immobilizing the foot in the shoe. This can also be accomplished by using an ankle-foot orthosis in combination with shoe adaptations [27], but this can have a negative effect on walking velocity and cosmesis [14]. Bottine shoes are used if the foot has a tendency to slide forward in the shoe. (Lee at al., 2001, Volume 28)

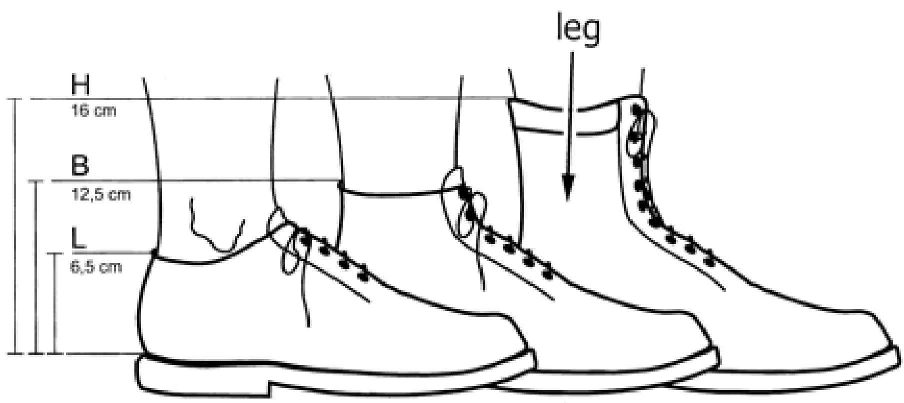


Figure. 2.4. Shoe height. Diagram shows high (*H*), bottine (*B*), and low (*L*) shoes (Lee at al., 2001)

2.2.1.3. The Last

Shoes are built around a last that resembles the shape of a foot and is not visible to consumer. The other definition is “the last is the form over which the upper is pulled and molded over during manufacture (Canavagh, 187).” The last is the "footprint" that the shoe is designed upon. (Janisse, 1992). It is the moulds for making the outsoles, the dies for cutting the upper patterns and so on (Cheskin 1987).

Figure. 2.5. An example of last

2.3. Elements of Footwear Design

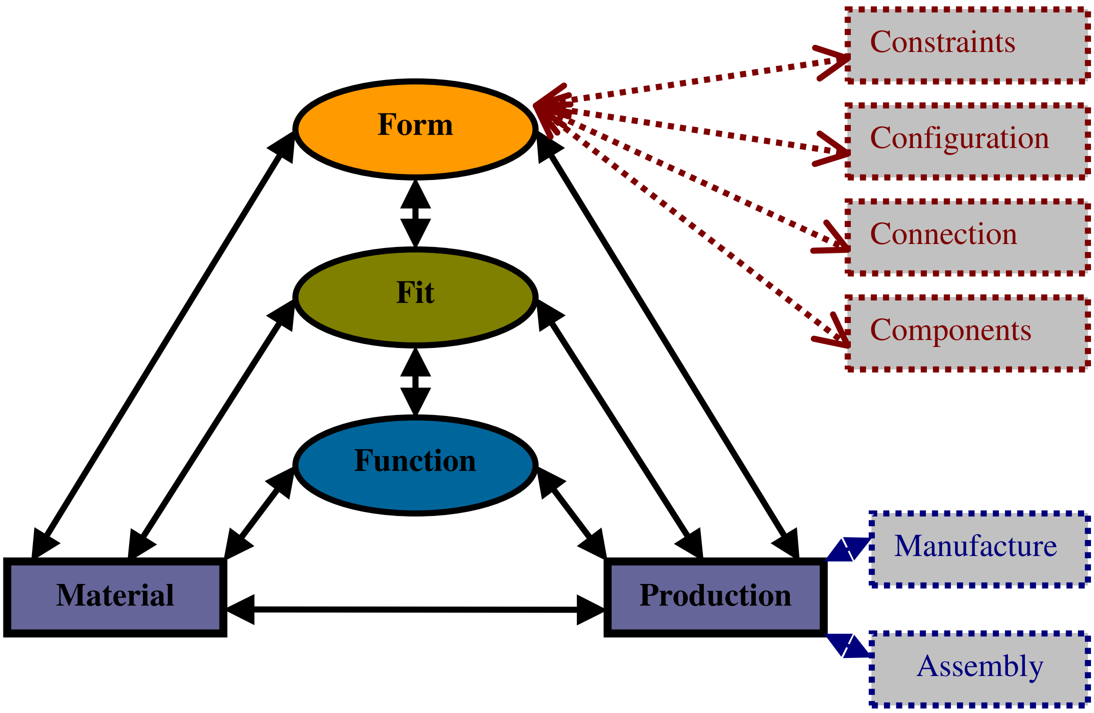


Figure. 2.6. .Elements of footwear design (Adapted from Ullman, 1997)

2.3.1. Footwear Comfort Factor and Human Performance

Custom products are becoming the trend because of the vast number of selection available. For this reason it has become difficult or may be seems impossible task to select the right product that will have the right appeal and right fit. Although, comfort plays an important role when people buy products, the “fit” of a product is assessed only after it has been tried in a physical setting. Comfort encompasses many different characteristics and has varied definitions: for example, it has been defined as a lack of discomfort (Hertzberg, 1972) and more recently it has been associated with feelings of relaxation and well-being (Zhang et al., 1996).

Designers responsible for the comfort factor regarding human engineering process for the average people. So these products have to furnish the necessary “comfort” that people require. At this point how can the designer design a product more comfortable not knowing the standards for comfort or even discomfort? Some directions based on sensation and pain to achieve the desirable fit between people’s feet and footwear has to be known. The concepts needed for exploring foot and footwear interaction will be presented. Because, product compatibility is necessary for person to experience comfort and satisfaction during use. However, compatibility is not so well known for all types of interaction between people and equipment (Karwowski, 2000).

Although the comfort and fit may not be optimal for different activities and different shaped feet, better understand comfort and discomfort and the mechanism will be solution in an effort to design the interface between feet and footwear optimally (Clarks, 1976).

2.3.1.1. Comfort

Comfort and functionality are features increasingly demanded by consumers. Footwear comfort is the result of complex interactions of several factors that affect the foot function during human activity.

Comfort is an important factor for footwear in all physical activities. Most people can quickly identify comfortable or non-comfortable footwear situations. Increasing interest in footwear comfort resulted in several investigations that associated comfort with plantar pressure distribution (Chen, 1994, p: 41), vertical impact force, rear foot motion (Milani, 1995), foot and leg shape and alignment (Miller, 2000), and foot sensitivity (Mündermann, 2001). It has been speculated that comfort is related to muscle activation and, and, thus, to fatigue and performance (Nigg, 1999) the specific design, physical properties and construction of footwear have been shown to be important factors for footwear comfort (Mündermann, 2001).

To improve the footwear design from the point of human engineering view, the first task has to be to explore the comfort factor to human performance development. "Comfort is a very complex and multi-faceted entity" (Goonetilleke, 1999). This means, a variety of factors go into making a shoe comfortable. Comfort embraces the whole shoe and the human foot interaction of all its parts. Many factors such as size, shape, flexibility, style, weight, inside shoe climate (temperature, humidity), materials, tread, cushioning are all known to affect footwear comfort (http://www.nh.ultranet.com/-dd1822a/facts.html). These complex interactions of several factors that affect the foot function during human activity and could be divided into;

- Mechanical Aspects,
- Thermal Aspects

Footwear comfort is required to quantify comfort and so determine valid relationships between comfort and shoe constructions, subject characteristics, and biomechanical variables. (Münderman, 2002, pp:39, Gait and Posture, Volume 16)

2.3.1.2. Fit and Sizing

In many cases, fit can govern **function** and is hence an important property. (Goonetilleke, 2000, vol.2, pp.516) Fit depends on many factors. Some of which are time of day, activity performed, a person's health status, and so forth. (Goonetilleke, 2000, vol.2, pp.515)

Shape-Form: The second component of fit is shoe shape. Several factors combine to make up the overall shape. The most important are: the last, toe box, vamp, and heel counter (Janisse, 1992).

Unless there is a reasonable match between shoe shape and foot shape, then fit, regardless of "proper size," is largely nullified. Hence the last, often overlooked in shoe comfort, is of vital importance.

In applications involving people, fit is generally not as well defined. Footwear tit has been understood to mean the preference for a shoe to accommodate an individual's foot. (Kolarik, 1995, p. 41) Clinical reports of foot problems such as blistering, chafing, black toes, bunions, pain, and tired feet are quite good evidence of poor fitting shoes. The need for a quality characteristic to evaluate the fit between a person's foot and the footwear he or she wears is of utmost importance for the scientific development of lasts and for improvement of footwear fit. Most shoe manufacturers still depend on artistic *lasts* for shoes even though many of the designer shoe manufacturers have now realized that comfort is an important criterion for survival in this vastly improving trade.

Factors affecting fit

Static fit, Weight bearing fit, Thermal fit, Functional/Dynamic fit (Chalk et al. 1995)

2.4. Human Engineering in Footwear Design

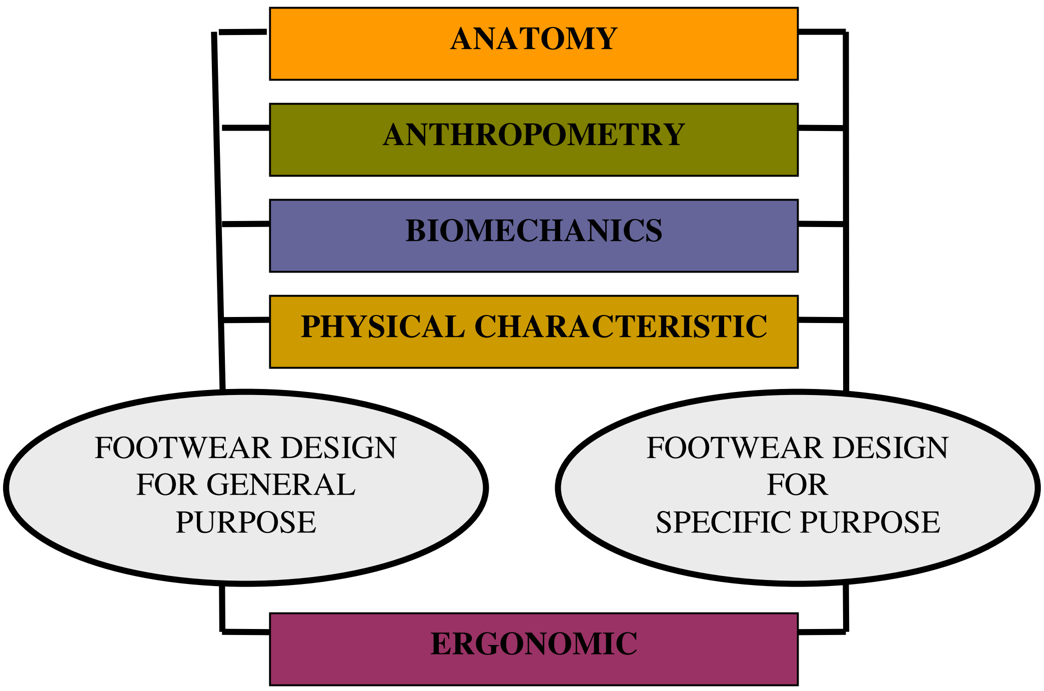


Figure. 2.7. Footwear design parameters

This type of footwear is designed generally by considering;

- Anatomy
- Anthropometry
    - **Age and Gender Differentiations**
    - **Individual Differentiations**
    - **Ethnic Differentiations**
    - **Foot Disorders**
- Biomechanics
    - **Static motion (unidirectional)**
    - **Dynamic motion (multidirectional)**
- Physical Factors
    - **Biomechanics of human body**
    - **Ground Condition (Slip, smooth, loose)**
    - **Thermal Condition**
- Ergonomic considerations
    - **Material**
    - **Manufacturing**

2.5.1. Footwear Design and Development Approach through Human Engineering

Utilize an exhaustive sturdy of the human foot and lower to create footwear that improves the wearer quality of life by minimizing interference with natural foot dynamics and function. Interface with manufacturers to attain goals set through specification. Create timelessness through succinct design.

Shoe designer has to know the anatomy of the foot and production methods of footwear to design effective shoes for improving human performance.

The following are key factors to consider:

- Mechanical Factors
- Anthropometric Factors
- Anatomical Considerations
- Physical Characteristics of The Shoes-thermal aspects
- Ergonometric Considerations

Footwear mechanically works together with the foot according to foot anatomy and biomechanics. For being footwear is an interface between the foot and ground, footwear should be designed to accommodate to environmental factors.

Shoe design based on the results of the survey and the biomechanical analysis, developed a shoe that is better adjusted to the human foot. The new design is described below and some of the design considerations are mentioned above; Approach to shoe design.

2.5.1.1. Mechanical Factors

A shoe is used to protect the foot to increase effectiveness and performance of human (people) while he or she is in motion and/or performing a specific task. Force generated within the human musculoskeletal-system is transmitted to the ground through the footwear. Reactive forces are generated from the ground (because of our forces) to the human structure via the footwear. Stresses on the human result from excessive forces and poor posture, which frequently are due to **poor shoe design**. Worse yet, when people are applying a large force on a shoe (because of running or weight) it slips or breaks down easily, they often find themselves in an unstable position, or they may injured from the recoil of force.

Footwear is designed with either **unidirectional** or **multidirectional** movement in mind. **The unidirectional shoe** should be used for straight-motion activities, such as running or walking, and **the multidirectional shoe** is for sports with lateral movement, such as basketball, tennis, or racquetball. (Hilderbrand, 2002)

Well fitting footwear is essential for protection of the foot against influences from the environment and for human performance. The fit of footwear is defined as the degree to which correctly fitted footwear has the geometrical and mechanical qualities that guarantee optimal wearing comfort.

2.5.1.2. Anthropometric Factors

Anthropometry is measurement of the dimensions of the body and other physical characteristics. There are two types of measurement: static and dynamic. This means; length, width, height, and circumference of the feet in two different positions

(Vass&Molnar, 1999, p.12). The dimensional characteristics of human are critical to the effectiveness of using objects or wearing clothes, hat and footwear. For example; particularly important to effective footwear is the design of footwear, not only so that they can be worn properly but also so that the footwear can properly works with the foot synchronously during movement and a given application of force of human weight and imposes its momentum.

Footwear Design requires two different dimensional approaches because of the foot biomechanics.

These applied anthropometry base on:

- Static Dimensions
- Dynamic (Functional) Dimensions.

Use of Anthropometric Data:

- Principles in the Application of Anthropometric Data
- Design for Extreme Individuals
- Design for Adjustable Range
- Designing for the Average

As consumers are becoming increasingly selective of what they wear on their feet, designers and manufacturers are experiencing problems developing and fitting the right footwear. Literature suggests that shoes with a shape similar to feet may be comfortable because they attempt to maintain the feet in a neutral posture. (Goonetilleke, 2003, p.364). The valid anthropometrical database is important in order to obtain more specific last design criteria. (Gonzales, 2001)

1. Static (structural) anthropometry

When the feet are not under strain, measures distance of bones between joint centers including some soft tissue measures in contour dimensions (includes the wobbly stuff that covers our bodies - muscle, fat, skin, bulk). This kind of measurement doesn't include clothing. Measures refer to a naked person (Vass&Molnar, 1999, s.12).

2. Dynamic (functional) anthropometry:

When the feet are bearing the weight of the body and when the body is in motion or engaged in a physical activity distances are measured. It includes reach (ex. could be arm plus extended torso); clearance (ex. two people through a doorway); and volumetric data (Vass&Molnar, 1999, s.12).

In general circumstances a healthy person's feet are the same size at any time of the day. However, they can be affected by:

- Temperature (extreme heat, for example)
- Strenuous exercise (walking for a number of hours, or engaging in high-intensity sport) (Vass&Molnar, 1999, s.12)

The valid anthropometrical database is important in order to obtain more specific last design criteria. (Gonzales, 2001)

2.5.1.3. Anatomical Consideration

The shoe design must reflect adequate consideration of the fact that the human foot and ankle have specific rotational characteristics and that whenever foot requires to twist, rotate, thrust or all, ankle rotational axes are therefore important to proper footwear design. Footwear is the posture that must be designed in order to permit the best biomechanical advantage.

- Stability
- Mobility
    - Static.....little muscle activity
    - Dynamic........... extreme and specific muscle activity

But, some factors should be considered to determine the foot shape;

- Whether it is inclined outward or inward with respect to an imaginary axis running lengthwise through the foot,
- Whether the inside arch is high or low,
- Whether the ankle sits lower,
- Whether the heel is strong or weak,
- The shape of the insteps and metatarsals and
- The presence of any characteristic malformations (for example flat feet, bunions, protruding little toes, big toes higher than usual, hammer toes) (Vass&Molnar, 1999, s.13).

2.5.1.4. Physical Characteristic of Footwear

Form has been the dominating factor in the sale of footwear over the last few decades. Even though technology enhancements are thought to improve functioning of footwear, some of them are simply ornaments to enhance form rather than functional elements that protect people's feet. Given the tremendous flexibility of the foot, it is important that the foot be accommodated in a way that allows a foot to function as 'designed'.

The basic footwear characteristics to be considered include the following:

- The shoe weight should balance close to the point of **human weight support**.
- The shoe material should be **enduring to the environmental factors** such as climate and humidity.
- Accommodation of different ground surfaces such as smooth surfaces or soft surfaces. The sole should have a fairly high coefficient of friction to **minimize slipping**.
- The overall weight should be compatible both the need to reduce the potential for fatigue while wearing the footwear and the need to minimize the amount of pressure the human required while walking, running, sport playing, etc. to increase the human performance to make the shoe perform as intended.

Thermal comfort is defined by microclimatic characteristics of footwear, which are decisive factors for global comfort, even shortly after wearing footwear (Kurz, 1992). These are **temperature** and **humidity**. Mechanical comfort is defined by pressure distribution and interaction with the human foot according to its morphological and biomechanical characteristics. Pressure at the human interface is generally considered to be an important parameter in comfort evaluation. However, the ideal pressure distribution between the human foot and footwear has yet to be defined. "A hard-core materials perspective to loading would be to distribute the force over an area as large as possible to minimize stress concentration.

2.5.1.5. Ergonometric Considerations

Ergonomics dictates good posture and many other specialized areas such as quality control, perception, and biomechanics can be reasonably well integrated into the design and development of footwear. (Goonetilleke, 2003)

The mater of human energy expenditure and how this energy is best exerted should underlie the conceptualization of each new footwear design. Such factors as human mobility, equilibrium, and posture, as well as consideration of potential ballistic movement advantage, all should receive the full attention of the shoe designer.

Ergonomic footwear design which enables optimal distribution of the leg load. It is based on a concept of *total* reflection of anatomic structure of man's foot on the outside of the footwear sole. Imitation of individual features of man's foot on the sole contributes to optimal distribution of the leg load and gives a natural sensation of a barefoot walk. Variants of design criteria should be evaluated.

CHAPTER 3

THE STRUCTURE OF THE HUMAN FOOT

The uniqueness of the human foot may be described as:

1. *Morphological:* the visible form and structure of the foot;
2. *Biomechanical:* the function of the foot.

3.1. The Anatomy of the Human Foot

As the external shape of the foot, the internal shape, the anatomy of the foot is important to design footwear. Because, the footwear is not only to provide a protective covering, but also to provide mechanical harmony for the human biomechanics for improving the performance with design and engineering solutions. This is bound to a well knowledge of the bone structure and musculature. (Vass&Molnar, 1999, p.18)

The foot changes from a flexible structure that is capable of absorbing force and adapting to the ground plane at ground contact (the beginning of the gait cycle) to a rigid structure for effective propulsion. The complete working mechanisms of the lower extremity are beyond the scope of this thesis; therefore, descriptions will be brief. It should be noted that anthropomorphic differences affects foot type and different feet change shape in different ways.

The process of footwear design analysis begins with understanding the foot anatomy and how each **Bones and Joints, Ligaments and Tendons, Muscles, Nerves, Blood Vessels** functions in human biomechanics (O'Connor&Schaler, 2001). Because foot shape and foot curvature play an important role to design footwear.

The structural and functional components of the foot are composed of highly refined interrelated segments which provide a stable base for supporting the body when standing, running, walking and jumping. The foot is made up of a complex interaction of bones, ligaments, and muscles. These structures help the foot alternate between being a mobile, flexible adaptor and a stable rigid lever. The foot is broken down into two functional parts, the forefoot and the rearfoot.

Overall, the foot functions in three primary ways:

1. Provides a stable platform of support
2. Attenuates impact upon loading
3. Assists in efficient forward propulsion of the body.

(Copyright © 1996-2002 The Nicholas Institute of Sports Medicine and Athletic Trauma)

The human body contains 206 bones, approximately 1/10th of which are confined to the foot. The largest bones, the tibia and fibula, are in the legs. Each foot is comprised of 26 bones, 32 joints, and 112 ligaments which are perfectly designed. Seven thick, short, tarsal bones compose the heel and back of the instep; five parallel metatarsal bones, forming the front of the instep, spread toward the front of the foot to form the ball. Fourteen smaller bones make up the toes; the large toe is composed of two phalanges and each smaller toe has three phalanges. All the bones are firmly connected by tough bands of tissues called ligaments; the plantar ligament runs from the heel bone to the metatarsal, keeping the bones in place. (McMinn & Hutchings & Logan, 1996, p. 48-63)

Our foot structure is arranged in order to support the body, maintain the stability of the body, and propel the body during its movement. One part of the foot supports the body while the other functions to propel it. In jumping off a countertop on to the floor; the foot propels the body off the countertop and also supports the force as the body contacts the ground.

The foot is divided into three segments:

1. Rear foot or hind foot, composed of the talus (ankle bone) and calcaneus's (heel bone);
2. Midfoot, The midfoot has five short bones and the main arch, which is the navicular, cuboids, and cuneiform;
3. Forefoot, which is the metatarsal (the ball of the foot) and phalanges (toes). (DiMaggio, Dr. 1994)

The tarsal and metatarsal bones form the two arches of the foot. The plantar arch runs from the heel to the ball of the foot and normally only touches the ground at each end. The metatarsal arch runs across the ball of each foot. These flexible arches, along with the thick layers of fatty tissue, absorb the pressure and the shock of walking and jumping, but because the foot cannot maintain the constant pounding of the human body, footwear-manufacturing companies have added extra support in the construction of shoes to assist in absorbing the pressure (Forner et. al., 1995, p.780).
Even though different width shoes are available, the variation of heel width within a given size of shoe is very small as the variation of heel width among people is relatively small. Thus, finding a shoe that fits in the heel area may not be that difficult. However, the variation of fore-foot width among people can be relatively large and thus the right fit in the fore-foot region is not that easy to achieve (Tremaine and Awad 1998).

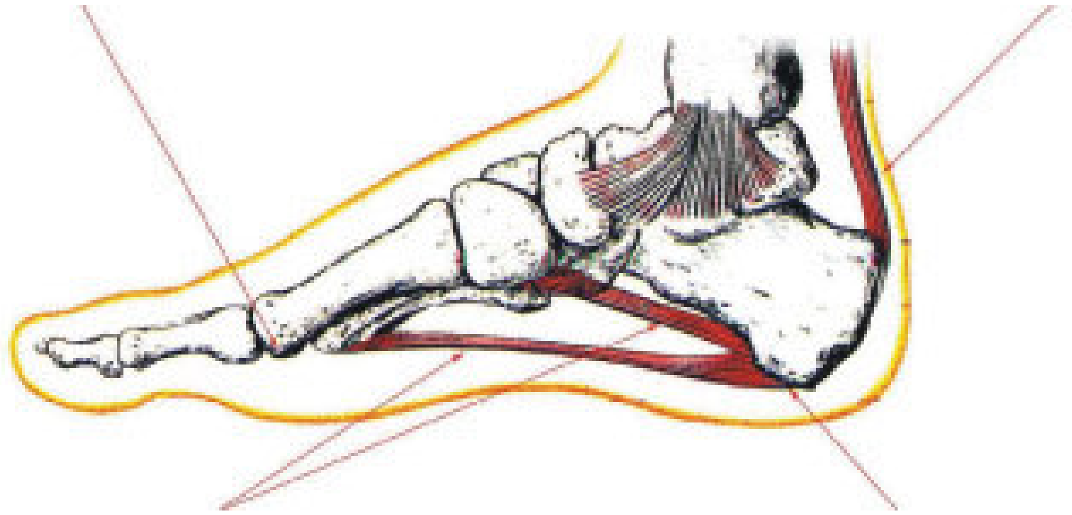
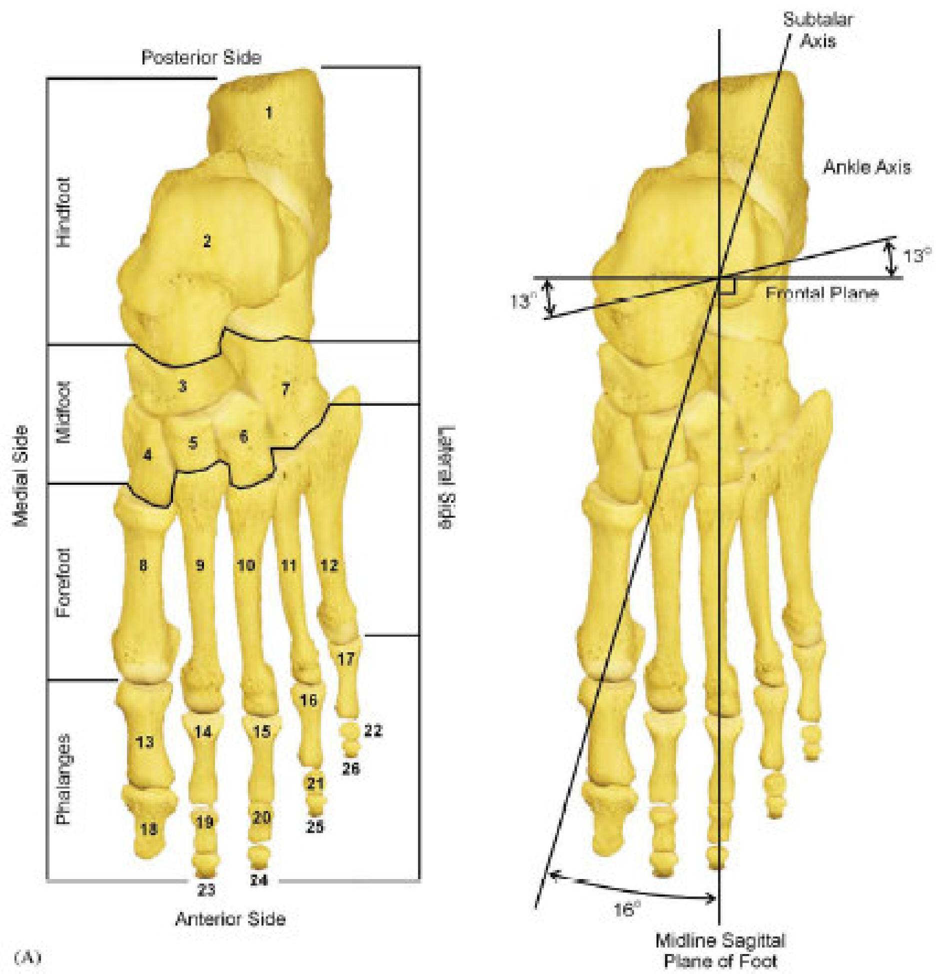


Figure. 3.1. Muscles of foot

The surfaces of foot are;

1. Plantar Surface: The surface that bottom part of foot contacts the ground,
2. Dorsal Surface: The surface that upper part of foot,
3. Letaral Surface: The outer part of foot,
4. Medial Surface: The inner part of foot.



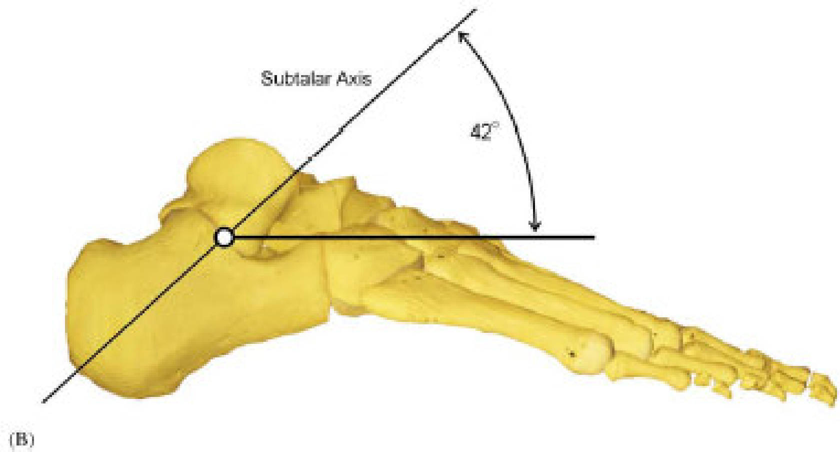


Figure. 3.2. Foot structure: (A) four segments: hindfoot (1, 2), midfoot (3, 7), forefoot (8, 12), phalanges (13, 26), (B) ankle and subtalar axes. 1; calacaneum, 2; talus, 3; navicular, 4; medial cuneiform, 5; intermediate cuneiform, 6; lateral cuneiform, 7; cuboid, 8; first metatarsal, 9; second metatarsal, 10; third metatarsal, 11; fourth metatarsal, 12; fifth metatarsal, 13-17; proximal phalanges, 18; distal phalange, 19-22; middle phalanges, 23-26; distal phalanges. (Abboud, 2002, p: 168)

3.2. Characteristic of Human Foot

3.2.1. Arches of the foot

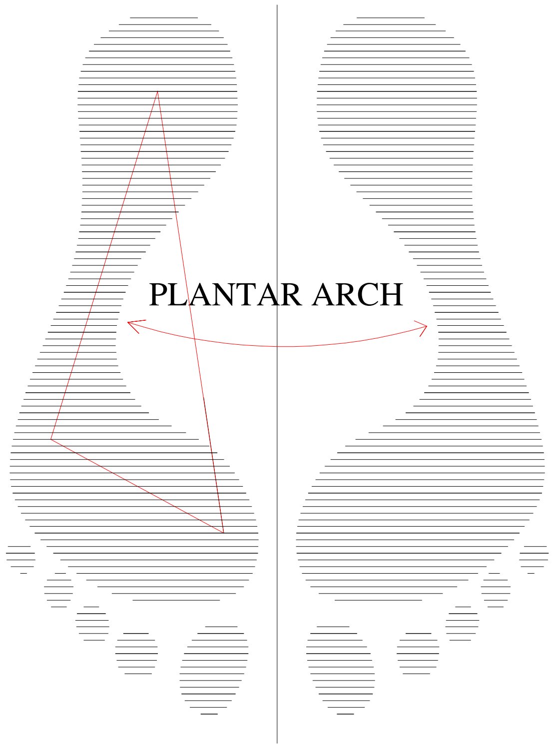


Figure. 3.3. Plantar arch of foot

The sole of the foot does not make the uniform contact with the ground. Instead the shape of the bones and the tendons and muscles connected them mean that it rests on an arch curved in two planes: the lengthwise curve and the transverse. The outer lengthwise curve of the arch joins the heel bone to the big toe; the inner lengthwise curve joins the heel bone to the big toe and finally the transverse curve joins to big and little toes to each other. When standing, the entire body weight rests on the three points where these curves intersect. (Vass&Molnar, 1999, s.24). A sole must also be individually adjustable for both the foot's longitudinal and transverse arches.

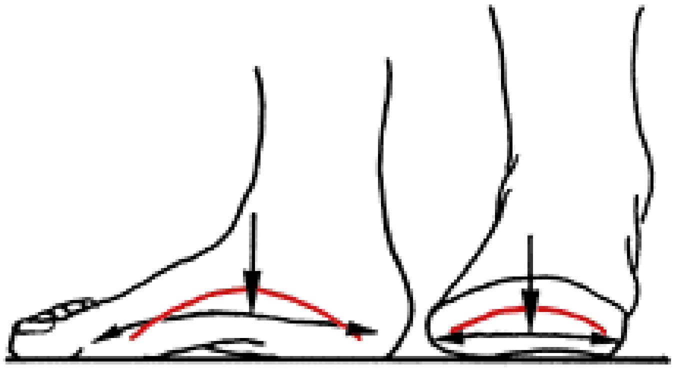


Figure. 3.4. Foot's longitudinal and transverse arches

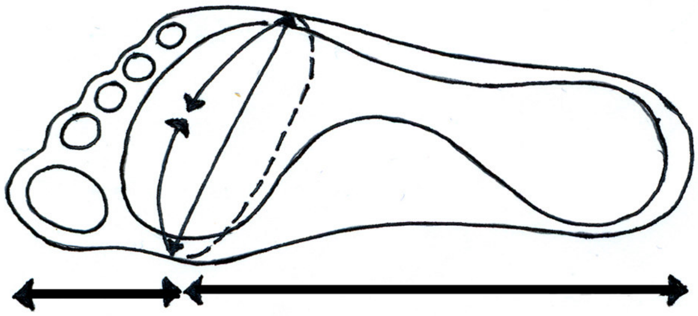


Figure. 3.5. The foot both widens and lengthens approx. 1 cm under load

3.2.2. **The Zones of Foot**

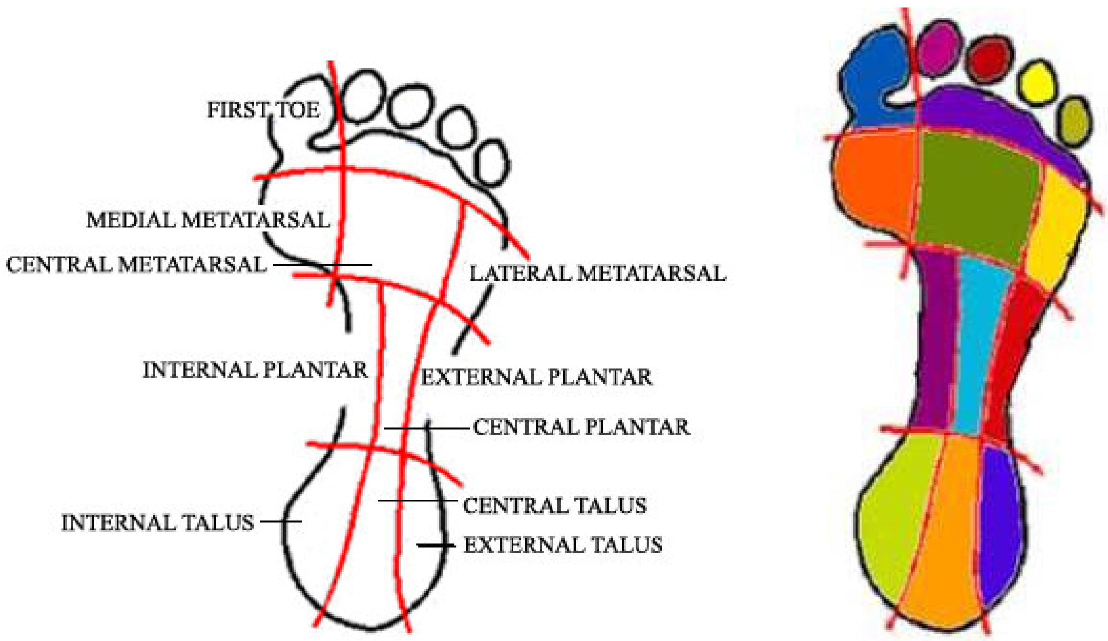


Figure. 3.6. The zones of foot

3.2.3. Foot Types

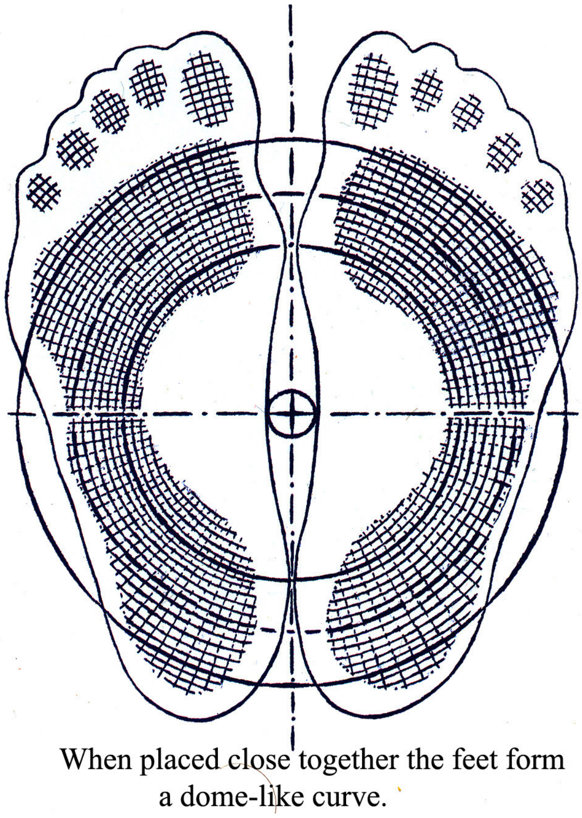


Figure. 3.7. Average foot imprint

Foot types are often categorized by arch height. The arch of the foot is formed by bones and is supported by muscles, tendons, and ligaments. Arches may be considered high (cavus), moderate, or low (planus). The arch height should always be evaluated when a person is standing with full weight on your feet, because a flexible foot may appear to have a higher arch when there is no pressure placed on it (http://www.shoedoc.se/skoeng.asp).

There are three basic foot types that affect the biomechanical needs of the feet.

1) **The normal foot** has a normal sized arch and leaves an imprint that has a flare but shows the forefoot and heel connected by a wide band. The normal foot lands on the outside of the heel and rolls inward (pronates) slightly to absorb shock.
2) **The flat foot** has a low arch and leaves a nearly complete imprint. That is, the imprint looks like the whole sole of the foot. This imprint usually indicates an overpronated foot that strikes on the outside of the heel and rolls inward (pronates) excessively.

3) **The high-arched foot** leaves an imprint showing a very narrow band connecting the forefoot and heel. A curved, high arched foot is generally termed a supinated or under-pronated foot. (Knight & Werd, 2004, p. 67)

4) **Kicked foot**

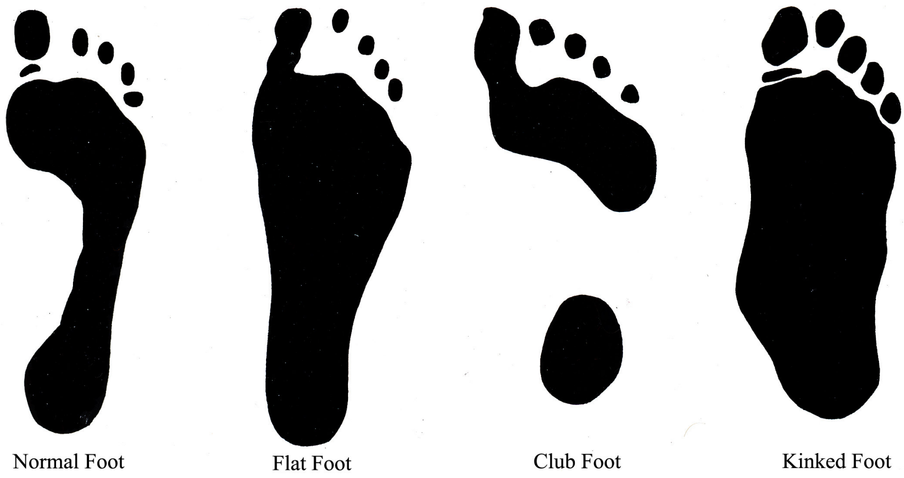


Figure. 3.8. Types of foot (www.backpack.com)

High-arched feet have smaller weight-bearing areas when they contact the ground and also tend to be more rigid, resulting in greater stress being transmitted to the foot and leg. A runner with a high arch may want to select a shoe that provides greater cushioning and shock absorption to make up for the lack of normal shock-reducing capabilities in this foot type. A high-arched foot will also tend to function better in a semicurve- or curve-lasted shoe.

If a person has a low-arched foot, it is generally a flexible foot that may be subject to excessive motion when he/she walks or runs. This motion may lead to overuse injuries. In a flexible, low-arched foot, motion control and stability are of prime importance when selecting a shoe. Often a straight- or mild semicurve-lasted shoe will be most appropriate.

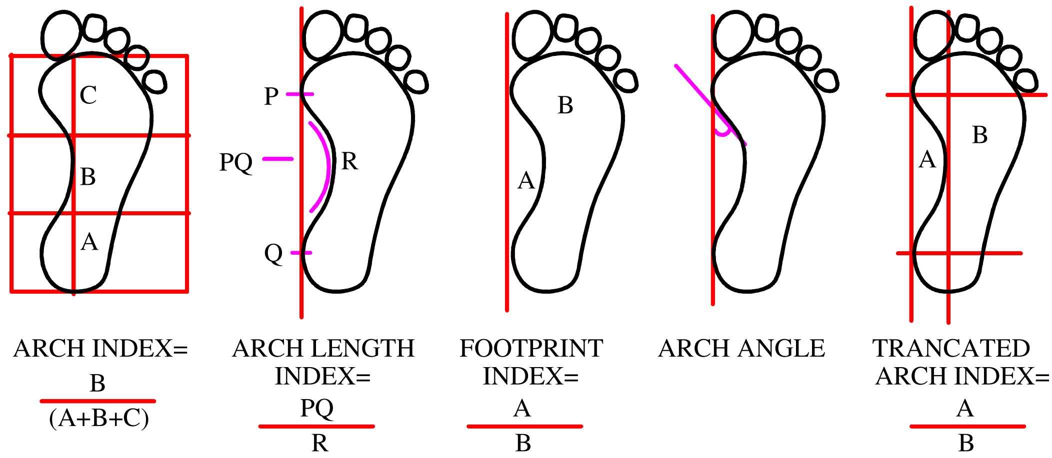


Figure. 3.9. Geometric analysis of foot types by examining arch

3.2.4. Gender and Ethnic Differences

The separation should be between the genetic differences (the "sex" differences) from those that contain a large element of cultural influence (the "gender" differences). Nearly all members of our society have some type of foot deformity due to the fact that we all wear shoes. Particularly during childhood, our feet grow faster than we acquire new shoes. That means that nearly all of us wore shoes that were too small during some part of our lives - and that lead to some foot deformity.

Exaggerated gender (culture based) differences come from the cultural trends that cause men and women to wear different types of shoes. If we take the most extreme example, women tend to wear high heeled shoes more than do men. High heels effectively cause the wearer to walk on the balls of the feet (on the metatarsal heads) the way a dog or a cat walks. This puts pressure on the metatarsal heads and causes the toes to twist, shrivel and bend inward. You see this type of deformity more often in women, and you can usually attribute it to the types of shoes that they wear. Still, there is a range of variation for both sexes (genders) with a considerable amount of overlap (Parham, 1987, p.240)

Gender and ethnic related differences in foot anatomy do not only have consequences for the construction of footwear but may also be the cause of specific foot complaints and injury prevalence. In addition to the obvious overall body dimensions, body composition is the major factor in differentiating women and men anatomically. Skeletal muscle mass as a percentage of total body weight is approximately 40 per cent for men and only 23 per cent for women. Sexual dimorphism in the pelvis is the major difference in the skeletal structure between the sexes. Adult foot size is attained at about 14 years of age in females and at about 16 in males, reflecting an earlier maturation in women. Women's feet have a considerably increased incidence of orthopaedic problems.

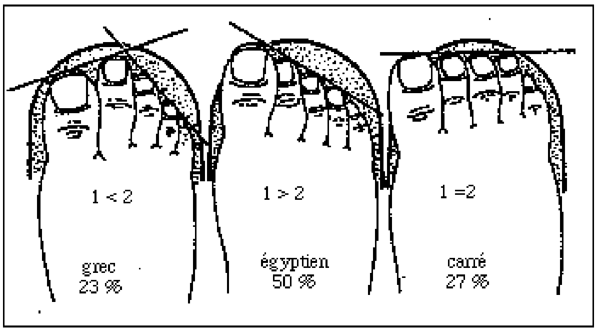


Figure. 3.10. Gender and ethnic related differences in foot anatomy

Podiatrists blame the high incidence of women's feet problems primarily on the fashion shoes that they wear. However, foot structure may also play a role in the higher incidence of lower extremity problems in women. If foot length is normalized, women have a more slender foot than men. Furthermore, women's heels are narrower in proportion to the forefoot. There are also differences in foot morphology in different parts of the world. When foot length is identical, Asian feet have a wider forefoot width, a lower longitudinal arch, and more pronated feet (Hennig, 2002)

3.2.5. Age Differentiations

When a child begins to walk, shoes generally are not necessary, allowing an infant to go barefooted in doors, or to wear only a pair of socks helps the foot grow normally and develop its muscles and strength, as well as the grasping ability of toes.

As children grow more active, and their feet develop, the need for shoes becomes apparent. It becomes necessary to change shoe sizes at a pace that frequently surprises and even dismays parents, to allow room for growth. For the reason that children grow there is some special criteria for their footwear design;

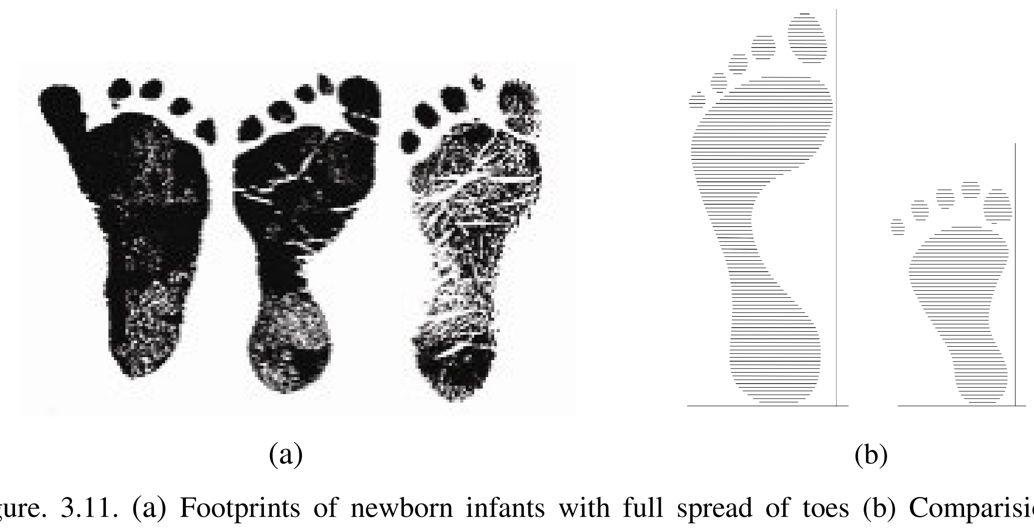
- It should have a firm heel counter (stiff material on either side of the heel), adequate cushioning of the insole, and a built-in arch. It should be flexible enough to bend where the foot bends—at the ball of the foot, not in the middle of the shoe.

- The child’s foot should be sized while he or she is standing up with full weight-bearing.
- There should be about one-half inch of space (or a thumb’s width) between the tip of the toes and the end of the shoe. The child should be able to comfortably wiggle his or her toes in the shoe.
- The inside of the shoe must not be any staples or irregularities and inside stitching hits the foot in the glue that could cause irritation.
- Shoes should not slip off at the heels. Children who tend to sprain their ankles will do better with high-top shoes or boots.

For older people footwear stability becomes more important parameter because of the importance of postural stability and foot’s getting weak against to forces. Older subjects underestimated the maximum foot supination more than younger subjects. The results suggest that soft midsoles predispose the wearer to falling, as they induce a more unstable position of the foot that is underestimated by the subject, thereby limiting postural adjustments to maintain stability. (Stephen R., 1999, p. 349)

3.2.5.1. Growth of the Human Foot

The foot of a newborn child has only one bone. The rest of the foot is made up of cartilage. Not all bones of the foot are present when first born, nor even in childhood. The final primary and secondary bony structures will have gradually emerged by puberty. When a child reaches 3 years of age much of the cartilage has become bone and by age 6 all bones have taken shape but are still partly composed of cartilage.



(a) (b)

Figure. 3.11. (a) Footprints of newborn infants with full spread of toes (b) Comparision of Infant and Adult Foot

The growth of the human foot comes in spurts. Studies show that during the first ten years of a child’s life the foot grows about one-half inch a year. Between the ages of 10 and 20 the yearly growth rate slows down considerably, with maturity of growth arriving between the ages of 19 and 20.

Figure. 3.12. By the child feet growing, the footwear extends in harmony with the foot. K2 in USA *‘Max, der Wurm’*

Even at a late stage of development, incorrect posture, poor walking and incorrect shoes can still destroy the joint alignment of the foot structure and the bones themselves.

3.3. Biomechanical Construction

3.3.1. Mechanics of the foot’s movement

The anatomy of the foot with its' many joints is complex. For the benefit of shoe customers a synopsis of the mechanics of the foot's movements should be analyzed in order to properly understand **the basis of shoe construction.**

The foot's movements during the most common running style begin with the heel contacting the ground, when the weight will immediately shift forward, rolling along the bottom and then unto the ball of the foot, to finally reach the big toe.

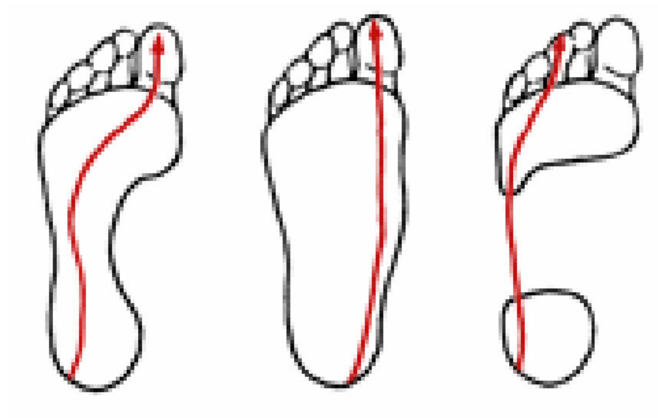
Biomechanics is the study of normal mechanics (kinetics and kinematics) in the musculoskeletal system by analyzing forces and their elects on anatomical structures. In order to electively treat any part of the human musculoskeletal system, it is important to fully understand its biomechanics. It is essential to design the right shoes. Small variations in shoe design have been found to cause ankle pain, and even headaches. (Cavanagh 53) The primary goal of shoe designer has to be achieving an optimal shoe design for the "average" person but the handicap is that all the people are anatomically and functionally different. Each individual is unique; differences in structure, movement and gait pattern require footwear to vary from person to person. **Efforts to meet this concern are further multiplied by the critical factors to be considered in the design of each shoe: Shock absorption, flexibility, fit, traction, sole wear, breathability, weight, etc.** Due to the diversity of the human form, it is impossible to provide for the needs of each person on the planet. Shoe designers manage this overwhelming demand by supplying some standard, user-defined, foot-ground interface. Shoe design involves the complicated task of finding the most versatile specifications for the human performance through human factors and biomechanical requirements.

3.3.2. Motion Analysis of Human Foot

The human foot has its own uniqueness and in some cases, under specific circumstances, can be placed back to a particular shoe. It is important to remember that how a person walks and steps is not only controlled by the feet, but by the rest of the human body. Each part of the body contributes significantly to the activities of the feet and their process. The human foot changes its behavior during each stride in normal gait. During the comparison of known shoes to unknown impressions, wearing characteristics that are observed can play an important part in an examination conclusion. Once the wear pattern begins it is hard to stop. That original pattern may not be unique, but as the wearing continues it will become unique to that individual. Since the foot can move in four different directions, this can influence the main portion of wearing characteristics on the outsole of a shoe.

3.3.2.1. The Cause of Motion: Forces

The foot changes shape and we can move, because forces act upon the structures of the body causing body segments to rotate around joint axes. Motion at a joint is rotational. During locomotion two kinds of forces are at work: external forces and internal forces. External forces are gravity, the ground reaction forces that counters gravity, and momentum. Internal forces are generated by muscle contraction.



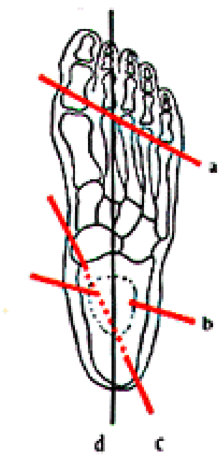
(a) (b) (c)

(a)Neutral runner (b) Pronator (c) Supinator

Figure. 3.13. Pressure curves along the sole of the foot;

During each step, the sole of the foot is subjected to forces, which, moving forward from the heel and along the sole, will take differing paths depending upon the type of foot as illustrated above. Shoes need to be strengthened in those areas where greatest stress occurs. These areas will vary with the type of foot and style of running.

The movements of the foot: terminology : The movements of the heel and of the forefoot occur around completely different axes.



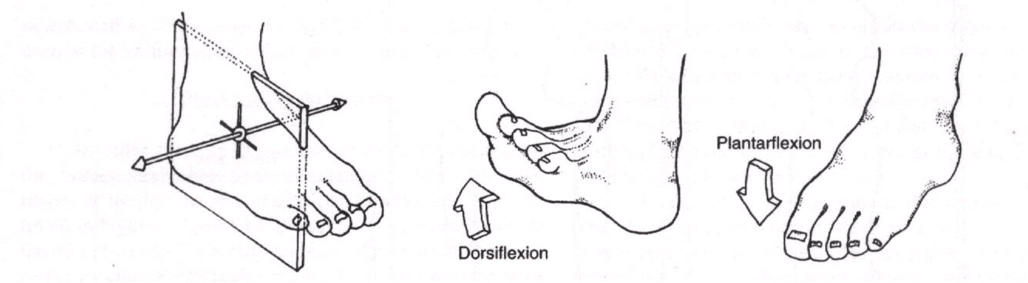
The heel's movements (in- and eversion) occur around the oblique axis. The forefoot's movements (pro- and supination) occur around the longitudinal axis. **Pronation** and **supination** are terms that describe exclusively the movements of the forefoot and midfoot, while **inversion** and **eversion** describe only movements of the heel (movements of the subtalar joints).

(a) Metatarsal break, (b) Transverse axis, (c) Oblique axis, (d) Longitudinal axis

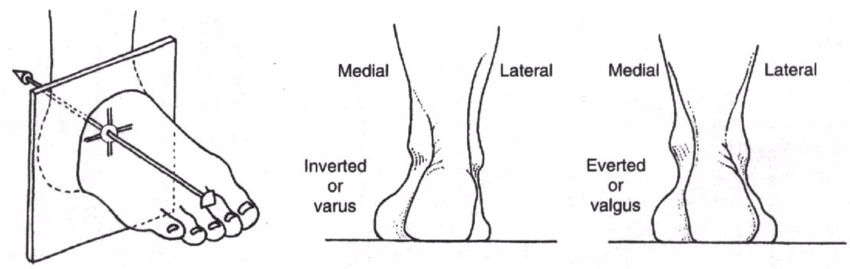
Figure. 3.14. Some important axes of movement of the foot

3.3.2.2. Planes of motion (foot)

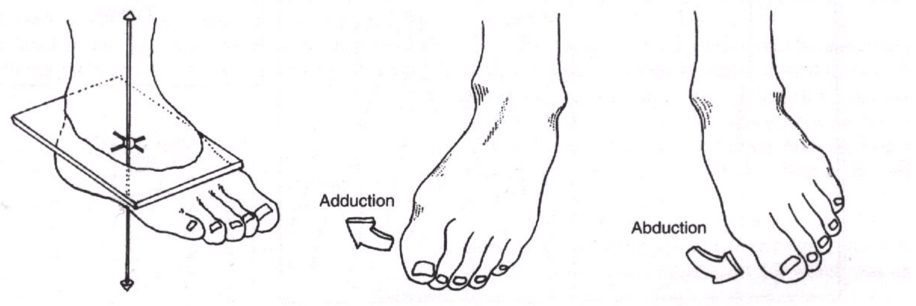
To understand the biomechanics of foot movement the movement planes should be analyzed. If the foot moves in the sagittal plane, the motion is called flexion & extension; if it moves in the frontal plane, the motion is called inversion & eversion, and if it moves in the transverse plane, the motion is called abduction & adduction.



(a)



(b)



(c)

Figure. 3.15. Planes of motion; (a) Sagittal - flexion & extension, (b) Frontal - inversion & eversion, (c) Transverse - abduction & adduction

3.3.2.3. Foot Biomechanics

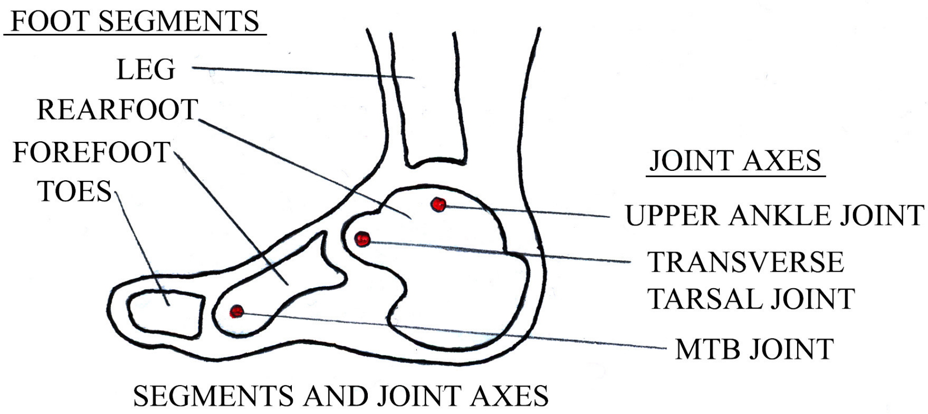


Figure. 3.16. Foot segments and joints

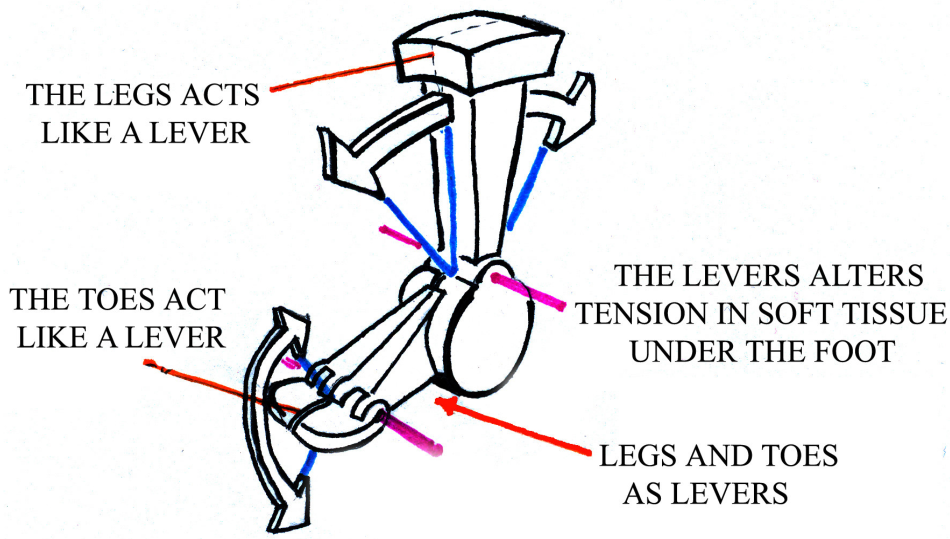


Figure. 3.17. Foot biomechanics as a lever characteristic of foot

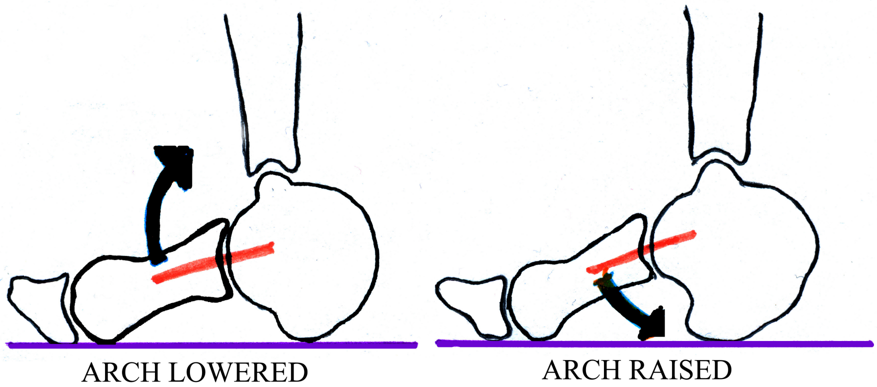


Figure. 3.18. Transverse Tarsal Joint Motion

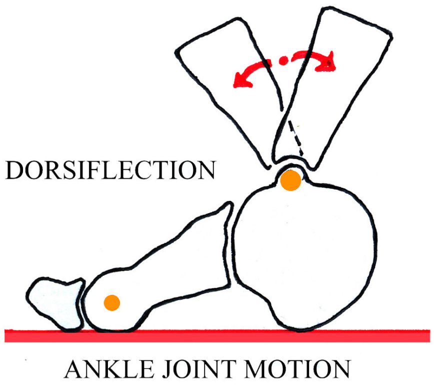


Figure. 3.19. Ankle Joint motion

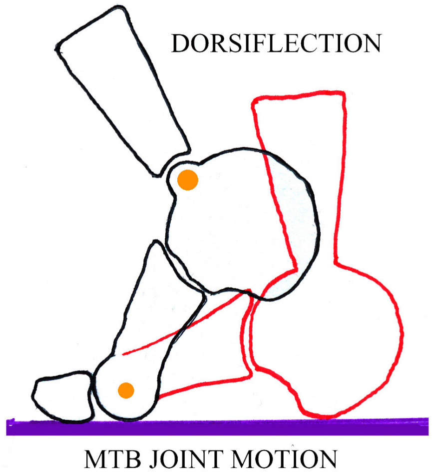


Figure. 3.20. MTB joint motion

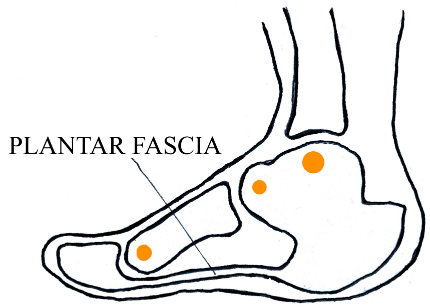


Figure. 3.21. Plantar Fascia

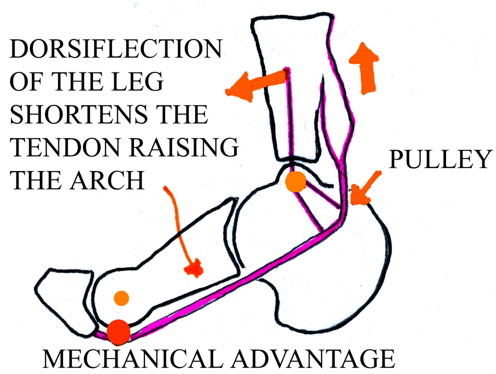


Figure. 3.22. Mechanical advantage

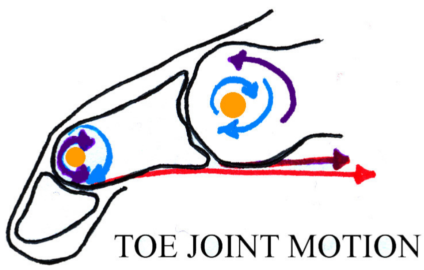


Figure. 3.23. Toe joint motion

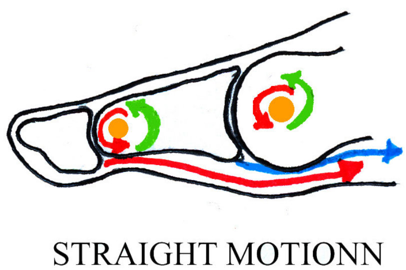


Figure. 3.24. Straiht motions

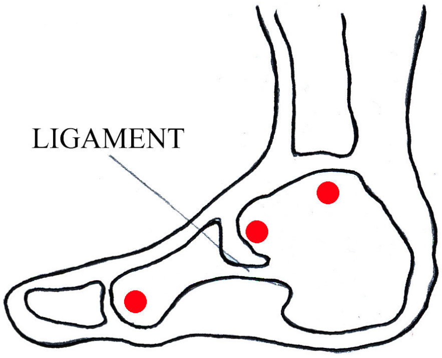


Figure. 3.25. Ligament

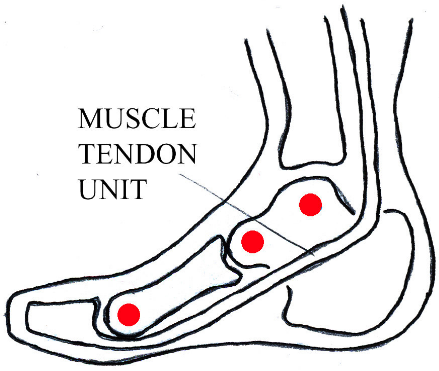


Figure. 3.26. Muscle tendon unit

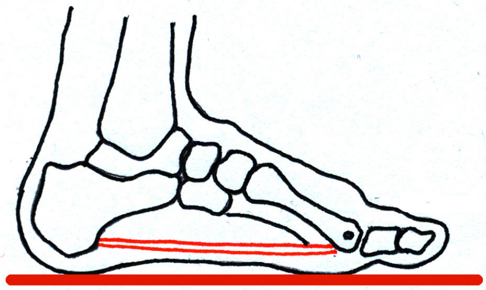


Figure. 3.27. Plantar fascia lowered

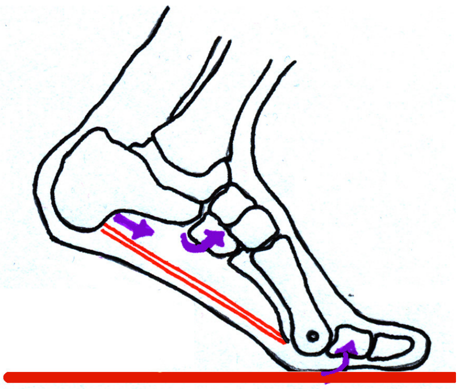


Figure. 3.28. Plantar fascia raised

Pronation is a foot motion that occurs normally when the heel strikes the ground to help the body absorb the impact. This motion appears as a flattening of the arch or a rolling in of the foot.

Supination is the opposite of pronation. It occurs normally right after heel strike to help the foot become a rigid lever to propel off of. Over-supination is very rare. What is more common is under-pronation, which can occur with a rigid, high-arched foot. A foot that underpronates is not able to absorb impact very well, which can lead to stress fractures, heel pain, knee pain, and other injuries. A foot that under-pronates needs a shoe capable of absorbing shock well. Motion control is usually not very important in this type of foot; however, in some cases orthotics can distribute pressure and support this foot type (Hennig, 2002, p.356)

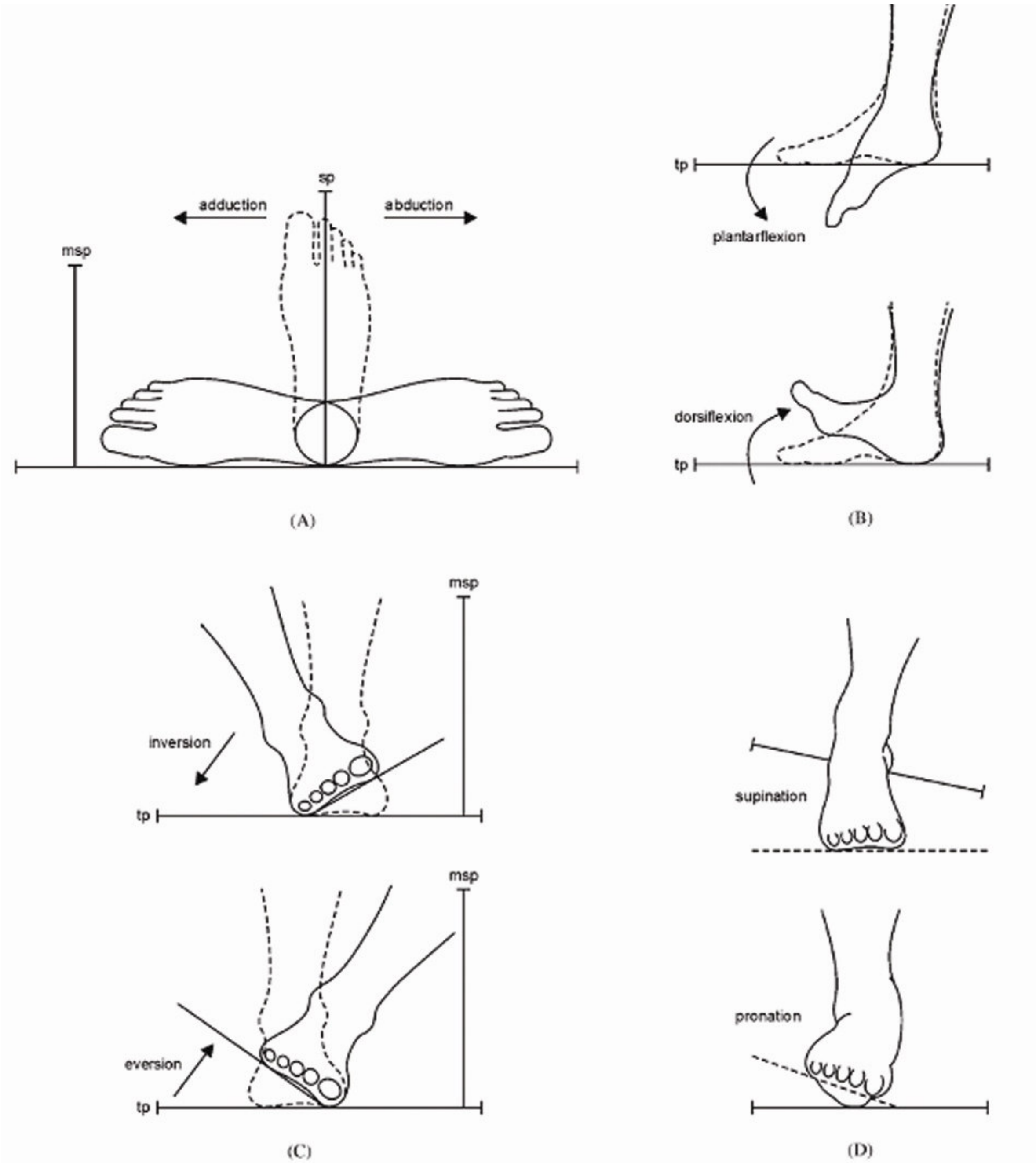


Figure. 3.29. (A)adduction-abduction, (B) plantarflection-dorsiflection, (C) inversion-eversion, (D) supination-pronation (Abboud, 2002, p.169)

Many feet fit in between these two extremes, and shoe companies have responded to this need by designing more versatile shoes that provide both cushioning and the necessary amount of motion control in one model.

These factors are combined to design and produce a shoe that fits well. These include **shock absorption** against pressure distrubition, **flexibility**, **heel counter stiffness**, rear-foot stability, overall rear-foot control, sole wear, traction, permeability to water.

3.3.3. Gait Analysis

Gait analysis is used by researchers and clinicians to describe an individual pattern of walking. In modern rehabilitation, there is an increasing need for objective and quantitative measurement of the relevant aspects of gait. This should ultimately lead to a better understanding of inter-related foot/limb function. Gait analysis also involves the measurement of muscle activity, and both kinetic and kinematical elements during gait. Most of the problems associated with foot disorders are in one way or another related to the weight-bearing process at the foot-ground or foot/shoe-ground interface.

3.3.3.1. Phases of the step

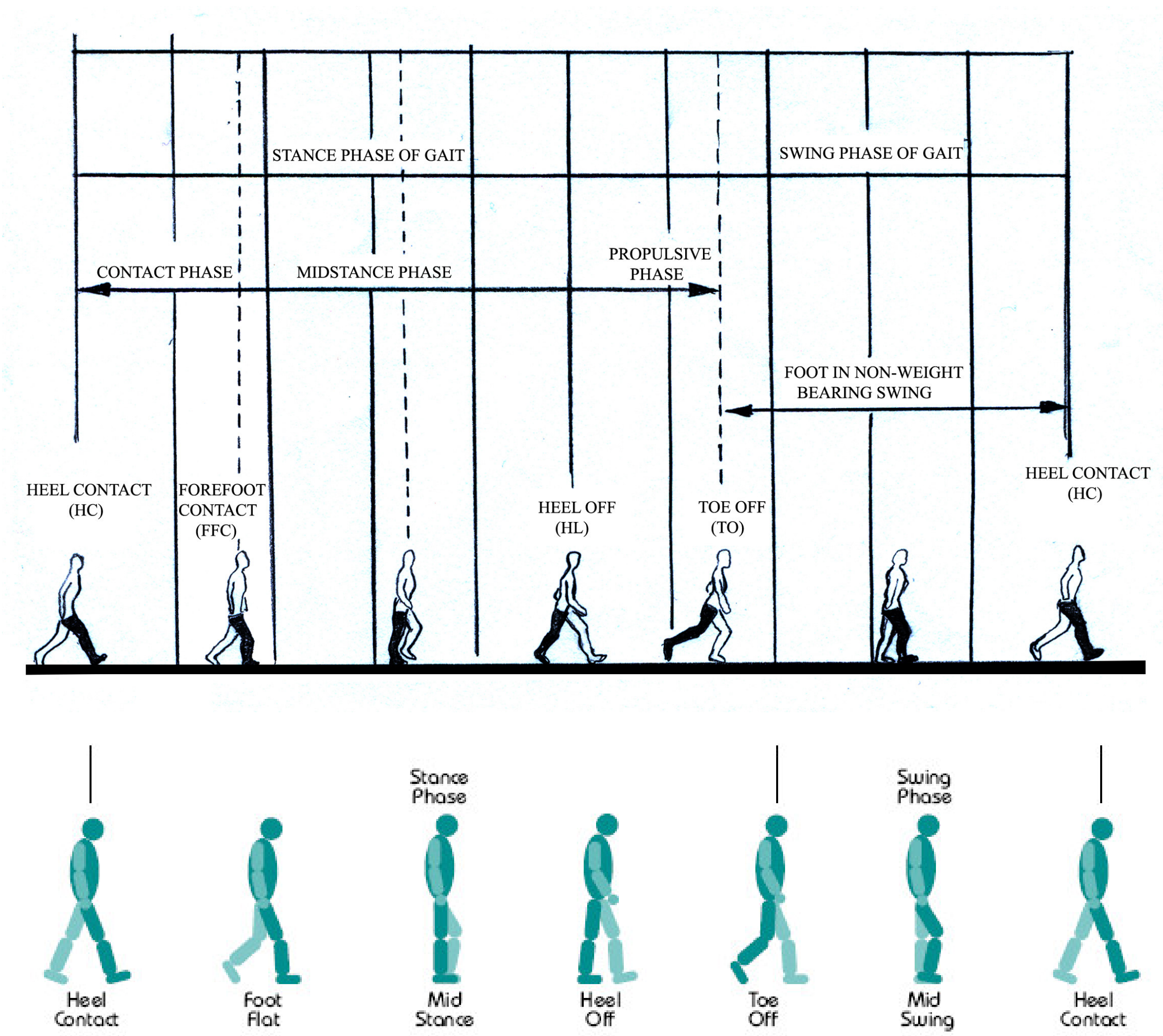


Figure. 3.30. Phases of step (Gage, 1990, p.298)

The gait cycle begins when one foot contacts the ground and ends when that foot contacts the ground again. Thus, each cycle begins at initial contact with a stance phase and proceeds through a swing phase until the cycle ends with the limb's next initial contact. Stance phase accounts for approximately 60 percent, and swing phase for approximately 40 percent, of a single gait cycle. (Downey, 1989, p.254)

Each gait cycle includes two periods when both feet are on the ground. The first period of double limb support begins at initial contact, and lasts for the first 10 to 12 percent of the cycle. The second period of double limb support occurs in the final 10 to 12 percent of stance phase. As the stance limb prepares to leave the ground, the opposite limb contacts the ground and accepts the body's weight. The two periods of double limb support account for 20 to 24 percent of the gait cycle's total duration.

Stance phase of gait is divided into four periods: loading response, midstance, terminal stance, and pressing. Swing phase is divided into three periods: initial swing, midswing, and terminal swing. The beginning and and ending of each period are defined by specific events.

The weight-bearing phases of the step can be divided into:

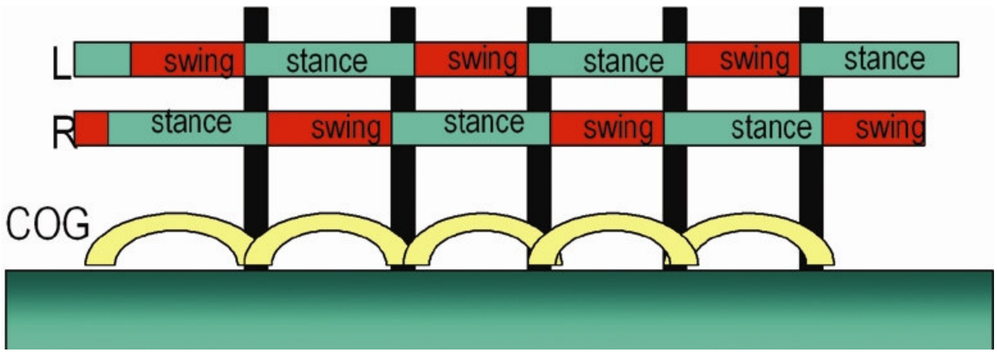


Figure. 3.31. Subdivision of gait phase

3.3.3.1.1. Stance Phase

The foot on the ground. It begins when the foot contacts the ground. Within milliseconds the foot is loaded with as much as 2--3 times your body weight of force. At this point, the foot begins to pronate. Pronation is simply your normal foot motion - from foot-strike on the outside of the heel through the inward roll to the ball of the foot.

1. Heel Contact: (Heel Strike or Shock Absorbtion Phase) Begins when the heel of the subject leg comes in contact with the ground Loading response begins with initial contact, the instant the foot contacts the ground. (Normally, the heel contacts the ground first). At the time of impact the foot is angled upwards (dorsally flexed) with its' sole at an approx. 15 degree angle to the ground for maximum stability.
2. Foot Flat: Heel contact continues as the foot becomes flat.
3. Mid-Stance: The non-subject leg then begins to move forward. Midstance begins with contralateral toe off and ends when the center of gravity is directly over the reference foot. (Note that this phase, and early terminal stance, the phase discussed next, are the only times in the gait cycle when the body's center of gravity truly lies over the base of support.) It begins after the foot reaches maximum pronation (when the foot is in the middle of its inward roll toward the toe) and the heel begins to lift off the ground. It is during this phase that the lower extremity prepares to lift the entire body off the ground. It is very important that a shoe possess adequate traction during this phase to maximize forward propulsion. (Perry, 1990, p.329)
4. Heel off: The heel begins to lift off of the ground Terminal stance begins when the center of gravity is over the supporting foot and ends when the contralateral foot contacts the ground. During terminal stance, around 35 percent of the gait cycle, the heel rises from the ground.
5. Push off: The whole foot except the toes is raised up as the calf muscles start pushing the body up and forward.
6. Toe off: The toe finally lifts off the ground. In this last part, the toes also go off and the whole foot leaves the ground. Preswing begins at contralateral initial contact and ends at toe off, at around 60 percent of the gait cycle. Thus, preswing corresponds to the gait cycle's second period of double limb support. (Leroux et al., 2002). Commonly, the heel is also angled inwards (inversion) at the moment of contact with the underside of the heel also at approx. 15 degrees. At higher running speeds the heel's inward angle often increases somewhat and the angle between its underside and the ground can be as much as 35 degrees. (Hennig, 2002, p. 171)

3.3.3.1.2. Swing Phase

Swing phase is when the foot on the air.

1. <u>Toe off:</u> (Acceleration) Begins when the toe of the subject leg is lifted off the ground. Initial swing begins at toe off and continues until maximum knee flexion (60 degrees) occurs.
2. <u>Mid-Swing:</u> Continues as the subject leg swings forward. Midswing is the period from maximum knee flexion until the tibia is vertical or perpendicular to the ground.
3. <u>Heel Contact:</u> (Deceleration) The heel of the subject leg makes contact with the ground. Terminal swing begins where the tibia is vertical and ends at initial contact.
4. <u>Heel Strike:</u> Heel striking the ground again. (Hennig, 2002, pp. 171-174)

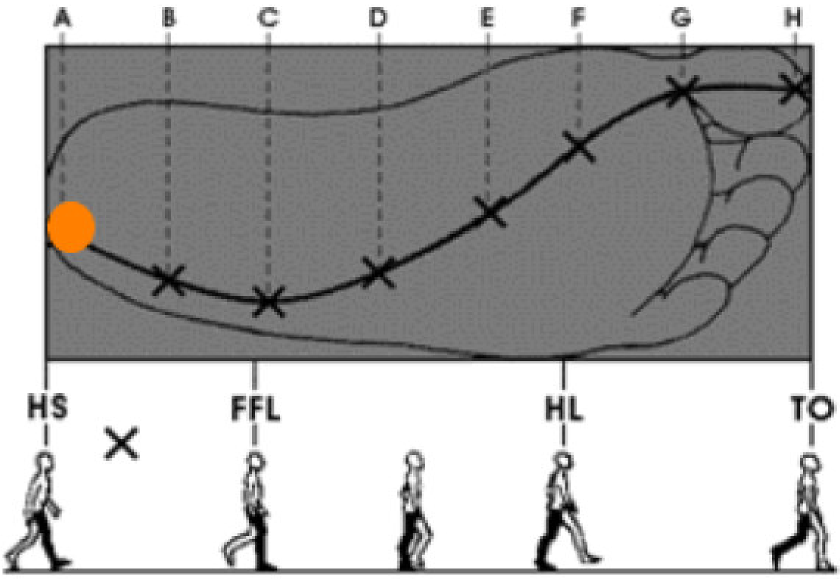


Figure. 3.32. Dynamic weight-bearing characteristic of foot

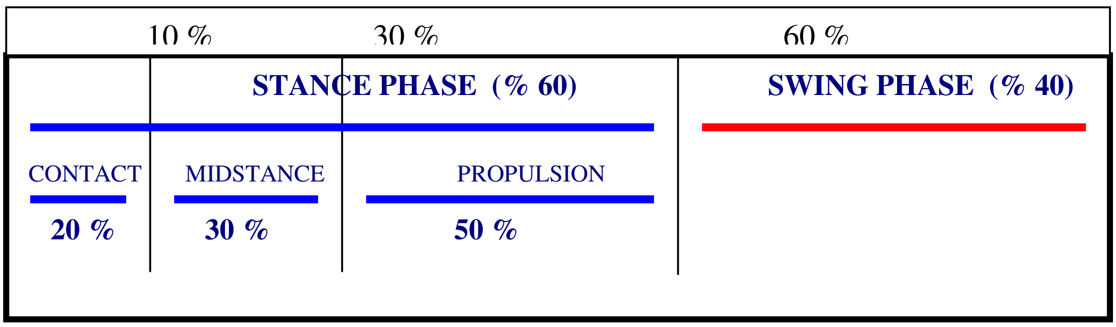


Figure. 3.33. An estimate on stance and swing phase during gait

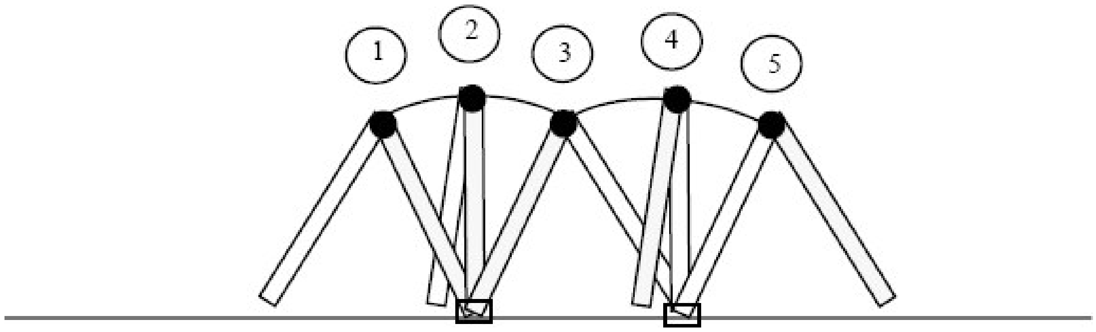


Figure. 3.34 The body's rocking as though on a spring (Bojsen-Moeller, 1978)

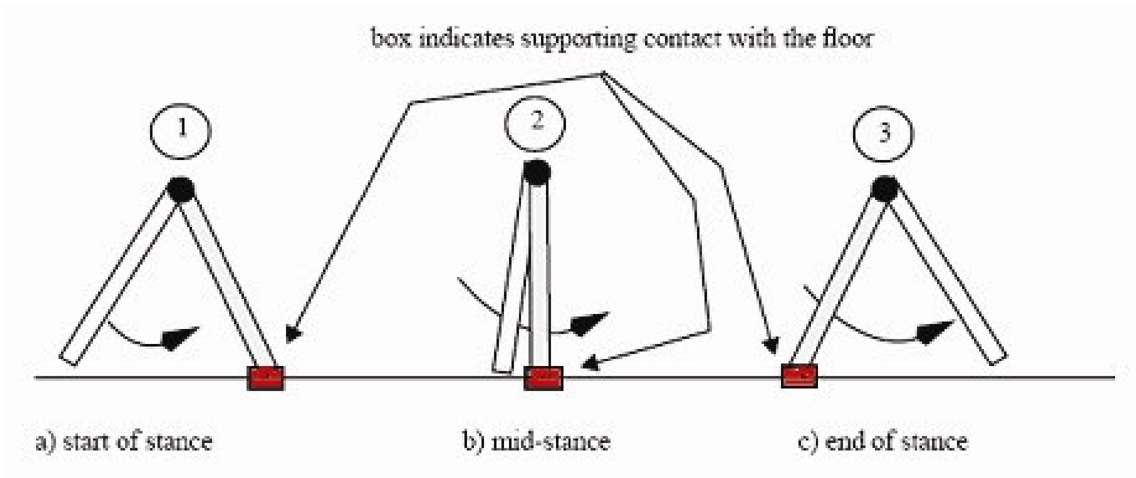


Figure. 3.35. Foot's weight-bearing on one foot in stance phase (Bojsen-Moeller, 1978)

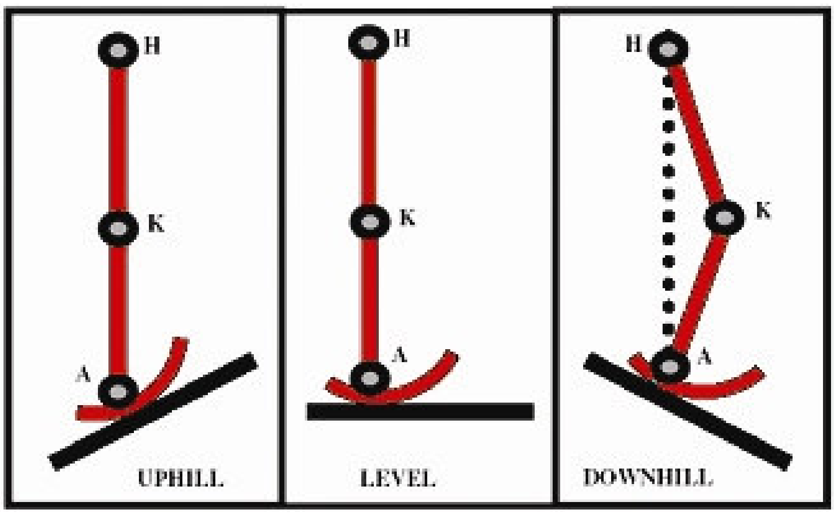


Figure. 3.36. Rocking characteristic of foot

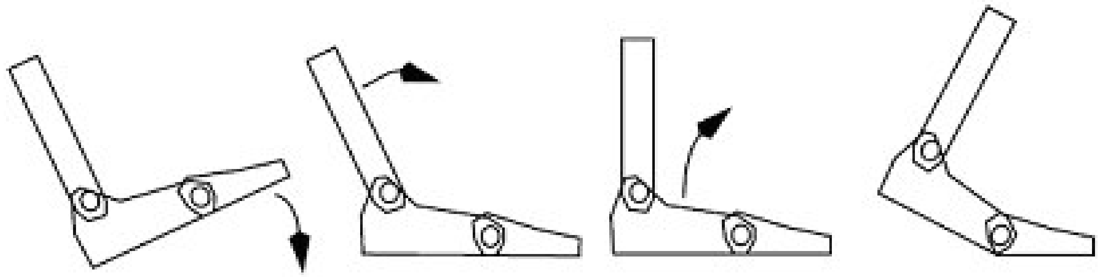


Figure. 3.37. Rotation of the ankle toe joint

3.3.3.2. Pressure Distribution

Pressure at human-product interface is unavoidable, and cause injury, pain and discomfort. For the footwear design, foot interaction with the ground is an important factor. Because, when people are walking, the load on the human body will mainly be the body weight and the reaction forces on the foot during floor contact. These forces are one of the few external forces acting on the human body during motion (Franke, 1951, p. 587).

Pressure is defined as follows:

Pressure (Pascal) = **Force/ Area** (Newton/m^2)

Alternatively, stress has a similar formulation and is generally in the form of compression, tension or shear:

Stress (Pascal) = **Force/ Area** (Newton/m^2)

(Goonetilleke, R. S. and Eng, T. J., 1994, p. 688-690)

There is a possibility of a relationship between shoe design and injury prevention. Various experiments suggesteed that stress fractures are caused by pressure overloads at various locations under the foot (Henning & Milani, 1995). Many injuries to the foot appear to be caused by repeated and excessive plantar pressures. Pressure distribution changes according to ground surface, the slope of ground, the heel height and the insole design. Interface pressure can play an important role in the development of products, devices, such as beds, handles, seat cushions and especially shoes. An understanding of the pressure patterns that are appropriate for the human body (that is the patterns that reduce discomfort or improve comfort) can make product design and usage very satisfying and fulfilling.

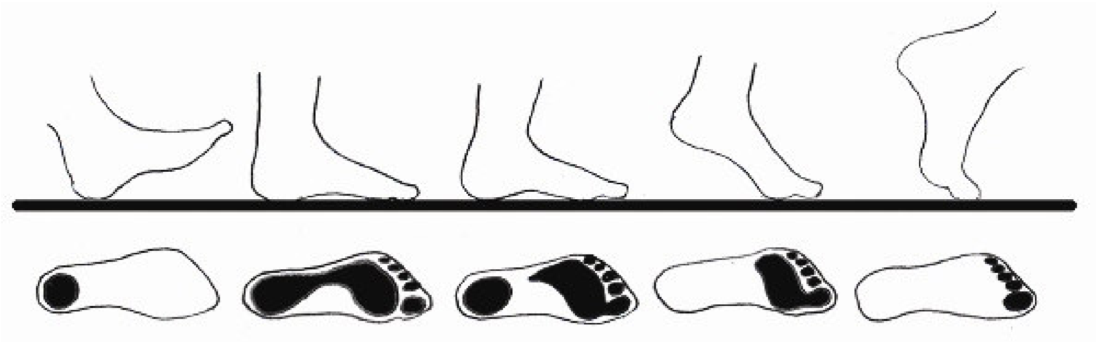


Figure. 3.38. Pressure distribution of foot during gait

Researchers have shown that this pressure pattern is related to the level of comfort and discomfort (Lueder and Noro, 1992). Generally, discomfort may be quantified using a combination of the following:

1. Peak pressure,
2. Pressure gradients and,
3. Contact area

It is quite unfortunate that the most appropriate pressure pattern for each individual or individual-product interface is still unknown. If it were known, product design for the human body would be so much easier. Part of the problem stems from the fact that contact area has been neglected in the past.

In general, forces can be supported in two ways:

1. Distribute the force "Uniformly"
2. Concentrate or load the "stronger" parts of the structure to reduce "breakage" (Floyd and Roberts, 1958).

Which one of the two strategies is best to maximize comfort or even minimize discomfort on the human body and why?

The main interaction that controls postural sway occurs at the interface between the plantar surface of the foot and the shoe, in short, the "foot-shoe interface". It is important for shoe designers to judge the effects of the footwear construction elements. The subjective judgment of cushioning, e.g. comfort level ratings, of shoe sole materials may lead to wrong conclusions. Although comfort is a high selling point in today's commercial market, comfort-pressure studies have not been successful to generate new theories to improve product design. Investigation in the relationship between comfort and pressure with special relevance to footwear are still in progress (Goonetilleke, 1997). In order to design shoes that are healthy to people who wear them, common treatments consist the use of cushioning inserts, changes in footwear, or the redistribution of plantar pressures.

The addition of elements, such as cushioning inserts, into a shoe is one of the methods for improvement in the shoe design. How do the shoe designers justify into what kind of insole material is the proper one? Future improvements in the footwear design related to develop new solutions for such problems in design. For example; to make the pressure distribution effectively to improve balance and human performance;

1. The choice of cushioning insole material is important. "Inserts merely allow the foot to get into the proper position so that the muscles can do their job in aligning the joints. It also facilities the bony architecture of the foot to support the body weight. A choice of insole material may be of a polymeric material made of a closed cell foam." (Lemmon, et al., 1997, p. 615-620).
2. The next improvement method is to simply change the type of footwear.
3. The third improvement method is the redistribution of plantar pressures. "In-shoe pressure systems are capable of measuring pressures at the foot-shoe interface during a given functional activity. Determination of the contact areas and the distribution of pressures within the feet is therefore of great interest. It is beneficial to use formal pressure measurement methods to find the suitable footwear to avoid overload in certain areas in the feet." (Goonetilleke, 1997).

If uniform pressure is the ideal pressure distribution for optimal comfort, interface design should be relatively easy, especially since pneumatic or hydrostatic balloons or bladders can be used to give this "constant" or uniform pressure at the interface. What could be affecting the pressure-comfort or pressure-discomfort relationship? Since the maximum pressure tolerance is dependent on the contact area, it may be concluded that, at high forces, a larger area may cause a higher level of discomfort than a smaller area when stimulated with the same magnitude of pressure. (Goonetilleke, 1994, p.689)

The ground impact force changes from one individual to another. The reason for this changes is the corresponding variability in the both the **magnitude** and the **direction** of the transient force vector. It is also affected by;

- The speed of walking,
- The type of footwear,
- The ground surface,
- The mood of the individual. (Whittle, 1999, p.264)

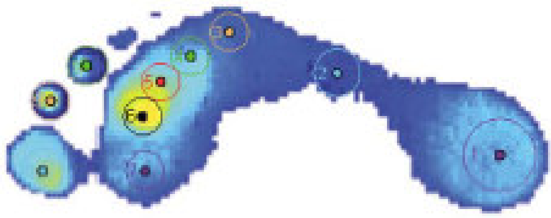


Figure. 3.39. Computer analzed joint pressures (Abboud, 2002, p:174)

When we walk there is a load placed on the foot and the leg. The human foot has a definite, although varying capacity to accept weight before injury results. The amount of weight tolerated before injury occurs varies with the time course of loading and the individual ability to dissipate the loading force. By modifications of footwear, it is possible to change the load delivered to the body at foot strike and thus decrease injury. Footwear may play an important role in maintaining normal foot function. (Barry, 1999)

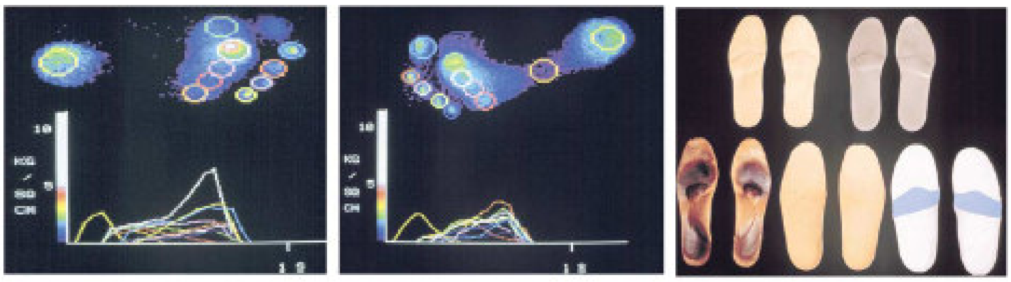


Figure. 3.40. Consumer dynamic pressure prints and the insole provided

3.3.3.2.1. Ground Reaction Forces

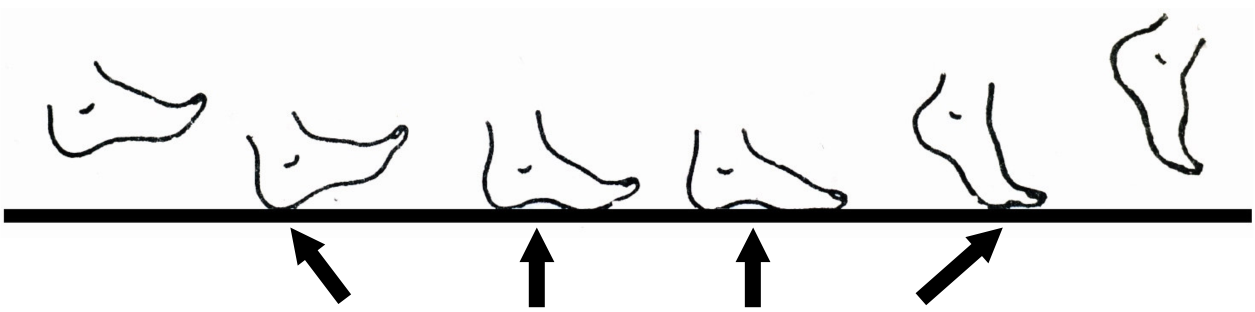


Figure. 3.41. Ground Reaction Force Vector

The body exposed daily to transient forces of body-foot-ground, due to the impact of the foot with the ground. Viscoelastic materials, both within the body and when used in footwear, are able to reduce these forces. The heelstrike transient occurs at the end of the swing phase of gait. (Whittle, 1999, p.264)

When a moving object, such as the foot, runs into a stationary one, such as the ground, there is an exchange of both energy and momentum between them. The material at the interface between the foot and the ground affects the transfer of both energy and momentum, and in doing so controls both the magnitude and the time-course of the forces generated.

Momentum exists in two forms: **linear**, which is defined as the product of velocity and mass (mv), and **angular**, which is the product of moment of inertia and angular velocity. The 'law of conservation of momentum' states that momentum (either linear or angular) cannot be generated or destroyed — merely transferred from one object to another. Following the impact between the foot and the ground, momentum is conserved, so that as the foot is brought to rest, its momentum is transferred to the ground; the increase in the momentum of the earth is equal to the decrease in momentum of the foot. The foot thus imparts a very small additional velocity to the earth. If the elasticity of the material below the foot causes the foot to rebound, momentum is transferred back to the foot again and the total change in momentum is increased (Fig. 3.37).

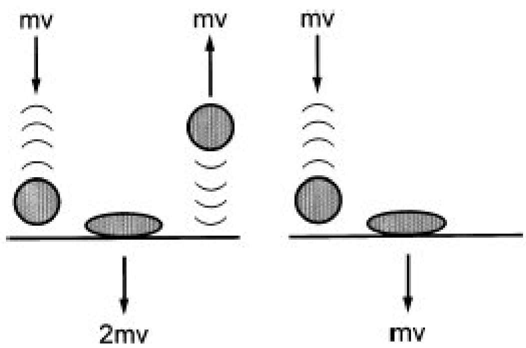


Figure. 3.42. Elasticity of the material below the foot causes the foot to rebound

When a falling object bounces (left) its downward momentum (mv, where m is mass and v velocity) is replaced by upward momentum, making the total momentum transferred to the supporting surface 2 mv. An object which does not bounce (right) only undergoes a momentum transfer of mv.

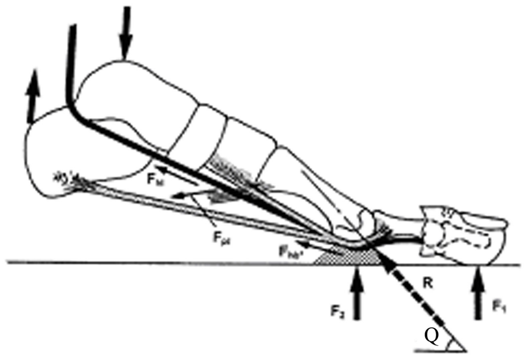


Figure. 3.43. Forces acting to foot (muscle forces, ground reaction forces)

The practical consequence of this is that the more elastic the interface, the greater the total change in momentum experienced by the foot — and by implication, the higher the transient force. Although energy cannot be created or destroyed, it exists in different forms and one type of energy may be changed into another. The moving foot possesses kinetic energy, equal to one half of its mass multiplied by the square of its velocity (1:2 mv2). If the foot is brought to a halt by the ground, part of the energy is transferred to the earth as kinetic energy, corresponding to the small increase in the velocity of the earth, as mentioned in the previous paragraph. Any remaining energy is changed into some other form, typically sound and heat and is thus dissipated. If elastic materials below the foot store energy and then return it to the foot, less of the energy is lost as heat and sound.

The way in which the heelstrike transient is generated and how it can be measured was reviewed by Collins and Whittle. Force is equal to the rate of change of momentum, so the magnitude of the heelstrike transient is determined by the rate at which the momentum of the foot changes. This, in turn, depends on two things: **the total change in momentum** and **the time during which that change in momentum takes place.** The total change in momentum depends on the velocity of the moving foot and the mass which is decelerated in the heelstrike event. The time taken to bring the foot to a stop depends on the amount and compressibility of the material beneath the calcaneus, which includes the anatomical heel pad, the shoes and insoles, and the ground surface itself. The ground surface may be very inelastic, such as steel or concrete, or very compliant, such as soft carpeting or mud. The further the calcaneus is able to travel in coming to a halt, the longer it takes and thus, the lower the forces. In summary, the force beneath the foot depends on two properties of the foot (mass and velocity) and three properties of the interface (thickness, elasticity and viscosity).

By increasing the performance of footwear design, walking speed, walking time increase and resting time decrease (Rose et al., 1991, pp. 571-578)

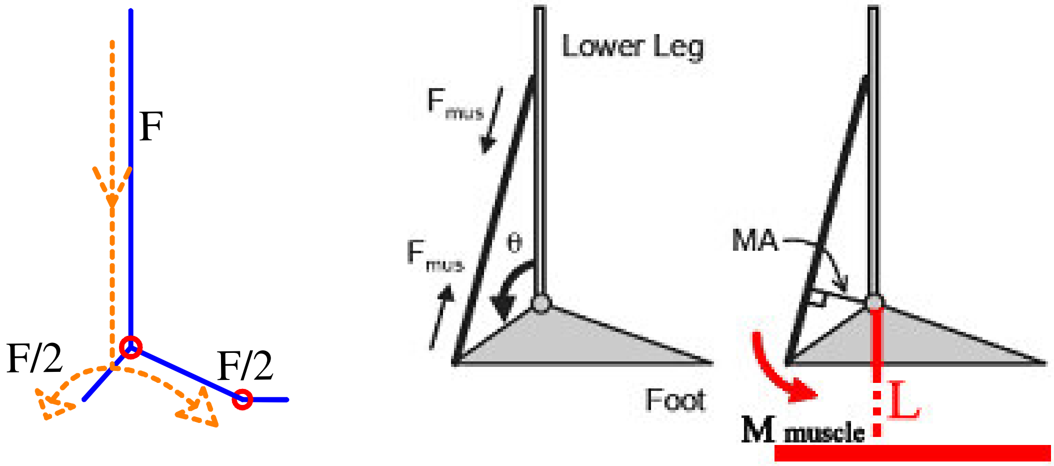


Figure. 3.44. Moments of foot and its interaction with the interface thickness

Joint moment (M joint) is produced around a joint, as a function of MA (moment arm length) and L (the heel height) and F muscle (muscle force) (Naganoa&Komurac, 2003, p. 1676)

M joint = MA. F muscle

M joint = L. F muscle

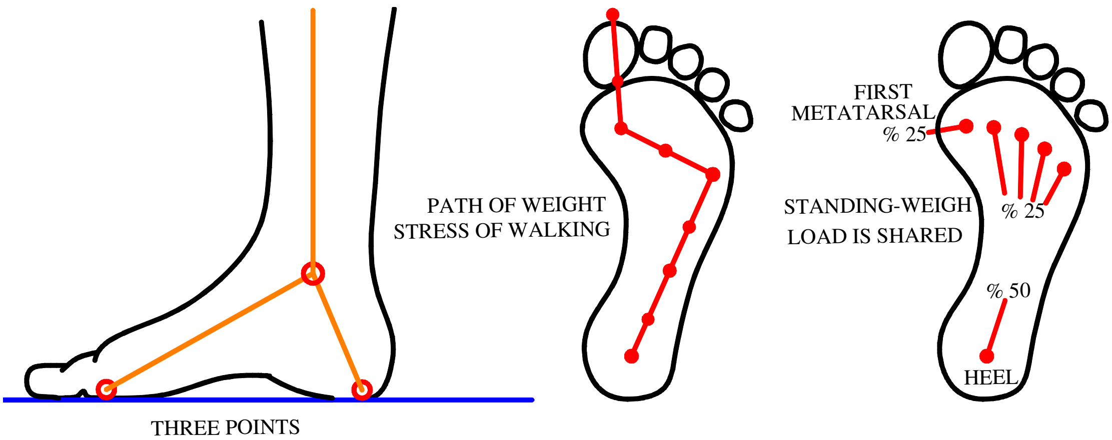


Figure. 3.45. Left, pattern of weight distribution on standing; right, path of weight distribution in step sequence.

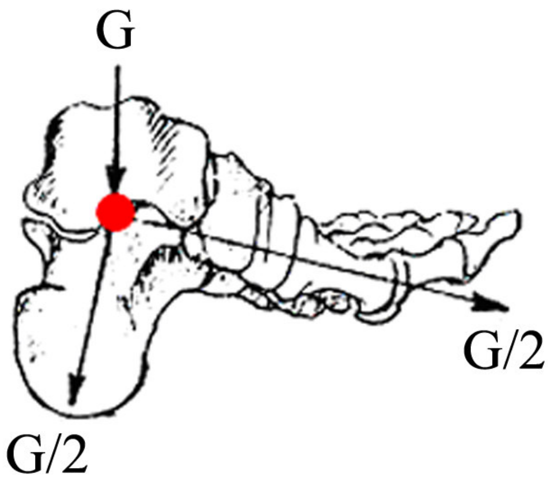


Figure. 3.46. Natural weight distribution

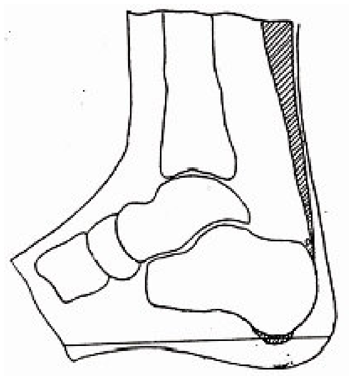


Figure. 3.47. Concave bottom of calcaneous, with protective bursa. This is normal site of heel strike, allowing foot and weight to roll forward easily with progressive sequences of step

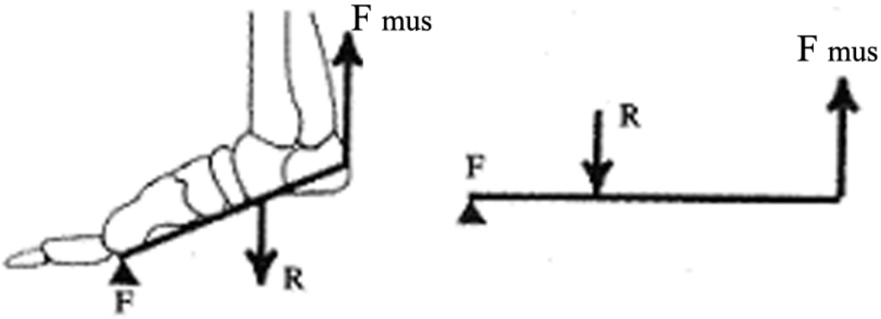


Figure. 3.48. Lever of foot.

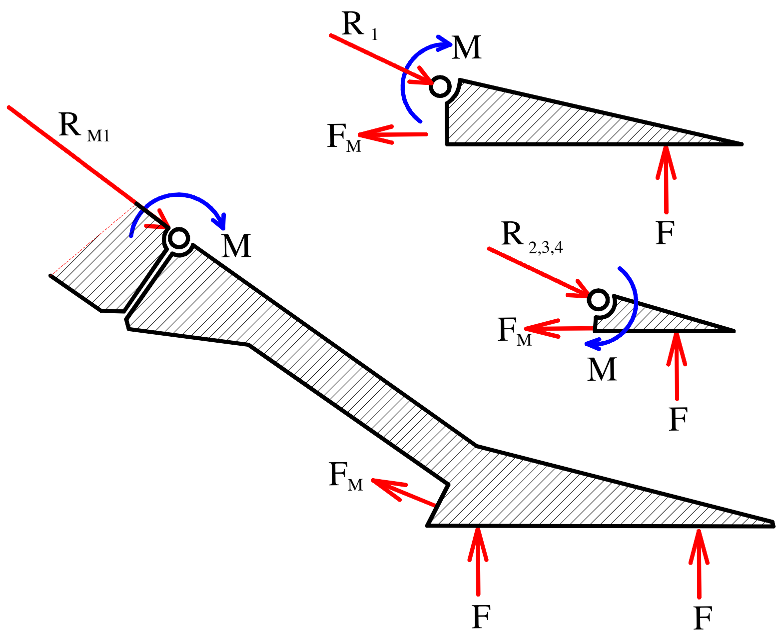


Figure. 3.49. Moments of Joints

$$M\ joint = MA.\ F\ muscle$$

$$M\ joint = L.\ F\ muscle$$

3.4. Footwear Design Faultiest and its Effects to Human Performance

The trouble-makers:

- the elevated shoe heel and shoe shank,
- crooked last,
- too much toe spring,
- concave last bottom,
- limited shoe and foot flexibility, etc.
- looseness and tightness of footwear
- flex line faultiest

These factors are force and changes the normal positions, or the normal share of weight-bearing loads. The amount and manner of these changes depends upon the degree of the underlying shoe faults.Their effects are:

- The body biomechanics change.
  - Gait Cycle changes.
  - Heel Strike Changes
  - The body column (Postural Alignment) and equilibrium changes.
- Then foot structure and working system changes.
  - Planter Fascia Shortening
  - Archilles Tendon Shortening.
  - Sustentaculum Tali Angle changing.
- The Tread Surface Being Reduced.
  - Weight and pressure distribution changes.

<u>High Heels</u>

Figure. 3.50. High heeled shoes

In order to satisfy their desire to be more beautiful, women started to wear high-heeled shoes (Linder and Saltzman, 1998). However, there are consequent negative side effects, such as **sprained ankles** (Nieto and Nahigian, 1975), **lower back pain**, due to increased **spinal curvature**, and **leg pain**, due to **added weight placed on the toes** (Jang and Kim, 1998; Yoe, 1994; Hyun and Kim, 1997), **shortened Achilles tendon** (Scholl, 1931), **increased oxygen consumption** (Mathews and Wooten, 1963; Ebbeling et al., 1994), **decreased stride length** (Adrian and Karpovitch, 1965; de Lateur et al., 1991) and **other changes in the gait pattern** (Gastwirth et al., 1991), **walking speed and mobility** (Murray et al., 1970; Alexsander, 1992) and even, potentially, an increased predisposition toward degenerative osteoarthritis in the knee (Kerrigan et al., 1998). Previous clinical research has showed that the height of a heel directly impacts the **lumber spine** as well as other parts of a body (Opila-Correia, 1990; Yoo, 1997).

Any elevated heel under a shoe automatically initiates an altered series of foot and body biomechanics. Standing barefoot, the falling line of body weight normally forms a perpendicular, a 90-degree angle with the 180-degree angle of the foot's plantar surface. Body weight is distributed equally between heel and fore-foot. The moment any heel elevation, even the most minimal, is applied to the footwear, the normal perpendicular of the body column changes. Therefore, falling line of body weight alters according to heel height. The higher the heel the greater the body column changes. On a two-inch heel, were the body a rigid column and forced to tilt forward, the angle would be reduced to seventy degrees, and to fifty-five degrees on a three-inch heel. Thus, for the body to maintain an erect position, a whole series of joint adjustments (ankle, knee, hip, spine, head) are required to regain and retain the erect stance.

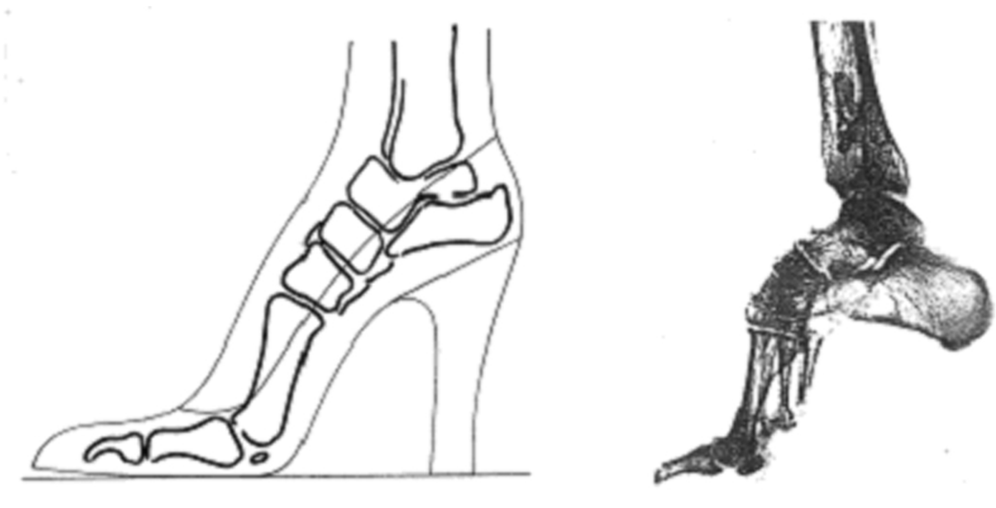


Figure. 3.51. Skeleton foot in modern high-heel shoe with anatomical position (right) much like that of Chinese bound foot.

1. If the body column was a single, unjointed column, then even a one-inch heel under the foot could cause the rigid body column to tilt forward or even fall. Like the Leaning Tower of Pisa, only a few inches tilt at the bottom results in a lean of several feet at the top. (Fig. 24) Some women in elevated heels maintain the 90-degree angle by keeping the knees “locked” with each step. But most allow the lower leg and knee to angulate. A profile view of the gait quickly reveals this. The result: body weight is no longer falling normally onto the foot, but is moved forward onto the forefoot.

Figure. 3.52. High-heeled footwear affect of lumbar flexion angle (Lee at al., 2001)

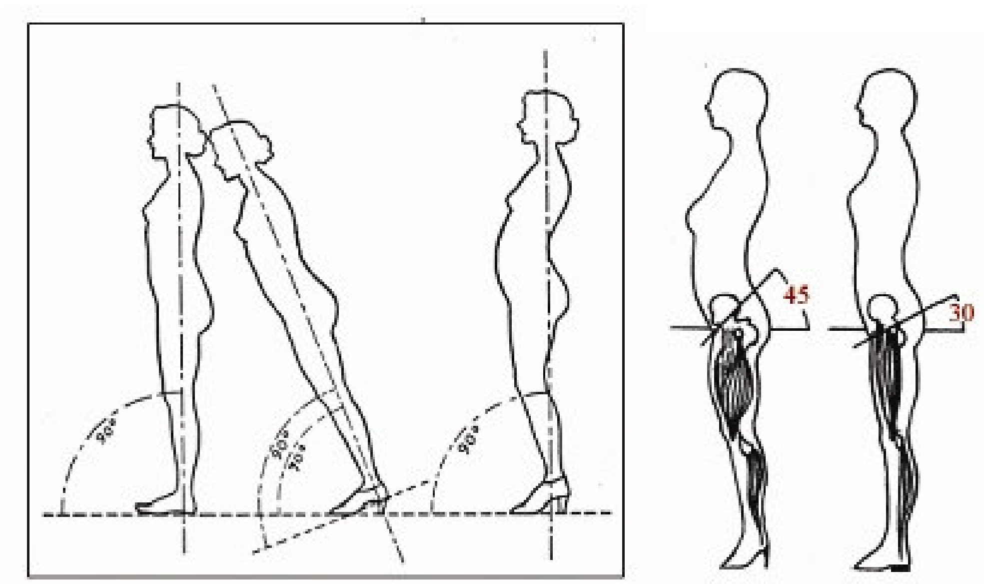


Figure. 3.53 Foot fault; natural posture (left) is tilted 20 degrees by shoes forcing the body to adopt poor posture (right) to regain erect stance, column makes “adjustments” to create new body profile with a 45 degree pelvis angle (Picture credit: Podiatry management)

Thanks to the body column is a series of adaptable joints the body column sections make "adjustments" to maintain its erect stance. Because the angle of foot makes the body column tilts forward. **Body Balance**

2. The other effect of height heel is the fascia's becoming permanently shortened for the habitual wearers of medium to higher heels. So the planter fascia becomes more vulnerable to strain or tearing when lower heels are worn.

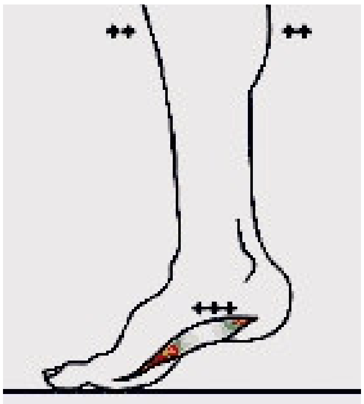


Figure. 3.54. The main affect of interaction between elevated shoe heels, low to high, and plantar fasciitis.

3. The line of falling body weight both in standing and walking, resulting in shifts in the path of weight distribution throughout the foot.

4. The muscles and ligaments associated with the body column and foot system must also make compensatory changes. Considering that the "simple" act of walking involves half the body's 650 muscles and 208 bones, the number of automatic "adjustments" is enormous. Inevitably the result is the most commonly leg and back aches and, of course, foot aches.

5. Wearing footwear with heels three-eighths to one-half inches in height causes shortened achilles tendon. (Willian A. Rossi., Footwar; The Primary Cause of Disorders, S:132)

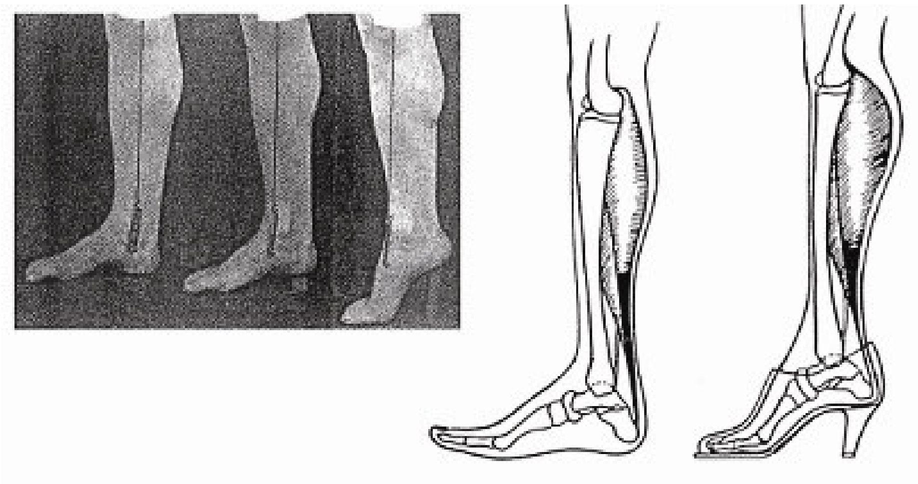


Figure. 3.55. Contrasting effect of elevated heel on foot. Achilles tendon and calf muscles.

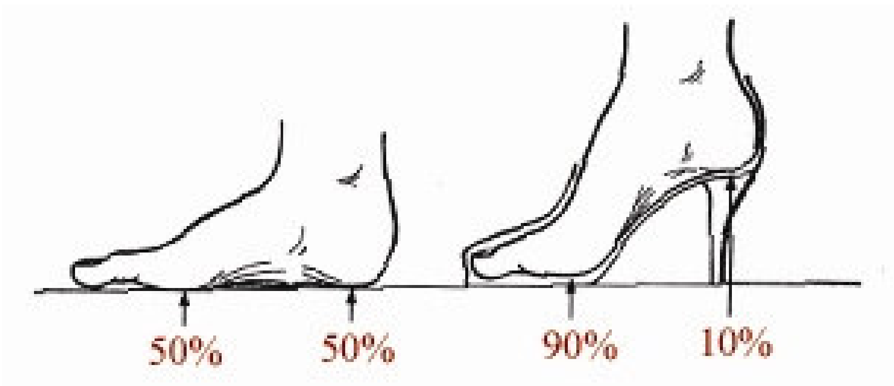


Figure. 3.56. Weight distribution on foot in standing, barefoot versus high heel. Left, barefoot, weight shared equally on heel and ball; right, on 3-inchheelweight shared 10% on heel, 90 % on ball

Figure. 3.57. Extremely high heeled shoes

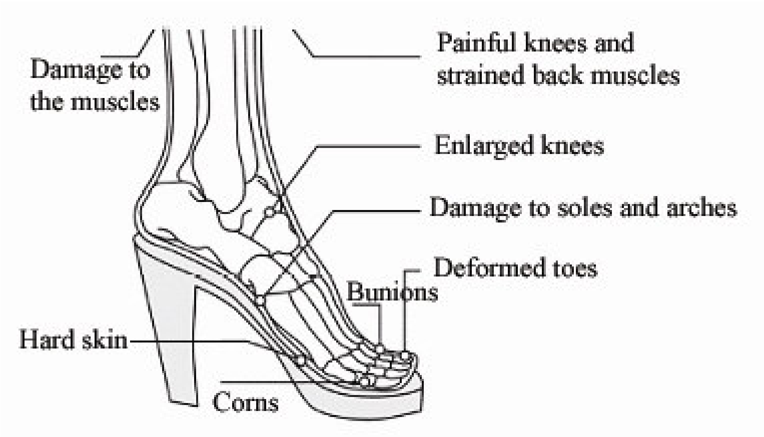


Figure. 3.58 Effect of high heel shoes functioning of foot (Current Orthopaedics, 2002, p.170)

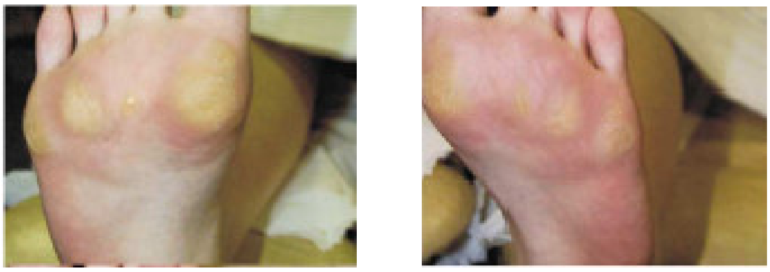


Figure. 3.59. High heel caused foot disorder

6. <u>The Sustentaculum Tali:</u> The sustentaculum tali is 180 degree plane on the human foot to maintain an erect posture in walking. It is one of the most important elements of the long arch, and in enabling the foot's whole elastic system to function efficiently in gait. (Fig. 3.56) If the direction of this line changes because of elevated shoe heel plus the crooked shoe last, body balance changes. (Rossi., 2001, p. 134) It is vulnerable and influenced by the biomechanics of the shoes beneath it.
7.

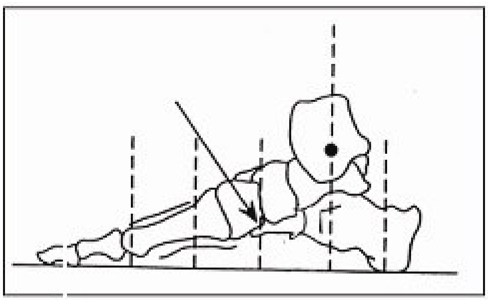


Figure. 3.60. A perpendicular line of weight falling from the body column to the foot passes exactly through the center of the sustentaculum tali.

8. Heel strike changes. Under these conditions the step sequence is no longer heel-to-ball-to toes and push-off, as with the bare foot. On heels two or more inches in height little weight is borne by the heel of the foot, and step push-off is almost wholly from the ball. (Rossi., 2001, p. 133)

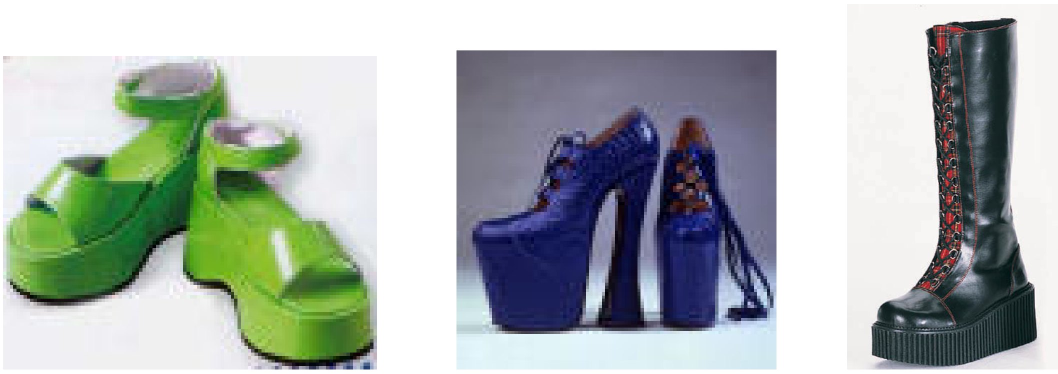


Figure. 3.61. Not flexible platform shoes changes the heel strike

9. The Tread Surface Reduced: One of the most insidious of the numerous negative effects of footwear on gait is loss of foot tread surface. With the shod foot, 50 to 65 percent of the foot's natural tread surface is lost. A footprint will show 50 to 70 percent greater tread surface.

Under these conditions the result is an unbalanced foot receiving excessive strain on small portions receiving the brunt of the wear. It is impossible for such a foot to "walk right," meaning with natural function and full tread. How a shoe treads (this is influenced by the last, heel, sole, construction and design or style) obviously influences how the foot treads. If there is a foot imbalance resulting from improper shoe tread, the consequence is lessening of shoe comfort. The combination of the elevated shoe heel, elevated shoe shank at mid-foot, toe spring, and concave shoe bottom at the ball, together force enormous changes in the plantar tread surface, which is in turn generate shifts in the gait pattern and weight distribution over rearfoot and fore-foot and also alters the normal alignment or the natural stance of the foot.

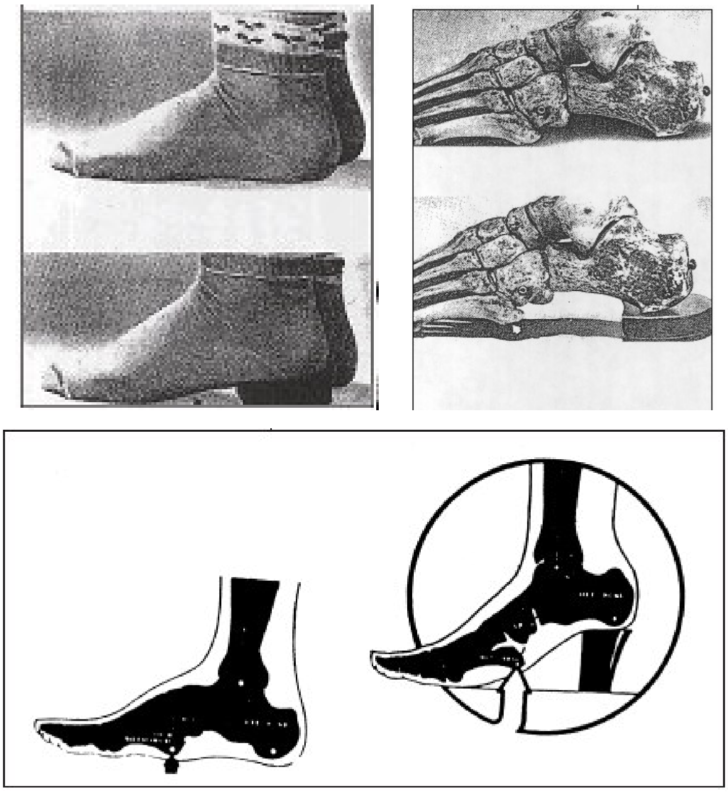


Figure. 3.62. Left, base of fifth ray as an important weight bearing element. Right, base of ray off ground by shoe heel, eliminating weight bearing function. Normal weight-load here now imposed on other parts of foot.

Normal footprints showing large tread area. Right, tread area on average shoe reduced by 60-80 percent as a result of faulty last design, elevated shoe heel and shank, toe spring, etc.

10. Gait Cycle Changes: Natural gait is impossible when most people wear faulty shoes.

    There are three main reasons for this;

    1) The shoe's elevated heel;

    2) The faulty design of the last as found in most footwear;

    3) Construction and design faults found in the shoe itself (components, materials, shoe weight, limited flexibility, toe spring, etc.).

    Separately or together they influence how the foot functions inside the shoe and how the individual walks. Whereas under these conditions the foot cannot function in a fully natural manner, the gait, so totally dependent on the foot, also cannot be its natural self.

11. The Momentum of foot changes:

On medium to higher heels, due to the reduced base of the heel top-lift, the line of falling weight shifts, causing a wobbling of the less-secure ankle, which tilts medially. The shift in the body's center of gravity alters the equilibrium of the body column and prevents a natural step sequence.

Figure. 3.63. Small base (toplift) of 2-inch heel diminishes gait stability as foot pronates.

12. Lacking of Enough Toe Space: Pointed Toes or Faulty Last

It is a dogma of footwear fashion that thin, curvy medium to higher heels are always accompanied by pointed-toe shoe styles. Higher heels and broad or round toes are esthetically incompatible. It is only when the higher heel is chunky or heavy looking that the round or broad toe is acceptable. This classic high heel has a double-barreled effect, front and rear. Pointed-toe footwear is mainly at fault for the toe squeeze, but the faulty design of the last. Were pointed-toe, high-heel footwear made on better engineered lasts, the common distresses of such footwear would be eliminated. While it would not transform the shoe into a "comfort" shoe, it would be considerably more comfortable to wear than such footwear of the past and present.

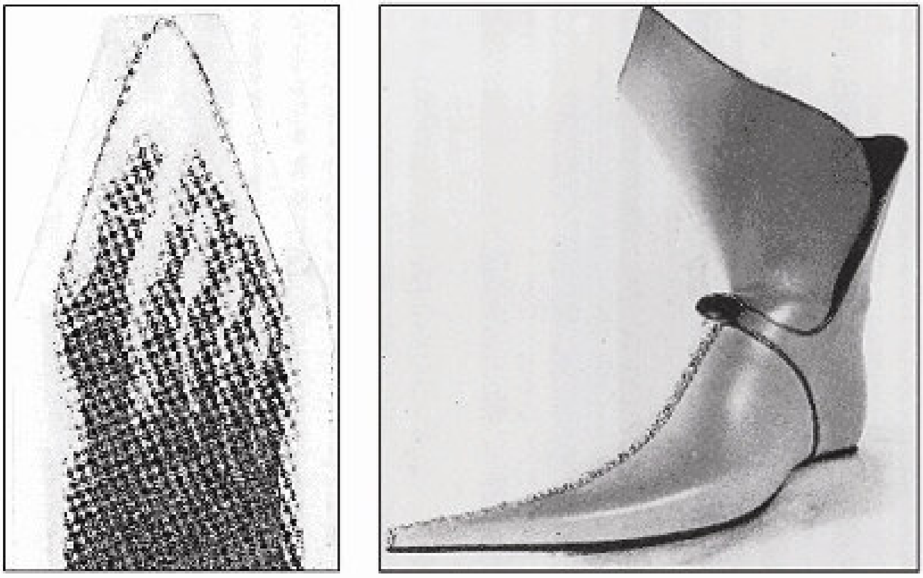


Figure. 3.64. Deformed position of toes inside shoe with pointed toes and faulty last.

Figure. 3.65. Foot disorders

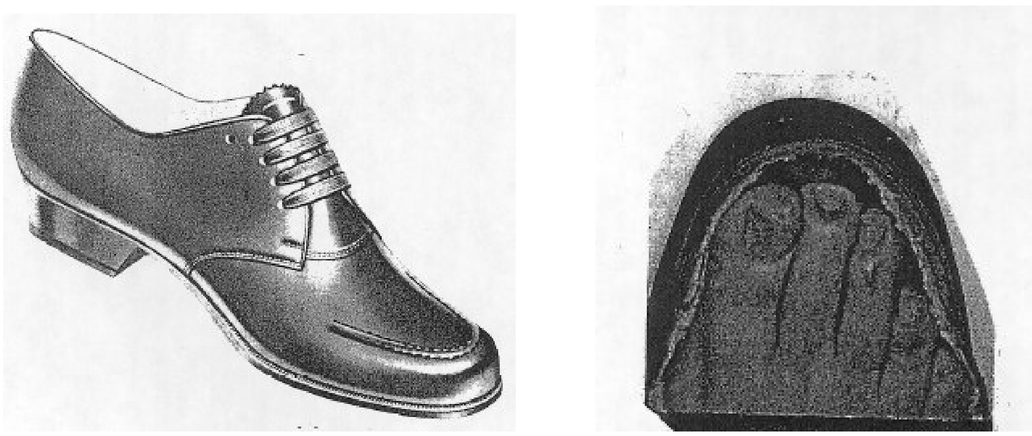


Figure. 3.66. Faulty last design squeezes toes much like pointed-toe shoes.

There are several built-in design faults with most commercial lasts, but two in particular have relevant influence on gait.

1. Almost all shoe lasts are designed with inflare, whereas almost all feet are designed on a straight axis. This automatically creates a biomechanical conflict between foot and last (or shoe). This is the prime reason why virtually all shoes go out of shape with wear—because foot and shoe are mismatched. If, because of this conflict, the foot cannot function naturally inside the shoe, it cannot take a normal or natural step.
2. A second common fault of the last is the concavity at most lasts under and across the ball, which is automatically "inherited" by the shoe at the same site.

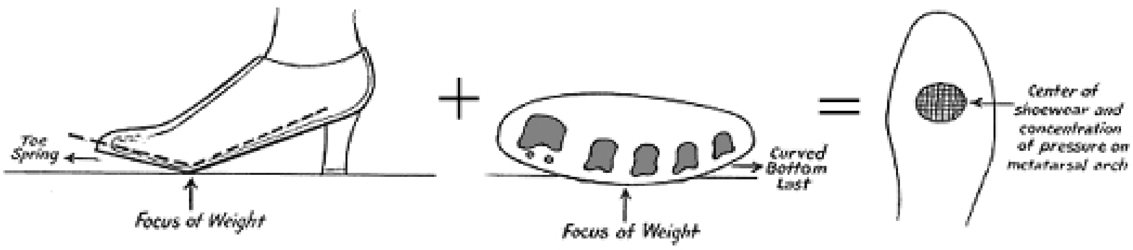


Figure. 3.67. Top, apex of heel wedge angle and toe spring angle focuses weight at "dagger point" at ball; center, concave bottom last across ball further stress weight (pressure) focus on the middle metatarsals; bottom, tread surface concentrated on center of ball.

Figure. 3.68. Left, concave-bottom last (common) causing "falling" of middle metatarsal heads; right, flat bottom last (rare) allowing normal flat plane of metatarsal heads.

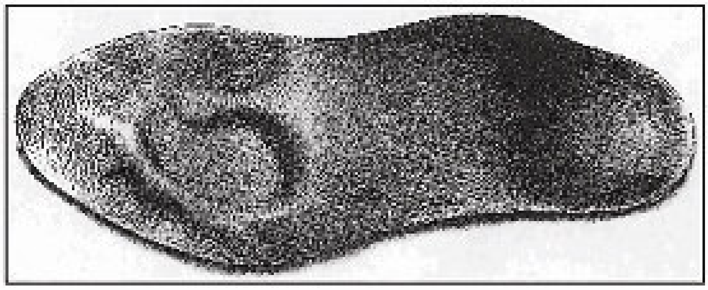


Figure. 3.69. Insole depression under ball caused by compression of bottom filler and concave bottom of last.

Figure. 3.70. Fit inflare; whole lateral rim of metatarsals and digits are pushed in by the shoe, depriving them of normal function.

Snug or narrow fit (tightness) has a negative effect on gait because the natural expansion of the foot with each weight-bearing step is prevented. The normal plantar surface at the ball is diminished, affecting foot balance and the security of the gait itself. Improper shoe fit can limit joint movement, constrict circulation, and decrease proprioceptive input and alter gait. (Janisse, 1992, p.257)

CHAPTER 4

THE FUNDEMENTAL DESIGN CRITERIA FOR FOOTWEAR

4.1. Anthropometric Factors in Footwear Design

4.1.1. Footwear Sizing System

The footwear business has had a standard measure since the eighteenth century, the stitch measure. Craftsmen of the various regions had agreed to adopt as a designation of length. But until the mass production of shoes started at the end of the nineteenth century, the shoe size, designation the length of the shoe, was of no special importance. (Vass & Molnar, 1999, p:26)

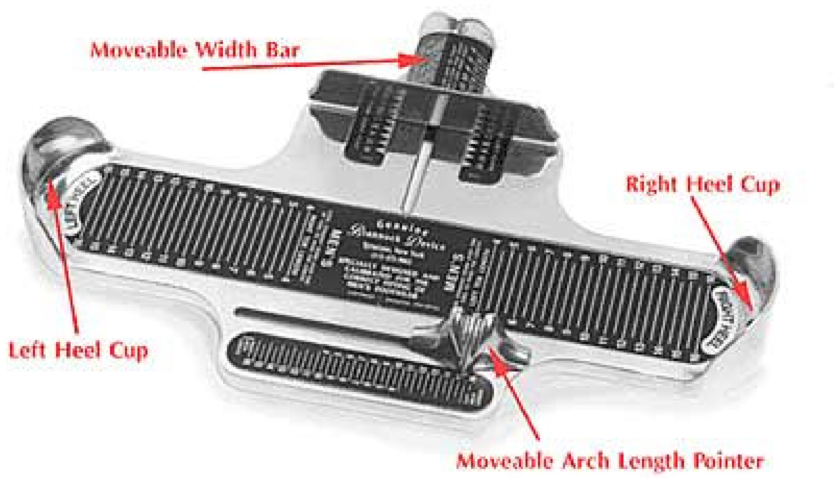


Figure. 4.1. 2D Size Device

<u>French Sizes</u>

The use of the Parisian stitch just over **a quarter inch** (6.667 mm) long became widespread in Europe at the time of Napoleon (the beginning of the eighteenth century). But this measure was soon found to be insufficiently precise, and half-sizes were introduced in some countries. French size 40.5, for example is equivalent to about 11 inches (27).

English Sizes

In this system three grains of barley were equal to one inch (2.54 cm) and 12 inches equal to one foot (30.48 cm). So the standard measure of English shoe sizes is the length of a grain of a barley, that is one-third of an inch (0.846 cm). Half sizes also came to be used: 1 half-size = on-sixth of an inch (0.423 cm).

English shoe sizes for adults start at size 1, some eight-and-two-thirds inches (22 cm) long (equivalent to the French size 33). This length is increased by the requisite one-third of an inch for each size. The French system 42, for example, is roughly equal to metric size 28 and English size 8: 8 inches + (8 x *1/3*) = 10,67 inches (22 cm + (8 x 0.846) = 28.77 cm

American Sizes (USA)

The American unit, 1 size, is the same as the English, but the difference lies in the starting-points: in the American system the scale begins one-twelfth of an inch (2.116 mm) lower, which means that each American size covers a rather lower range than its English equivalent.

Metric or Mondopoint Sizes

The metric system is just as suitable for measuring the length of a foot or a shoe as for anything else, and the metric scale does indeed exist. But foot some reason it has never caught on as a designation of shoe sizes.

Metric	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36						
French Size	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
English Size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17				
	1 1/2	2 1/2	3 1/2	4 1/2	5 1/2	6 1/2	7 1/2	8 1/2	9 1/2	10 1/2	11 1/2	12 1/2	13 1/2	14 1/2	15 1/2	16 1/2	17 1/2				
USA Size	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18			
	1 1/2	2 1/2	3 1/2	4 1/2	5 1/2	6 1/2	7 1/2	8 1/2	9 1/2	10 1/2	11 1/2	12 1/2	13 1/2	14 1/2	15 1/2	16 1/2	17 1/2				

Table 4.1. Footwear sizing systems

4.1.2. 2D Measuring Methods

Size is an obvious factor. Shoe size must conform to foot size. The footwear sizing system is primarily based on foot length and is sometimes based on foot length and foot width. Footwear manufacturers however, resort to using length, width and girth measures, and a mismatch in any dimension generally results in poor fitting. In order for a shoe to fit a person's foot, fitting ought to be more than just length and width. Proper fit means achieving the right fit in terms of heel width, heel-to-ball length, arch fit, and top line fit, toe box space, total volume space, and so on. In other word proper fit requires a good understanding of the total 3D shape.

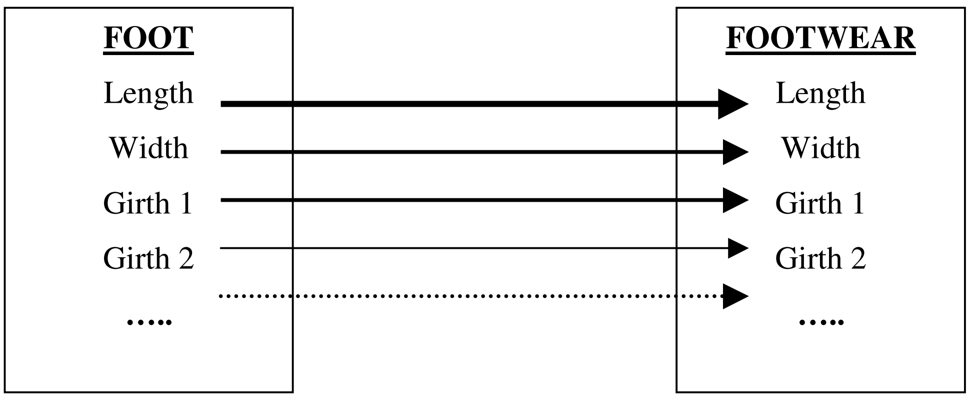


Table. 4.2. Foot to shoe mapping for fitting feet

Shoe fit is a combination of size and shape characteristics. Proper shoe size accommodates the first metatarsophalangeal (MTP) joint in the widest part of the shoe. This is termed a "ball fit," and allows for correct function of the MTP joints. Since toe lengths vary greatly, a shoe fitted by overall length may be under-sized. All fitting and sizing must be done weight-bearing, because the foot lengthens and widens under physiologic loading as the day progresses. When standing, there should be 3/8" to 1/2" from the longest toe to the end of the shoe (Janisse, 1992, pp: 257-262). One important study found that 88% of women tested were wearing shoes that were too small for their feet (Frey, 1993, p: 78-81).

Characteristic paramaters for the shape of the last;

- Length of the foot,
- Width of the foot,
- Circumference of the ball of the foot.(Anil et al. 1997)

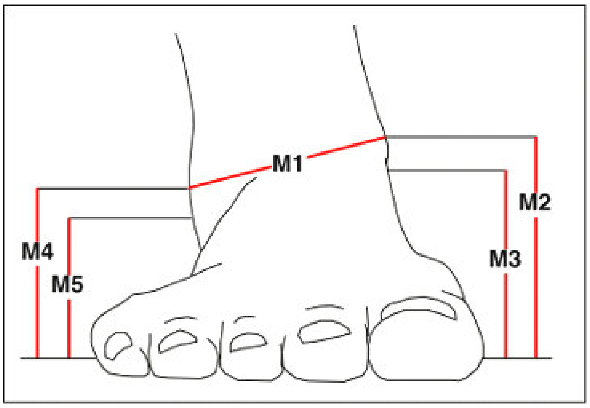


Figure. 4.2. Frontal view of foot

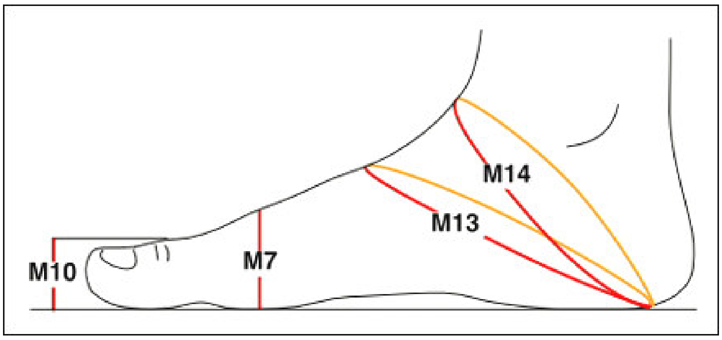


Figure. 4.3. Medial view of foot

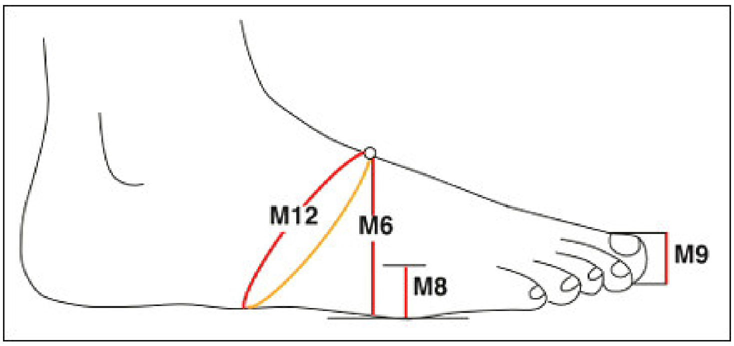


Figure. 4.4. Lateral view of foot

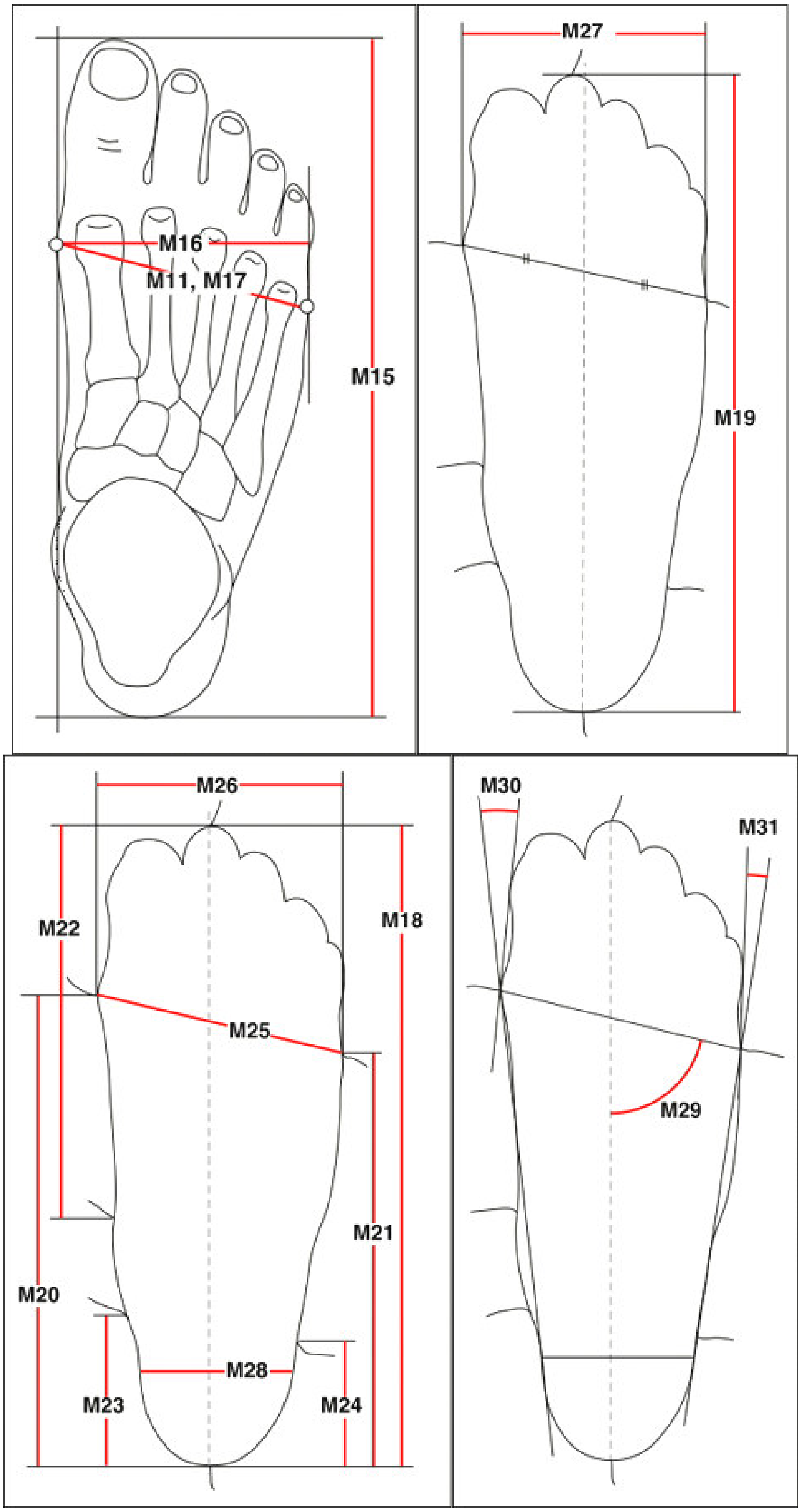


Figure. 4.5. Plans of foot

	ID	Measurement item	Comment
1	M1□@	Bimalleolar breadth	Figure M1
2	M2	Medial malleolus height	Figure M1
3	M3	Sphyrion height	Figure M1
4	M4	Lateral malleolus height	Figure M1
5	M5	Sphyrion fibulare height	Figure M1
6	M6	Dorsal arch height	Figure M2
7	M7	Ball height	Figure M3
8	M8	Outside ball height	Figure M2
9	M9	Great toe tip height	Figure M2
10	M10	Great toe height	Figure M3
11	M11	Foot circumference	Figure M4
12	M12	Instep circumference	Figure M2
13	M13	Heel circumference	Figure M3
14	M14	Diagonal ankle circumference	Figure M3
15	M15	Foot length	Figure M4
16	M16	Foot breadth	Figure M4
17	M17	Foot breadth, diagonal	Figure M4
18	M18	Foot length (JLIA)	Figure M5
19	M19	Foot length (DIN)	Figure M6
20	M20	Instep length	Figure M5
21	M21	Fibular instep length	Figure M5
22	M22	Back of foot length	Figure M5
23	M23	Heel to medial malleolus	Figure M5
24	M24	Heel to lateral malleolus	Figure M5
25	M25	Foot breadth, diagonal (JLIA)	Figure M5
26	M26	Ball breadth	Figure M5
27	M27	Foot breadth (DIN)	Figure M6
28	M28	Heel breadth	Figure M5
29	M29	Ball flex angle	Figure M7
30	M30	Toe I angle	Figure M7
31	M31	Toe V angle	Figure M7

Table 4.3. Foot measurements

4.1.3. The Landmarking of Foot

To attempt to maintain the feet in a neutral posture by designing footwear with a shape similar to the feet to prevent the consumers to experience the problems developing and fitting the right footwear. This is an anthropometrical solution with drawing the subject weight, height, foot length and foot width outlines. So some landmarks that are studied and marked on each of the two-dimensional foot outlines. (Goonetilleke, Ergonomics, 2003, Vol. 46, No.4) The acceptable positive error (indicator of looseness) and negative error (an indicator of tightness) is subjective and should be quantified. For footwear design to find the right foot outline as an important component for footwear functionality and fitting using some critical landmarks. The selected landmarks can be used as a lower bound so that designers and last makers can provide well fitting shoes.

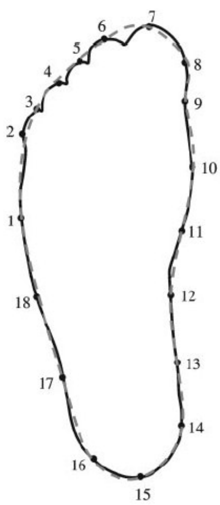


Figure. 4.6. Critical landmarks

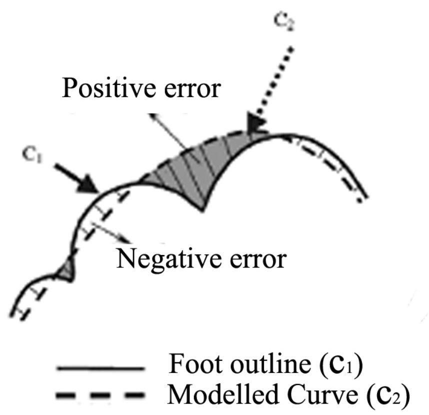


Figure. 4.7. Foot Landmarking (Ho, 1998, pp.367)

By aligning the foot outline and the shoe outline in the heel area, the fit mismatch can be quantified.

(a) (b) (c)

Figure. 4.8. Possibilities for "positioning" a foot inside a shoe. (a) Matching backseam (b) Matching midfoot height (c) Tongue restriction on forward movement

If the foot is within the boundaries of the shot, the shoe can be said to be “loose” in the area. Tightness results when the foot outline is outside the shoe boundary. The differences between the shoe outline and the foot outline were quantified using the dimensional difference (“error”) as shown in (Fig. 4.7.). Error was measured as the normal distance from any point on the foot to the shoe outline**. Tightness** is a **negative error** and **looseness** is a **positive-error.** The variation in error for a good fitting shoe and poorly fitting shoe is shown in (Fig. 4.8.). The effects of flare arc very clear from (Fig. 4.9.).

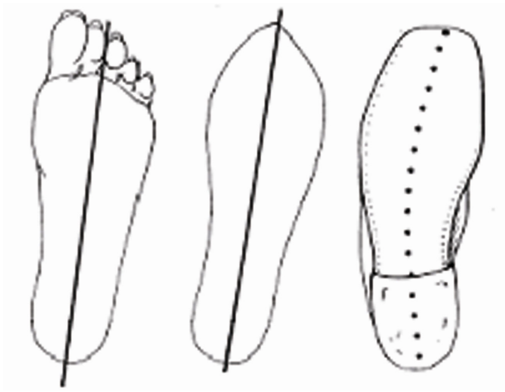


Figure. 4.9. Left, normal straight axis of foot, divided into two equal longitudinal halves; center, corresponding straight-axis last, right, inflare last, typical of most, conflicts with straight-axis foot.

When the shoe heel region is aligned with the heel, mismatches in the shape between the shoe and the foot requires the shoe or foot to deform. If the shoe does not match the foot, the foot will articulate in the forefoot area in order to “sit” inside the shoe.

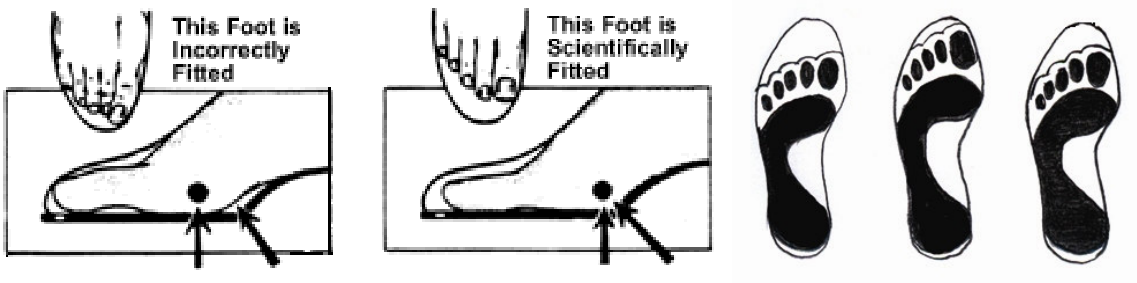


Figure. 4.10. Mismatched flare will always result in an excess level of error in the metatarsal region.(Goonetilleke R., et al., 2003, p. 369)

4.1.4. Computer Based 3D Measuring Methods

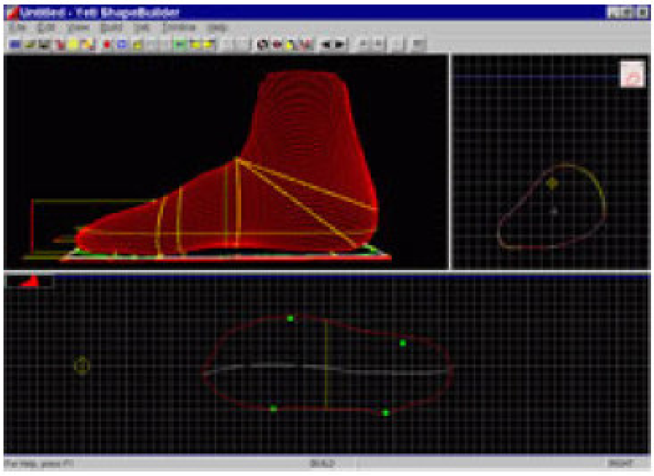


Figure. 4.11. **3D** visualization CAD system

With the advent of powerful 3D visualization CAD system, modeling and scanning techniques, there is an increasing need for tools supporting the automatic search for objects in 3D archives. The geometric approach adaptation could be possible to 3D object comparison to an industrial application of finding the best fitting shoe given a 3D foot scan. The geometric similarity estimation is well suited for search among objects with relatively stiff structure, in the presented setting we also have to cope with the reconstruction of 3D models from point clouds, and the definition of location dependent weighting based on anatomic properties of the foot. The basic idea of the solution is to compare the lasts **(positive and negative error of foot)** which were used to manufacture the shoes and the scanned feet of the clients.

- 3D systems enable the last and design to be viewed from any perspective and several angles even simultaneously.
- Complex shapes can be generated, both speedily and accurately, from the 3D computer representation of the appropriate last.

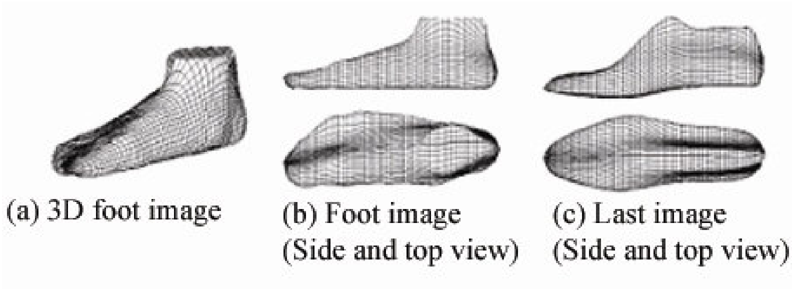


Figure. 4.12. Scanned images of a foot and a last. The apparent mismatch in shape and size between the "irregular" foot and the regular-shaped last can be seen from (b) and (c) (Karwowski et al., 2001).

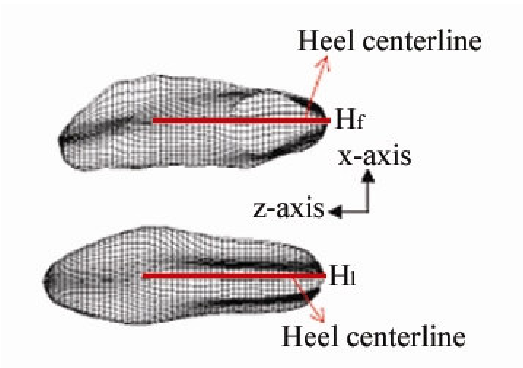


Figure. 4.13. Heel center line of foot and last.Hl and Hf are the heel points of the last and foot respectively.

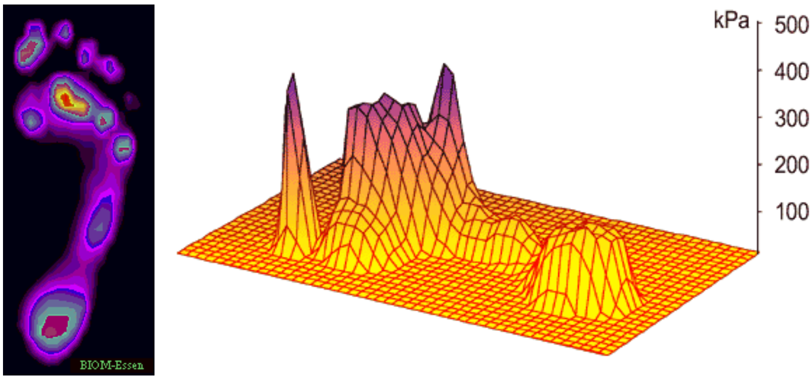
3D geometric comparison

In this section we first outline our original algorithm for similarity estimation, and then we show how to modify it to tackle the problem of finding the best fitting shoes.

The outline of the algorithm is as follows:

1. **Pose Estimation:** As already indicated, the foot and the last are already approximately aligned after the scanning process. However, in order to get an optimal pose estimation, we use the principal axes of both objects to align them optimally.

2. **Projection of the weight function:** In this step, we project the weight function from the last to the foot as described in the next subsection – this way the areas with larger relevance will be taken into account with larger weights in the final error function.



Biom-Essen-Hennig

Figure. 4.14. Peak pressure wire frame diagram for a subject during walking

3. **Computation of geometric similarity:** The algorithm for similarity estimation is applied. As result we get an error measure for each foot-last pair, which can be used to establish an ordering of best matches.

Figure. 4.15. Last and foot intersection

4.1.5. Computer Aided Design in Shoe Industry

The software integrates a 3-dimensional image of the patient's foot, weight-bearing imprint information and medical requirements of the footwear into a computerized design process. Alternatively, designer use measurement and weight-bearing imprint information alone as a starting point to design a custom last. In either case, the design is fully controlled by the operator.

To prescribe the design of the insole; then, the simulation of the pressure distribution serves as an accompanying control of the design. Alternatively, the simulation may be performed iteratively in order to automatically find an ``optimized'' design. With respect to feet, many sources of foot anthropometry are available (e.g., Randall et al., 1951;Jeffery and Thurstone, 1955).

4.1.5.1. Matching of last and foot

After the foot and last were matched along the heel centerline, the foot shape was adjusted" along the y direction (Figure 3a, b) to account for the toe-spring and heel height of the last (Figure 3c). The foot and last after matching are shown in Figure 3d.

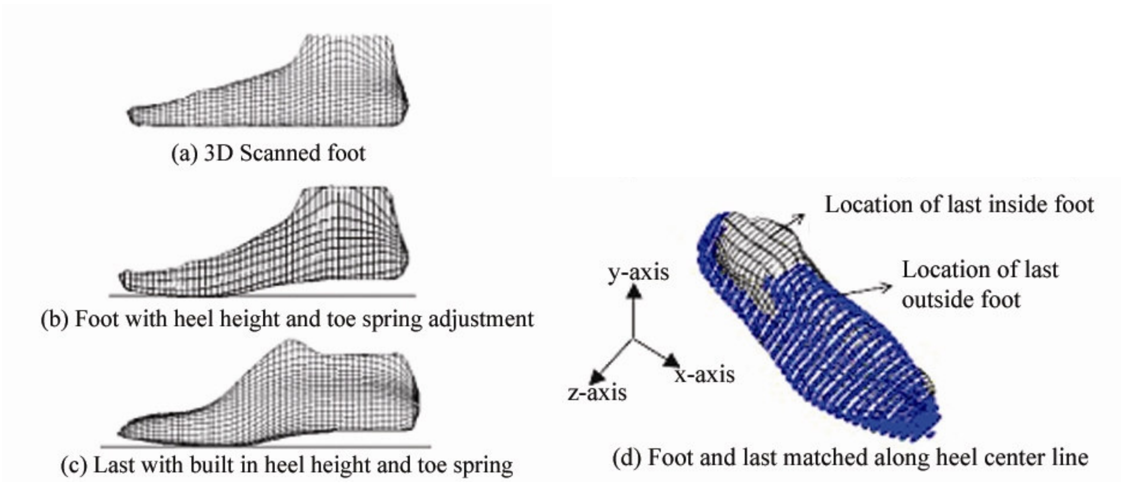


Figure. 4.16. Foot and last matching

Feet are somewhat irregular in shape and footwear is designed to have smooth contours (Adrian 1991, Anzelc 1994). So fitting footwear involves matching an irregular shape to a regular shaped object. Thus, it would be useful if the correct support points on the foot could be located, so that they could match with those in the footwear. In this way, the rest of the foot and shoe could have some additional clearance to provide for the necessary expansion of the foot. By `holding' the foot at the proper points or by reducing the degrees of the freedom of the foot within the shoe, the functionality of the foot might also improve. (Goonetilleke, Ergonomics, 2003, Vol. 46, No.4, pp.378)

Important aspects of shoe design include the last of the shoe and how the shoe is lasted. Because, as described above the last is a component of footwear only used in design and the manufacturing process. The last is usually designed to reflect the shape of the foot. However, as we all know, no two pair of feet is identical. In fact, each foot is slightly different, unique like our fingerprints. Actually, this last represents the shoe designer's idea of what the average foot is shaped like.

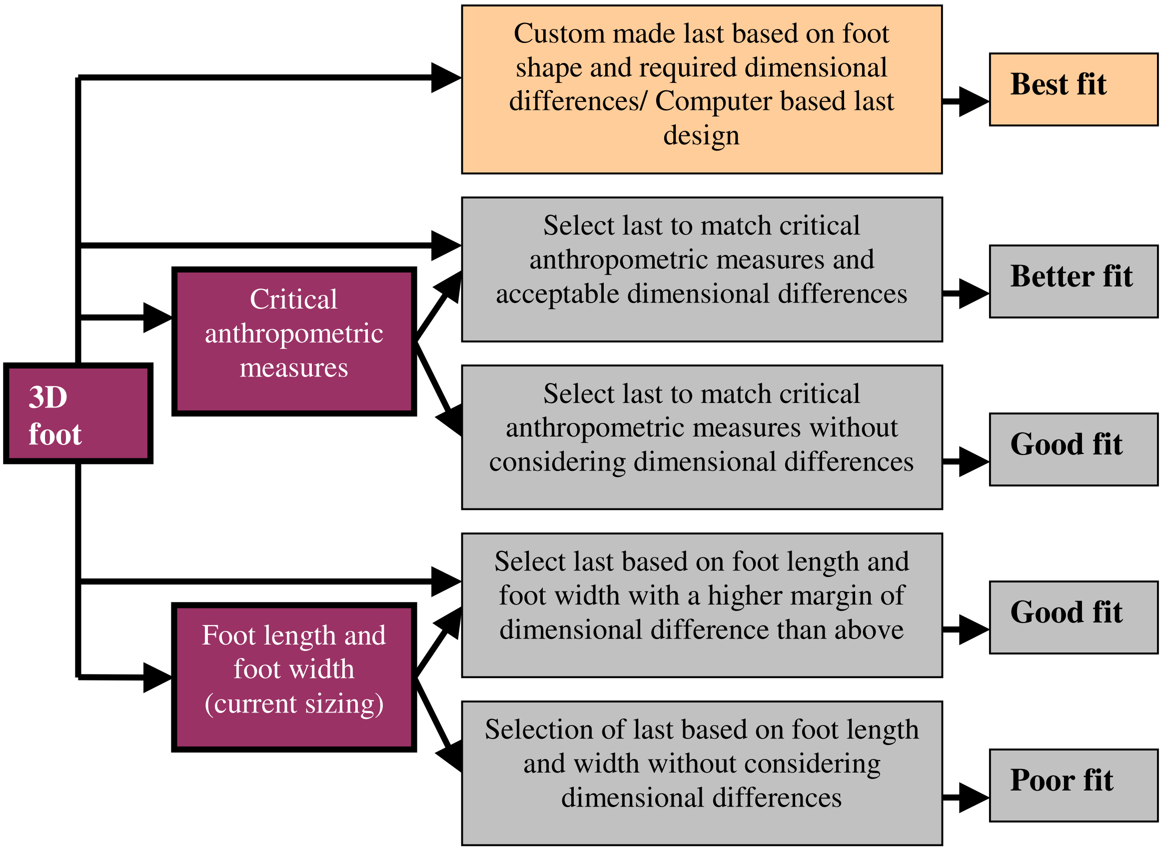


Figure. 4.17. Last selection to archive different degrees of fit

4.2. Physical Factors in Footwear Design

The main features of shoe design that are implicated as playing a role in postural stability are heel height, the cushioning properties of the midsole, and the slip resistance of the outersole, weight, durability, flexibility, the tread surface, traction. Each of the design components that may affect postural stability is discussed in more detail in the following sections.

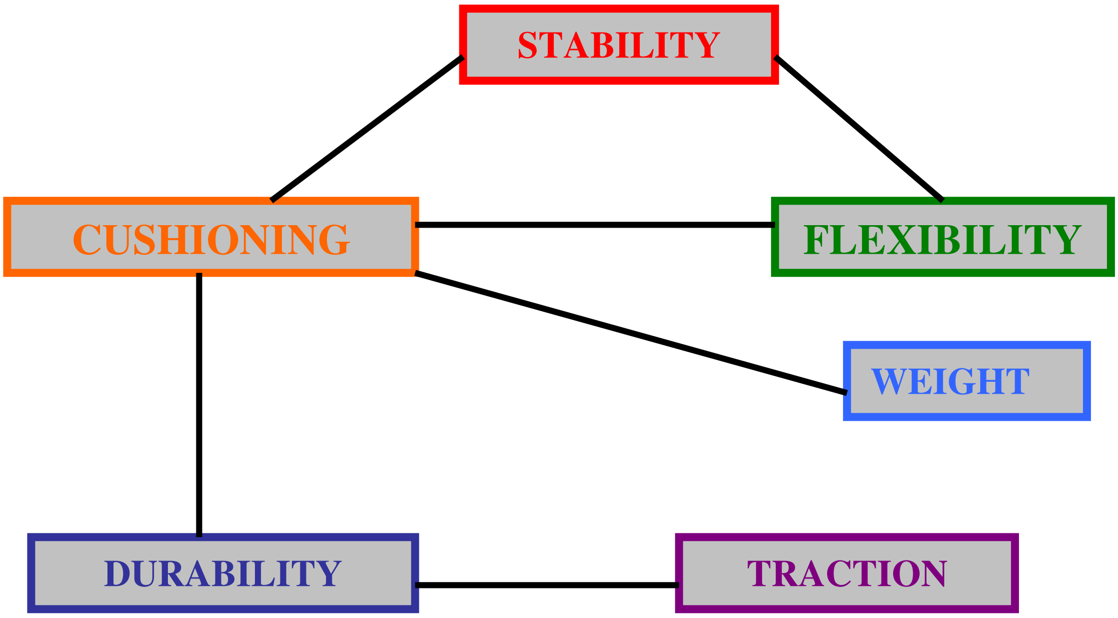


Figure. 4.18. Design Interaction

Flexibility refers to the shoe's pliancy - its ability to yield and bend. Depending on the sport, flexibility is built in or minimized in a shoe. For example, a football place-kicker requires a stiff area in the forefoot (the area between the ball of the foot and the toes), while a running shoe deforms with the human foot's natural flex lines. There are tradeoffs. A highly flexible shoe can jeopardize stability and durability. As you can imagine, the cushioning system used in the midsole may compromise flexibility. However, athletic shoe scientists and designers endeavor to meld flexibility into the shoe's midsole and outsole along the foot's natural flex lines.

On taking a step, the foot normally flexes approximately 54 degrees at the ball on the bare foot (Fig.20). But all shoes flex 30 to 80 percent less than normal at the ball. (Fig. 20) This obviously creates flex resistance for the foot by the shoe. The foot must now work harder to take each of its approximately eight thousand daily steps. The required extra energy imposes undue strain and fatigue on the foot.

Why are most shoes inflexible? First, the average shoe bottom consists of several layers of materials or components: outsole, midsole, insole, sock liner, filler materials, cushioning. This multiple-layered sandwich poses a formidable challenge to bending or flexing. Second, many types of footwear—athletic, sneakers, work and outdoor boots, walking, casual, etc.—have thick soles which add further to inflexibility.

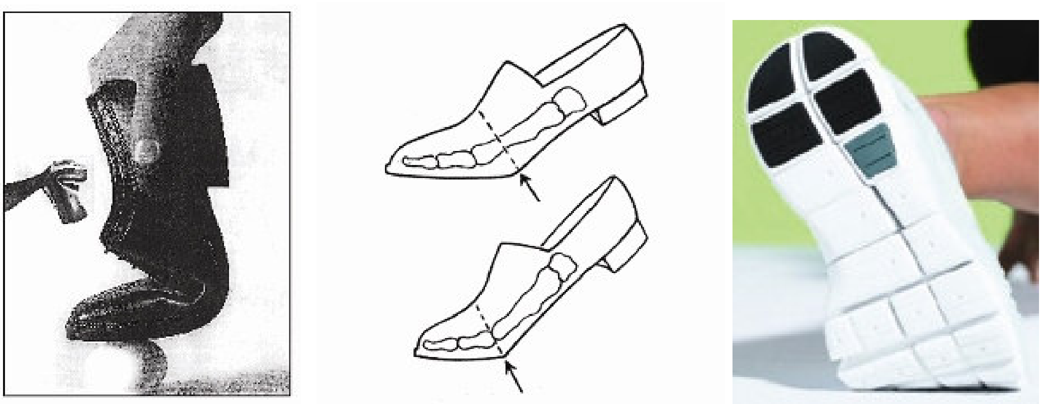


Figure. 4.19. Two views of deceptive shoe flexion. The flexion is behind, not at the ball.

“An average pair of feet flexes at the ball about 7,000 times a day. Whatever the degree of "flex resistance" by the shoe is the degree to which a work overload is imposed on the foot at the expense of comfort. Shoe flexibility involves the outsole, insole, upper materials, and the construction of the shoe.

Top, wrong shoe flexion, with bend behind ball; bottom, correct flexion at ball. The more inflexible the shoe, the more flat-footed the gait manner. With inflexible or semi-flexible shoes (which include most) the step push-off is almost wholly from the ball, thus fulfilling only half to three-fourths of the natural step sequence.

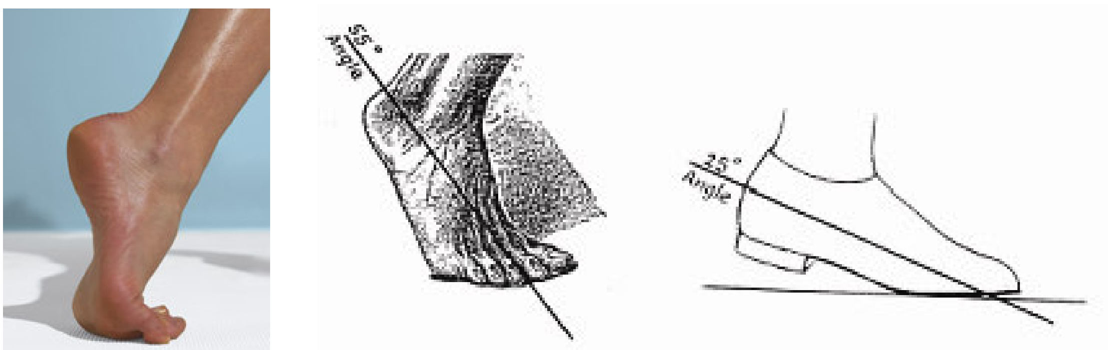


Figure. 4.20. Left, normal 55 degree angle of foot flexed for step pushoff; right, typical 25 degree flex angle of shoe, creating flex resistance and energy strain for the foot.

Weight is also important when designing a shoe based on foot biomechanics. An active person who weighs around 150 pounds and overpronates may not require as much stability from a specific shoe model as a heavier individual with a similar foot type. Although the actual biomechanical function of the foot may be similar, a shoe that offers a high degree of motion control may be too firm for a lighter active person and could result in overuse injuries.

A lightweight pair of 16 grams shoes amounts to a cumulative four *tons* of foot-lift load daily (16 grams times 6,000 foot-lift steps). If the shoes weigh 16 grams, daily foot-lift load is eight tons; 22 grams adds up to 11 tons a day. Every added four grams of shoe weight adds another one ton to foot-lift load. These foot lift loads impose an energy drain not only on the foot but the whole body. No footwear, with certain exceptions, should weigh more than 12 grams a pair for women, 16-18 grams for men. Excessive shoe weight forces an alteration of natural gait form. The drag effect and **energy drain of the shoes** creates alterations in the natural step sequence—a smooth, easy movement heel to lateral border to ball to toes is disrupted.

The heavier the shoe the more "foot-lift" work load on the foot, with consequent lessening of comfort. The issue of weight is very important. American army research has shown that wearing 1 kg on your feet makes you as tired as carrying 7 kg on your back (source lost). The reason is simple physics: the farther the load from the center of gravity, the heavier the energy and “lift” strain.

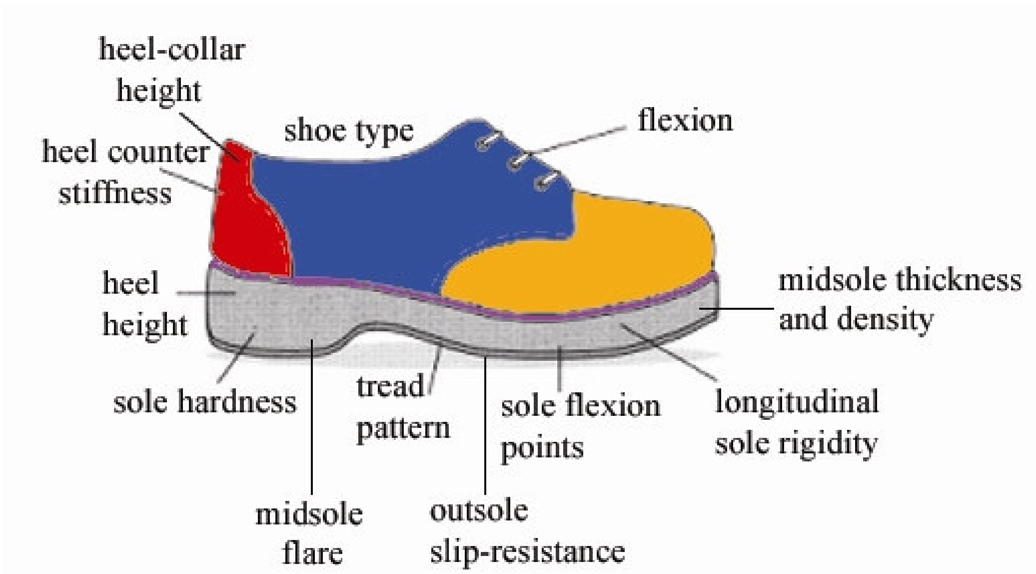


Figure. 4.21. Features of shoe design that are thought to affect postural stability.

4.2.1. Types of Lasts

A shoe (and the last or shoe mold) is characterized by its longitudinal "curvature" as being straight or curved (Cavanagh, 1980; Cheskin, 1987). The last shape determines many of the functional characteristics of the shoe and is often classified as being **straight, semicurved,** or **curved.**

Straight: The arch area is filled in for increased stability. People with flat feet and heavy heal strikers do well in shoes built on a straight last. A straight-lasted shoe is filled in on the inside or medial part of the shoe, which increases its stability and generally allows it to fit a flat arch better. (Holscher and Hu, 1976; Rossi, 1988).

Semi-curved: This last has a gentle arc from front to back. A semicurved last, designed for the average (normal) foot, has a small curve on the inside and is the best last shape for most fitness-minded individuals. The curvature of a semicurved last depends on the specific brand and model of the shoe.

Curved: As the name implies, the arc is greater than in the semi-curved last. (Goonetilleke&Luximon, 2003, p.370). It is designed for the high arch foot that underpronates. These shoes have a wider lateral aspect to provide stability. In addition to the curve in these shoes, the outside or lateral portion is wider, which provides forefoot stability for underpronation.

This type of shoe is usually reserved for faster runners. Faster runners are often midfoot strikers, which mean they land on the front part of their feet. Midfoot strikers with no previous history of injuries tend to run better in shoes built on a semicurved or curved last. (Cavanagh, 1980; Cheskin, 1987).

The amount of turn is characterized using a measure called flare. Today, identical left and right shoes are rarely seen even though they were common in the 19th century. Most shots have a 6-degree (Holscher and Ho, 1976) or 7 degree (Cheskin, 1987) flare angle.

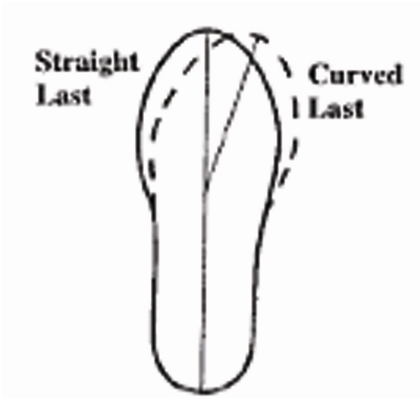


Figure. 4.22. Straight and curved last

In ergonomics, "neutral posture" is claimed to be essential to minimize overuse injuries (Putz-Anderson, 1988). An excessive flare or an insufficient flare in footwear will result in deviations from neutral postures.

4.2.2. Design Characteristics of Sole

It is important to capture the correct points on the foot for support. For example, the metatarso-phalangeal joint (MPJ) is important in the design of the flex groove so that the shoe flexes in the right place for good foot movement (Rossi and Tennant 2000). This means that the foot is held in the right places for proper functioning. Generally, the flex line of a shoe is centred on the MPJ area (Rossi and Tennant 2000) so that the shoe has good flexibility. The big toe is generally critical in the determination of foot length, while the arch location can help in the provision of arch support. Shoe design, at present, places great emphasis on the shape of the heel contour (that is, the stiffener at the shoe's rear part) in an attempt to `hold' the foot, as a stiff heel counter can prevent shape distortions. Indeed, the resulting landmarks have a known importance in shoe design and thereby in foot health.

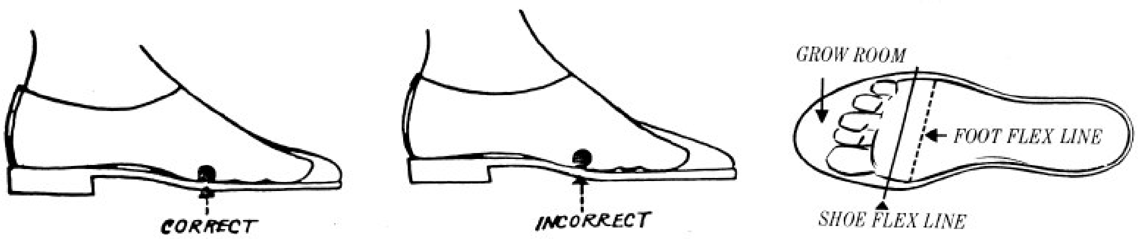


Figure. 4.23. The wrong and right flex line of foot and footwear together

Figure. 4.24. This footwear designed for the ability to adapt different foot positions which is classic ADIDAS design with modern technology

The sole's construction and function varies with the use for which the shoe was designed both in respect to dynamic motion and static motion. For each activation, shoes have special requirements regarding stiffness and insulation. Winter shoes /winter training shoes must have soles insulated against the cold ground. The sole's tread must be efficient for running on slippery surfaces. Heavy individuals, and those with extremely high arches, need shoe soles with greater shock absorption in order to run in comfort. The sole must be rather soft and able to bend at approx. 1/4 of the sole's length from the toe - where the foot bends. A test for this can be done at home or at the store, using common bathroom scales: pressing the toe portion of the sole on the scales at approx. a 30 degree angle should not require more than a 5 kg pressure to bend the shoe. Competition shoes may be even softer than this, but shock absorption must never be compromised.

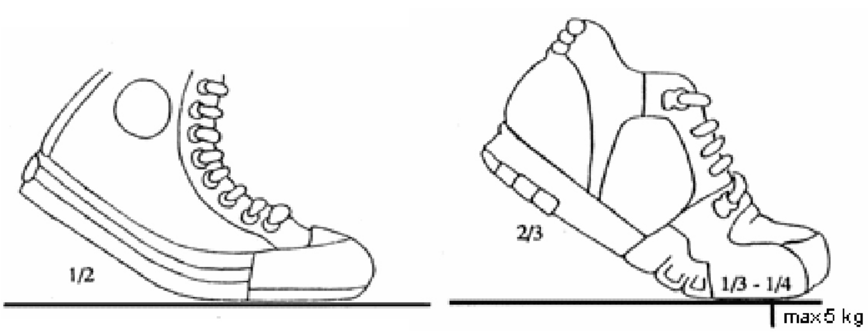


Figure. 4.25. A shoe must not bend in the middle: the foot does not bend naturally here

Figure. 4.26. The sole must resist torsion to discourage pronation/supination in the forefoot- of great importance on hard and level surfaces, of lesser import in the forest / for orienteering.

Figure. 4.27. Example of a poor shoe, lacking torsion-resistance

Besides resisting torsion, the sole may also be required to resist a tendency for pronation or supination, which some may feel are same problem. However, these tendencies not only vary from one person to the next, they also may vary between an individual's left and right foot. This requires that shoe designs must be available in several size variations.

4.2.2.1. Toe Spring

This describes the elevation of the undersurface of the sole at the toe to give a slight rocker effect to the shoe. The amount of toe spring (built into the last) depends on the shoe style, sole thickness and heel height. This is built into the last design and compensates for the stiffness of the footwear and provided a stress free take off into propulsion. The more rigid the soling material the greater the toe spring. Many shoes will also display a slight heel spring.

Figure. 4.28. Extreme Toe Spring

4.2.2.2. Rocker Sole

The midsole tapers down as it passes from the metatarsal heads to the tips of the toes. It also lifts up off the ground and can feel like there is nothing under the toes. The reason for this design is to help the foot roll off the toe during propulsion and toe-off. This prevents slapping during forefoot loading and is more efficient because you do not have to fight the shoe in order to toe-off. (Diabetes Care 20, 1997, pp.637-641)

With toe spring, the toes of the foot are constantly angled upward five to twenty degrees, depending upon the amount of shoe toe spring. Functionally, they are "forced out of business," denied much or all of their natural ground-grasping action and exercise so essential to exercising of the *whole* foot because 18 of the foot's 19 tendons are attached to the toes.

Figure. 4.29. Rocking footwear

A rocker-bottom profile can have its pivot point at different levels. In cases of limited mobility of the forefoot, a rocker bar with the pivot point at the level of the MTPs is sufficient; we call this a normal pivot point (Fig. 4). When relief of MTPs is necessary, the pivot point needs to be proximal of the MTPs; we call this an early pivot point (Fig. 4.30.) A rocker bottom profile always requires a toughened or stiff outsole. (Lee at al., 2001, Volume 28)

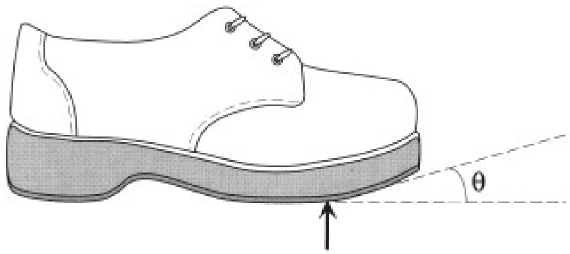


Figure. 4.30. Assessment of longitudinal sole rigidity and sole flexion point

The examiner exerts firm pressure to the front of the shoe, and documents the angle (q) between the sole and the horizontal as the degree of longitudinal sole rigidity. The point at which the shoe first flexes when pressure is applied is the sole flexion point. (Menz et al., 2000, pp.660)

4.2.2.3. The Outsole

The outsole has three key functions – (**durability and traction and dynamic pressure distribution**)

- Durability is rarely a factor these days because of the improvement in outsole materials. The cushioning and stability of the shoe will almost always be worn out before the outsole is worn through. Carbon rubber is harder and denser and can be made thinner without losing strength.
- Traction created by the friction between the outsole and the surface allows the shoe to grip the surface. As surfaces, conditions and motion change, traction may need to vary. A shoe needs to grip well when walking but not when pivoting. For hard ground the shoe should not grab the surface oppositely. Traction is a function of the softness of the outsole material, the configuration of the outsole lugs, and the surface people are moving on. Softer compounds like blown rubber will grip better on **smooth surfaces**, particularly if they are wet. High profile lugs are important if you run off-road over **loose surfaces**. Many shoes have a mix of carbon rubber in the heel for durability and blown rubber in the forefoot for traction. (Bkz. ADIDAS_1 as an example)
- Dynamic pressure distribution is the changing area of pressure points during gait cycle. The footwear design is responsible to meet this point respectively.

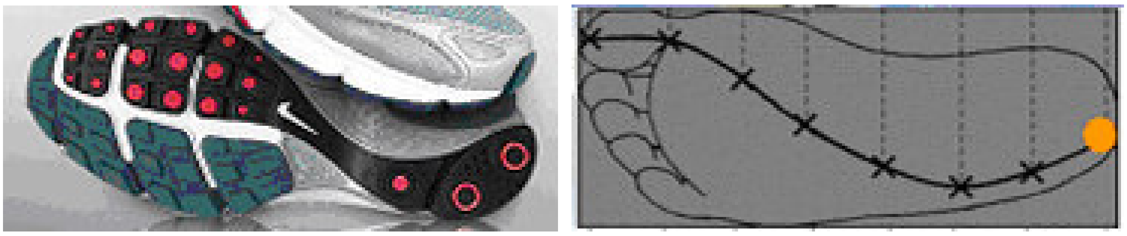


Figure. 4.31. Tread area and the outsole design meets the foots required pressure point

4.2.2.3.1. Slip Resistance of Footwear Outsoles

What is slip resistance?

A slip resistant surface is one that will permit an individual to walk across it without slipping. Contrary to popular belief, however, some slippage is in fact necessary for walking, especially for persons with restricted gaits who may drag their feet slightly. While increasing the slip-resistance of a surface is desirable within certain limits, a very high coefficient of friction may actually hinder safe and comfortable ambulation by persons with disabilities. In fact, a truly non-slip surface could not be negotiated.

While visual inspection can provide some Information about a surface such as its degree of cleanliness, whether it is wet or dry, and even the type or texture it exhibits, it cannot provide sufficiently accurate information about a surface to be used in design.

Even clean, dry surfaces with readily-apparent texture will not always be slip resistant. Materials which might be suitable for level surfaces may be inappropriate for sloping surfaces; materials specified for dry conditions may be unsafe when it rains; a leather shoe may perform poorly on smooth dry surfaces yet provide adequate traction when wet. The presence of moisture or other contaminants, the characteristics of the shoe sole or crutch tip making contact, the direction (uphill and downhill effects differ) and slope of travel all will affect the slip resistance of installed surfaces. It is this interaction of material characteristics and human responses which fully characterizes slip resistance.

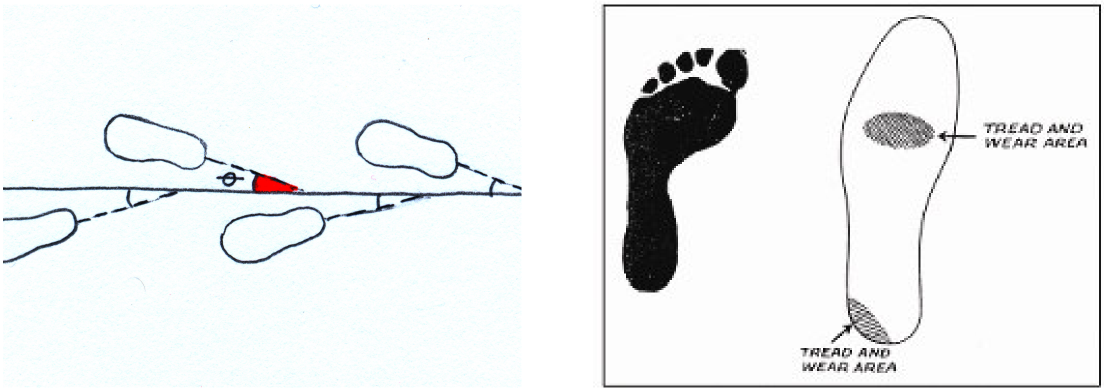


Figure. 4.32. Tread and wear area

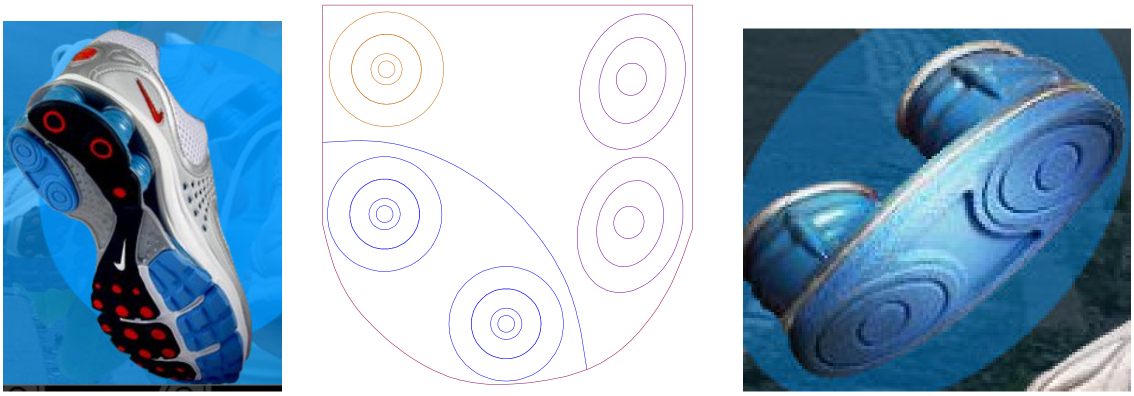


Figure. 4.33. The outsole system according to foot tread and wear area to hold the ground strongly

Figure. 4.34. Example of tread surface design and focus points from NIKE

Slipping on flat, wet surfaces suggests that linear grooves in the outersole may act to disperse fluid from under the shoe, and may therefore be preferable to suction cups, which act to retain fluid under the shoe and thereby increase lubrication of the outersole. Somewhat surprisingly, these experiments also found that during walking on a wet surface, a smooth sole may improve tread area but, may provide slip resistance superior to that of a textured sole by increasing the surface area for contact with the ground using a specially designed apparatus, evaluated the slip resistance of a wide range of shoe sole materials when subjects were dragged over a surface covered with ice (Bruce et al, 1980). Results revealed that the tread area and tread pattern of the sole influences friction on the ice surface. The holes (closed areas) collect the water inside. The horizontal cogs prevent the footwear from slipping while climbing stairs. Horizontal and vertical split prevents the sole to be broken. Continued lines, large smooth areas could make a slipping effect. Sharp wedges, geometrically small positive projections make point effect reducing tread surface.

Figure. 4.35. Tread pattern for slipping surfaces

Sole material hardness was linearly related to the coefficient of friction: as the sole hardness increased, the coefficient of friction decreased. The authors suggested that softer soles would be safer when walking on ice. The best sole material was a double-density, soft microcellular polyurethane, and the worst sole materials were leather and a polyvinylchloride rubber material.

Figure. 4.36. An example of changeable outsole design for slipping surfaces

Using the same apparatus, Lloyd and Stevenson conducted a follow-up investigation to evaluate the effects of a beveled heel on slip resistance. Two shoes were tested on five different surface configurations: one shoe had a square-edged heel, and one had a bevel of approximately 10º. Because of the normal variation between individuals with regard to the angle of the foot in the sagittal plane at heel strike, the authors tested slip resistance with the apparatus set at 4º, 6º, 9º, and 12º. Results revealed that the beveled heel performed better than the square heel under all surface conditions, in particular when the foot angle at heel strike closely approximated the angle of the bevel. The authors concluded that heel beveling improves slip resistance by increasing the surface contact area at heel strike, and therefore may be useful in the prevention of slip-related accidents.

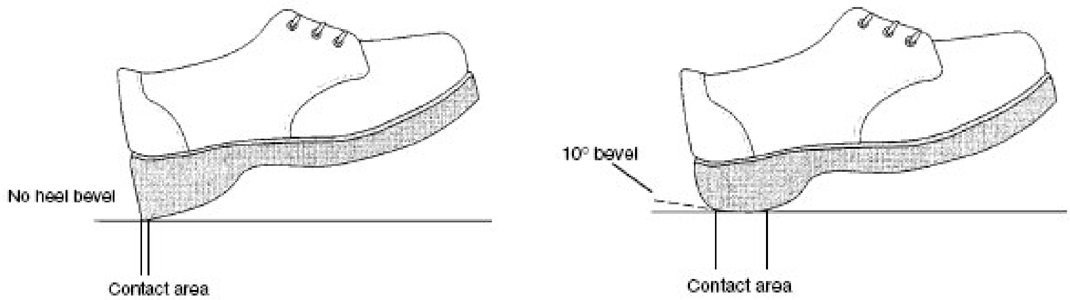


Figure. 4.37. Effect of heel beveling (round heel) on slip resistance at heel contact, as described (Lloyd and Stevenson, 1999)

4.2.2.4. The Midsole

The support of the shoe is very much based on the construct of the midsole. In general, it used to be that the more supportive midsoles resulted in a heavier and less cushioned shoe. Today, knowledge of foot function and advances in materials and shoe design has blended together to produce shoes that offer maximum support without sacrificing cushioning or weight. Some shoes contain different densities of foam or more rigid devices (such as plastic heel plugs) in the midsole that aid in controlling abnormal foot motion.

The midsole cushioning can be too soft, leading to maximum compression of the material, which can in turn result in a loss of support Also, with less cushioning comes less shock absorption is linked to degenerative changes in joints and low back pain. Finally, one needs to be aware that the use of designing footwear with extremely soft midsoles may decrease their ability to control abnormal motion.

4.2.2.4.1. Cushioning (Underfoot Resilience)

During walking, the ground reaction force is approximately 1.25 times the body weight and during running, the ground reaction force can reach levels of 2 to 3 times the body weight (Cavangh and LaFortune, 1980, Dickinson et al, 1985). Thus, midsole cushioning is supposed to attenuate or dampen the impact forces acting on the body during usage. Shoe designs attempt to concentrate on stability and cushioning in addition to weight and durability. Good support (that is, stability) may feel uncomfortable to a person while too much cushioning will make activities such as walking and running quite difficult. Most research has concentrated on comparing different shoes or materials rather than comparing the basic physical characteristics of the materials (Encapsulated gases, Gels, Fluids, High density plastics, Composites, Rubber) that are used.

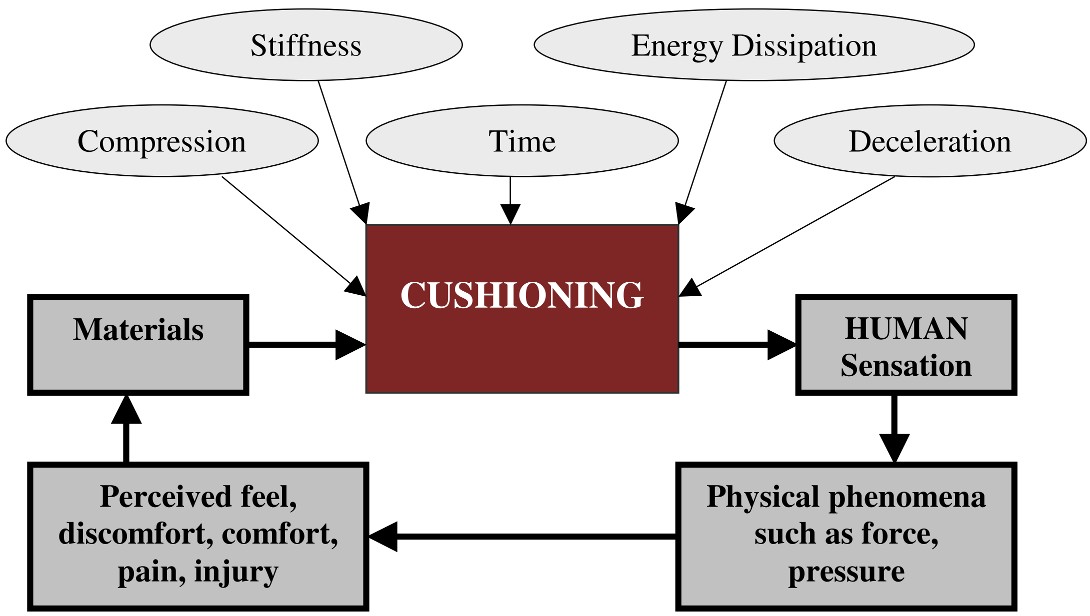


Figure. 4.38. Contributors to cushioning and their effects (Goonetellike, 1999)

The feet bear a cumulative total of about 800 tons of impactive body weight daily in a series of about 7,000" step shocks." Under natural conditions (resilient soil, etc.) the foot is equipped to absorb such impact. But under the unnatural conditions of non-resilient ground surfaces common to us, it is not. Hence a measure of underfoot cushioning built into the shoe is essential to shoe comfort.

Figure. 4.39. Cushioning system with jel inside

Figure. 4.40. Cushioning system with elastic material and cavity

Nike Womens Shox TL

Fig. 4.41. Provides essential heel cushioning and arch support while providing

Adidas GP III

Figure. 4.42. Cushioning system with open spaces in midsole and elastic material

Figure. 4.43. Cushioning system pressure meet points design solution

Cushioning technology is quite varied with manufacturers marketing air soles, pads, pods, gel or fluid soles and so on. Even though midsole cushioning is supposed to attenuate or dampen the forces on the body, the actual force acting on the body remains relatively unchanged with footwear (McPoil, 2000). Thus, most problems arise when a wearer of a shoe perceives a relatively false sense of security when a footbed and foot covering are present.

Figure. 4.44. A coil spring based footwear design for cushioning

The footwear (Fig.4.44.) is made with a rigid nylon and glass fiber UCB style prefabricated orthotic mounted on a coil spring at the heel to absorb impact and return some of the stored energy to the foot. The footwear has an excellent forefoot rocker with a thick neoprene sole and a cushioning design not found in other footwear (www.zcoil.com).

Interface elasticity

As indicated above, a highly elastic interface will return stored energy to the foot, thereby increasing the total change in momentum. In general, this will result in an increased force between the foot and the ground, although this will also depend on the time course of the return of energy.

Interface viscosity

A highly viscous interface absorbs most of the energy of the impact and produces a lower force than would be seen with an elastic interface. However, to be useful, any material beneath the heel must be able to recover following deformation. If a purely viscous substance, such as putty, was placed beneath the foot, it would absorb energy on the first step, but thereafter would remain flattened. Thus, an element of elasticity is always needed to provide recovery before the next step and all practical materials are viscoelastic; i.e. they combine elasticity and viscosity. Viscoelastic materials 'flow' out of the way when force is applied, absorbing energy in the process, but recover when the force is removed again. (Whittle,1999, p.270)

Midsole Flaring

The term "midsole flare" refers to the difference between the width of the midsole at the level of the upper and its width at the level of the outersole (Fig. 3). A number of authors have suggested that a large midsole flare is beneficial in shoes of older people, as it provides a broader base of support, thereby enhancing the stability of the shoe. These recommendations appear to have been developed in response to the recognition that narrow heels (such as those found in most high-heeled footwear) may cause instability in older people. However, there are no studies in the literature that have directly evaluated the effect of midsole flaring on balance ability.

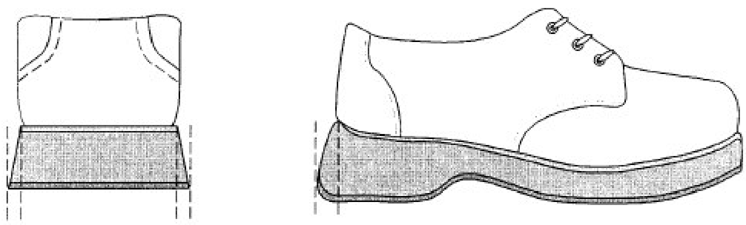


Figure. 4.45. The midsole flare of a shoe.

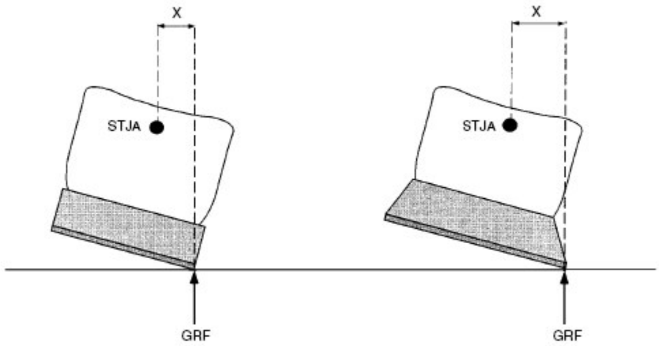


Figure. 4.46. Effect of midsole flaring on foot pronation at heel strike during running.

Ground-reactive force (GRF) is applied to the lateral plantar aspect of the shoe sole. The addition of a 30º. lateral flare to a running shoe increases the lever arm for pronation (X) around the subtalar joint axis (STJA).

Stability : The upper and midsole are key to providing stability to the foot. Stability is the capacity to resist forces which would cause motion or a change of motion. One concern for designers is that cushioning systems may be so soft that they compromise stability - an important design consideration.

4.2.2.5. The Heel

It is the bottom part of the shoe that provides elevation. The higher the heel, the greater the pressure on the front of the foot.

4.2.2.5.1. Heel height

Heel height was measured using a metric ruler, and documented in one of three ategories: 0-2.5 cm, 2.6–5.0 cm, and above 5.0 cm. If the heel of the shoe extends backwards too much or if it is too hard, the shin muscles can be overworked from having to break the foot before it makes full contact with the ground. This causes strain, leading to aches and pain.

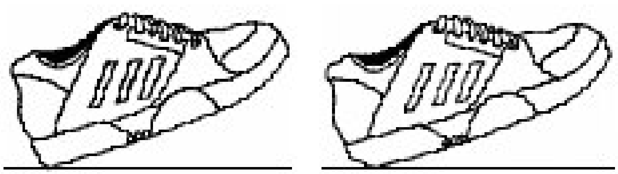
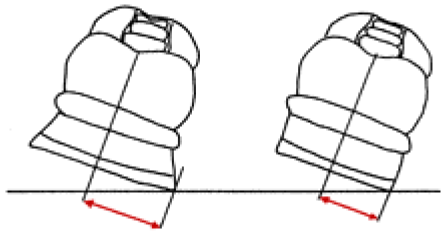


Figure. 4.47. Beveled heel design

One solution is a beveled trailing edge on the shoe's heel, allowing the foot to roll forward in its' step, softening the movement. Less muscle strain means less discomfort. Another solution, which can give the same effect, is a softer, shock-absorbing heel material in this trailing edge.



(a) Less transverse torsion (b) Greater transverse torsion

Figure. 4.48. Transverse torsion comparison

4.2.2.5.2. Heel Wedge Angle

But shoe heels have other, lesser-known influences on gait. For example, any heel, low to high, requires a compensatory alteration or forward slant on the last, which is translated to the shoe. This slant is known as the "heel wedge angle." This is the slope or slant of the heel seat, rear to front, to compensate for the shoe heel height. The higher the heel, the greater the angle, shifting body weight forward to the ball.

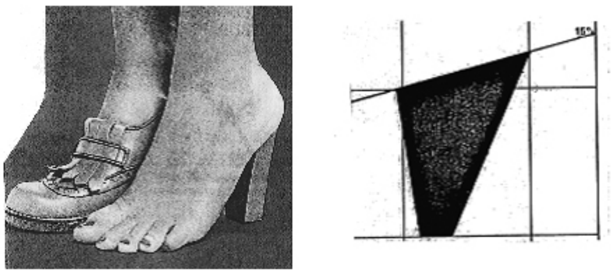


Figure. 4.49. The effect of wedge angle on angle of foot

4.2.2.5.3. Heel Width

Heel width on shoes for a normal runner should not exceed 7 - 8 cm. A normal heel width is better than wider ones, which can greatly strain the inner leg muscles when they strive to alleviate the transverse torsion at the moment of impact with the ground. To counteract an incorrect impact angle, the heel can be narrowed/widened differently per side. For correction of inversion, the heel should be **widened** or **hardened** on its' outer edge, while for eversion the converse would apply.

The heel's degree of hardness and shock absorption is of great importance to the comfort of the shoe while running. A heavy person or hard track surfaces requires a better degree of shock absorption. A good shoe should not, at the moment of impact, allow the heel to tilt excessively inwards or outwards but should remain somewhat straight. In the case of shoes specifically for moderate running speeds, a slight inward tilt is allowable.

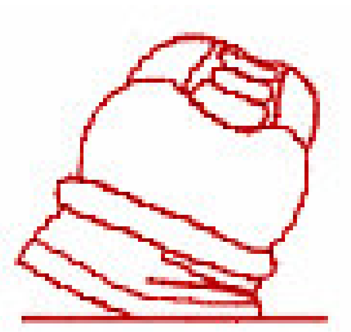


Figure. 4.50. Many shoes are too soft in the heel's outer edge. At the moment of impact, the heel material is overly compressed, leading to problems due to unacceptable inward tilting or deviations in the heel angle.

Figure. 4.51. An example of sole design wider in the heel and ball

4.2.2.5.4. Heel Shank

The shank is the inner part of the shoe that extends forward from the heel. Its purpose is to prevent excessive pressure on the medial longitudinal arch of the foot. A shoe with a weak or non-existent shank provides poor support and will contribute to over-pronation and eventual breakdown of the longitudinal arch. The shank is a stiffener that controls the flexibility of the sole. Full-length shanks offer additional torsional rigidity and protection to the underside of the foot.

The shankpiece or shank spring can be made from wood, metal, fibreglass or plastic and consists of a piece approximately 10cm long and 1.5 cm wide. The shank spring lies within the bridge or waist of the shoe, i.e. between heel and ball corresponding to the medial and lateral arches. The shankpiece reinforces the waist of the shoe and prevents it from collapsing or distorting in wear. The contour of the shank is determined by heel height. Shoes with low heels or wedged soles do not require a shank because the torque between the rear and forefoot does not distort the shoe.

Figure. 4.52. Steel heel shank design

4.2.2.6. The Insole

The Arch Support: The arch support originally was a separate cookie glued under the insole. It then progressed to being a part of the insole. Now most arch supports are incorporated into the midsole. This can be a problem if it is the wrong shape, as the midsole does not conform to the shape of the foot but maintains its shape. Blistering in the arch has become much more common for this reason.

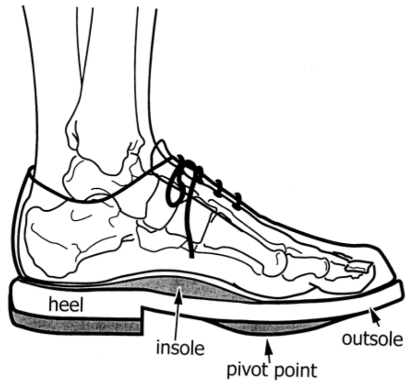


Figure. 4.53. Foot inside snug-fit shoe. Low shoe with a full-contact insole and a rocker bar with a normal pivot point. (Lee at al., 2001, Volume 28)

There is a confusing knowledge that, the function of the insole as being for cushioning and it is necessary to replace it when it flattens. While it is made of foam like the midsole it is not resilient. Instead it is designed to quickly mould around the foot). This gives you better traction inside the shoe and a better fit.

4.2.3. Design Characteristics of Upper

"High top" or "three quarter" height uppers may provide additional support to the ankle to prevent sprained ankles.

4.2.3.1. Vamp:

Another element of shoe design that affects fit is the vamp. In this area, the shoe manufacturer has complete leeway. Shoes that measure the same length and width may fit differently depending on the vamp style.

The vamp covers the dorsum of the foot (over the instep, includes the tongue piece) and superior aspects over the toes. This is the upper middle part of the shoe serves to give the shoe its shape as well as protect the toes where the laces are commonly placed. Sometimes Velcro is used instead of laces. Lacing pattern can affect how the shoe fits. Some people experience impingement of nerves and tendons on the top of their foot if the laces are not in the proper place. There are alternative methods to lace shoes up that can help prevent the heel from slipping during ambulation/running or relieve pressure points that can result from a high instep.

The vamp is often made of more than one piece, creating a decorative pattern. There are various types of vamps suited to different styles of shoes.

4.2.3.2. The Heel Counter

Shoe parts, such as the ankle collar and Achilles cushion, help provide comfort around the ankle, but can also cause friction and abrasion, leading to inflammation of the Achilles tendon. The heel-counter part of the shoe should be stiff to ensure that the heel is held in place over the midsole enveloping the foot.

Heel counter stiffness:Flexibility of the heel counter of the shoe was determined by the examiner exerting firm pressure half way up the posterior aspect of the heel. The degree of buckling of the heel counter relative to vertical was visually estimated and categorized as minimal, less than 45 degrees, or greater than 45 degrees (see Figure 4.54.). Backless shoes were simply documented as 'not applicable' in this section.

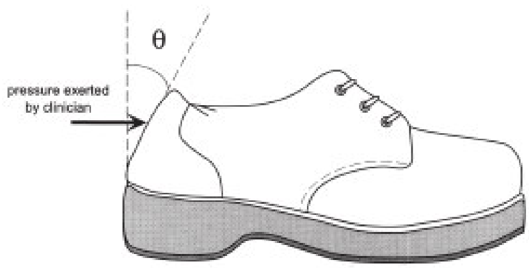


Figure. 4.54. Assessments of heel counter stiffness and an example from NIKE

To add stability, heel counters have been integrated from the midsole to the upper. (Janisse, 1992). The examiner exerts firm pressure half way up the posterior aspect of the heel, and visually estimates the angle (q) the heel counter makes from the vertical. (Menz et al., 2000, pp.659, volume.14)

4.2.3.3. The Heel Tab

High heel collars are commonly found in safety footwear and in shoes designed for specific sporting activities such as soccer and basketball.84, 85 Much of the literature regarding the effects of heel-collar height evaluates the ability of the shoe to prevent ankle sprains. Two main theories have been suggested to explain why high heel collars may be of benefit in ankle sprain prophylaxis. First, the mere presence of the material surrounding the ankle region is thought to provide mechanical stability to the ankle and subtalar joints in the frontal plane such that rapid excursions of the foot into eversion or inversion are restricted by the shoe. (Hylton&Menz, 1999, p. 349)

4.2.3.4. The Tongue and Laces

Two important parts of an ideal shoe; band around instep prevents foot sliding forward and pressure behind heel to prevent foot sliding back. The tongue should be soft for cushioning and breathable for ventilating the footwear under the laces. To much support may not be essential for an ideal functioning foot. But laces and Tongue prevents foot from sliding.

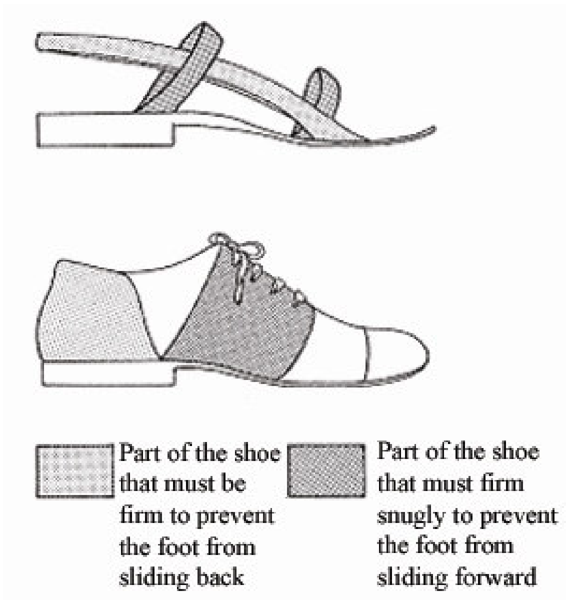


Figure. 4.55. The parts of a shoe needing to fit well to prevent forward and backward movement of the foot

Footwear with attachable upper could vary the fitness to different characteristics of foot. All other shoes without laces constrict blood circulations of foot vessels to the varying degrees.

Figure. 4.56. The strap design to prevent the foot from sliding

4.2.3.5. The Toebox

The toebox must be deep enough to accommodate the height of your toes and should follow the same shape as your foot but the width and height of the toe box vary because of its design among brands and models. The size of the toe box is particularly important for people with bunions, hammertoes, and other "fit" problems related to the front part of their feet. These conditions can be irritated by toe boxes that are too small. Pointy toes can cause bunions and hallux valgas while shallow toeboxes will cause black toenails.

Figure. 4.57. The space allowance for a foot in any footwear design

The height and width of the toe box is dictated by shape of the last used to construct the shoe. Having adequate space can decrease the friction and irritation from these problems. Toebox design varies from model to model. Some models are specifically made deeper and wider to accommodate for various foot shapes.

A narrow toe box will crowd and pressure the metatarsals and phalanges, while a short toe box will jam the toes and cause nail pressure problems to develop (especially in athletes). An unnatural narrow shape will cause calluses and discomfort, with possible deformity and clinical problems (Janisse, 1992).

Figure. 4.58. The toe room with black, harder material covered to prevent the toes

4.2.3.6. The Quarter

In athletic shoes the topline is often padded and referred to as a collar. The medial and lateral sections join in a seam at the posterior end of the shoe. In Oxford style lacing shoes, the eyelet section is formed by the superior part of the quarter (while the underlying tongue is part of the vamp). The heel section of the quarter is frequently reinforced with a stiffener. This helps support the rearfoot. In boots the quarter is often referred to as 'top'. In the **Bal method**, the front edges of both quarters are stitched together and covered with the back edge of the vamp. In the **Blucher method** the quarter panels are placed on top of the vamp, and the front edges are not sewn together. In comparison with the Bal method, the Blucher method permits the fitting of a larger foot girth by broadening the throat of the shoe. A convalescent shoe (open to toe) is a variation on the Blucher method in which the lacing extends to the front edge of the vamp. In athletic shoes the vamp and quarter panels are often one continuous piece of nylon or leather with additional leather pieces added to reinforce critical areas of the shoe. Reinforcement added to the region of the medial longitudinal arch are termed the saddle if it is added to the outside of the shoe or the arch bandage if it is added to the inside of the shoe. (Hughes JR, 1995, p. 30)

4.2.3.7. The Lining

In quality shoes the quarters and vamps are lined to enhance comfort and durability. Linings may consist of various materials i.e. leathers, fabrics, and manmade synthetics. The lining on the insole segment is called 'the sock' and may be full-length, three-quarter or just the heel section. Many linings are made of synthetic material and are usually confined to the quarters and the insock. The lining should be smooth and free of seams which may create unanticipated pressure points within the shoe.

4.2.3.8. The Throat

The central part of the vamp just proximal to the toe box. The throat is formed by the seam joining the vamp to the quarter i.e. throat-line. The position of the throat line depends on the construction of the shoe, for example a shorter vamp and longer quarters define a lower throat line. This gives a wider lower opening for the foot to enter the shoe. The throat is defined by the connection of the rear edge of the vamp and the front part of the quarter. The location of the throat will vary with the design of the shoe. Because the vamp and quarter panels are often one piece in the athletic shoe, the throat is at the eye-stay. This refers to the point where the lacing is attached to the vamp. The throat of the shoe dictates the maximum girth permitted by the shoe. (Rossi WA, 2000)

4.3. Ergonomic Factors in Footwear Design

Good shoes should behave like an extension of the foot, which is a complex structure of bone, muscle and fatty tissues. To enhance performance, sophisticated shoe structures are employed which make use of viscous and elastic foam materials such as ethylene vinyl acetate (EVA) and polyurethane (PU). The use of viscous plastics in the heel area serves to absorb the impact forces during the initial ground contact, and provides the foot with a soft ‘cushioning’ effect. In the forefoot area, on the other hand, highly elastic plastics are used, which help to minimize the loss of the energy transmitted to the shoe during the running movement. For the foot to be protected, it is of fundamental importance that the shoes do not ‘bottom out’. This happens when, even at relatively low forces, the whole deformation capacity of the sole materials is used up, so that at higher forces there is no more deformation capacity left.

4.3.1. Materials Characteristics

A shoe upper material contributes to comfort in proportion to it's (1) breathability; (2) conformably; (3) weight; (4)suppleness or softness.

Exercising or mobility makes human's feet overheating. The material from which the shoe is made can affect fit and comfort. Softer materials decrease the amount of pressure the shoe places on the foot. Stiff materials can cause blisters.

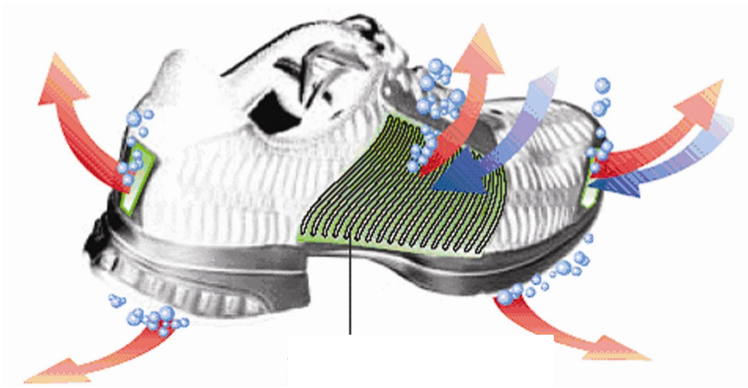


Figure. 4.59. A mesh ventilation panel positioned over a breathable membrane

Inside-Shoe climate: According to qualified investigators (Satra, Natick Army Research Laboratories, Tanners Council Research Laboratory, etc.) inside-shoe climate is among the most important shoe comfort factors -- and, one of the most overlooked by consumer. Inside shoe climate involves temperature, humidity, moisture, breathability, insulation; in short, the thermal conditions.

Breathability: It is the combination of **heat**, **moisture**, and **friction** that combine to break down materials inside the shoe. Since the feet have more sweat glands per square inch than any other part of the body (approximately 250,000), adequate air circulation is essential to keep them healthy. Socks that absorb moisture are made of cotton, wool, or a mixture of both. Trapped in tightly laced-up shoes with little room to breathe, our feet often suffer in an unpleasant environment and in turn make the human uncomfortable as well. **Special openings** in the sides, toes, heels and soles should allow fresh air into the shoe exactly where it is needed.

Moisture absorbency: Leather absorbs moisture away from the foot and out of the shoe. Shoes that are made of leather and that fit well, healthiest and most comfortable design. A great deal of sweat is absorbed by insoles and by the uppers of shoes.

Summer Shoes:

- Thin leather or inserts and the woven leather at the certain points of the upper.
- Holes punched in the leather for the total air permeability.
- Open areas of the upper allow air circulation for the cool and comfortable footwear.
- Thin leather or the materials which allow air circulation.
- Thinner and lighter soles.



Figure. 4.60. Open areas of the upper allow air circulation

Winter Shoes: **Winter shoes /winter training shoes** must have soles insulated against the cold ground. The sole's tread must be efficient for running on slippery surfaces.

Weight: Suede leather is usually lighter than full-grain leather, and heavy synthetic fabric (Cordura etc) is lighter than leather. Equally, big clumpy soles are obviously heavier than thinner soles.

New lighter stronger and more durable materials, particularly in the outsole and midsole, have drastically reduced the weight of shoes. Many shoes have replaced part of the midsole in the midfoot with a thermoplastic or carbon fibre plate. This reduces the weight without sacrificing any stability.

Figure. 4.61. A design example from NIKE

Durability: A shoe's durability is often determined by the hardness of the outsole rubber, the density and firmness of the midsole foam, and the strench of the upper materials. Durability, of course means, the shoe's ability to endure and perform over time - to last and continue to maintain its stability, traction, flexibility and shape (fit). Durability is dependent on the materials, structure and construction of the shoe and is managed in each shoe component differently. Durability of the upper is dependent on the materials used commensurate with the sport and foot motions.

4.3.2. Materials Most Used in Footwear Industry

EVA: Ethylvinyl acetate - Closed-cell synthetic rubber foam in the midsole that's lighter and softer than the other major midsole fabric — polyurethane.The spongy material found under your foot in many running shoes. A shock-absorbing material that's lighter than polyurethane. Compression molding distributes the EVA foam within the midsole to areas that need the most cushioning.

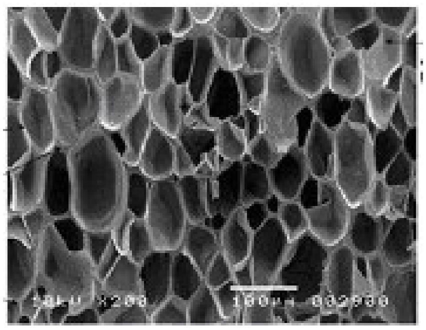


Figure. 4.62. EVA foam cut

PU Polyurethane - Synthetic soling material. Expanded PU is produced by mixing two chemicals which combine inside the mould to produce polyurethane foam. As little heat or pressure is involved the moulds are relatively cheap and easy to produce, allowing relatively short runs. It is flexible for use in bottom units which are soft and light, wear well and resist slip. There is a rigid version which is used for platforms. For flexible closed-cell foams used in the footwear midsoles for the cell air compression characteristics.

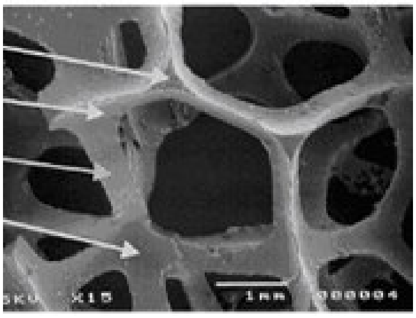


Figure. 4.63. PU Polyurethane cut foam

One of two major types of midsole cushioning. A dense and durable material, it can add stability to the shoe, but also weight. A rubber-like material used for shock absorption. Heavier than EVA.

TPU Thermo polyurethane - Imported rubber-like material that is extra lightweight and strong, durable and flexible.

Microporous Natural Rubber - Rubber with a cellular structure. The cells are filled with air and provide support and cushioning. Generally firmer, more durable and slightly heavier than EVA and PU.

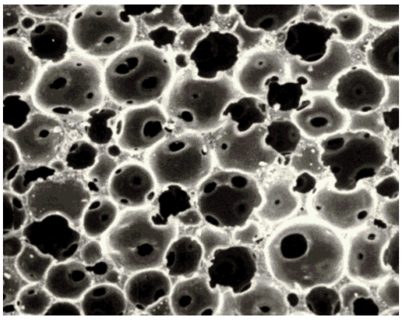


Figure. 4.64. Rubber foam cut

TPR (thermoplastic rubber) - A synthetic rubber similar to resin-rubber or a blend of petroleum-based synthetics. Produces rubber-like qualities, but can be fused by heat and therefore processed into soles by injection molding. a plastic material which can be repeatedly softened and remolded by heat, while retaining the molded form in ambient temperatures. Thermosetting plastics sole TPR compounds are lightweight and extremely flexible in cold temperatures. Available in translucent or opaque colors, as well as clear, thermoplastic.

PVC (polyvinyl chloride) - polyvinyl chloride (PVC) - a synthetic plastic widely used for soling and coated upper materials, either dense or microcellular.Rubber-like material that gives excellent protection against impact and oils. PVC / urethane blends with good abrasion, oil resistance, and low-temperature flexibility. Available with high flow properties, Garathane is suited to demanding industrial environments.

4.3.3. Materials Used in Footwear Upper

Leather remains the preferred shoe upper material. The following qualities make it one of the best components for shoe manufacturing:

- Breathability – Pores in leather permit fresh air into shoes.
- Customization – Leather will assume the shape of the wearers' feet, providing individualized fit. This quality maximizes comfort and minimizes foot disorders.
- Durability – Leather resists tearing and puncturing.

All parts or sections of the shoe above the sole that are stitched or otherwise joined together to become a unit then attached to the insole and outsole. The upper of the shoe consists of the vamp or front of the shoe, the quarter i.e. the sides and back of the shoe, and the linings. Uppers are made in a variety of different materials, both natural and synthetic. Leather became the obvious cover of choice because it allowed air to pass through to and from the skin pores thereby providing an opportunity to keep the feet, cool. The plastic properties of animal skins further help mould the shoe to the foot beneath. The ability for leather to crease over flexor surfaces facilitates the function of the foot. Ironically synthetics used as uppers display elastic properties, which mean the shoe upper never quite adjusts to the foot, shape in the same way as natural leather. Synthetics are cheaper to mass-produce and are now found in most mass produced footwear. Synthetic uppers are more waterproof. Woven fabric such as cotton corduroy can be used as uppers. Classified as breathable fabrics these help aeration.

The bottom inside portion of the shoe that is in direct contact with the foot. Most shoes have removable insoles that aid in creating space when prescriptive inserts or orthotic therapy is needed.

The upper holds the foot to the sole and is generally the most aesthetic part of the shoe (colorful, company logo, etc). One should be warned. While how a shoe looks is important; it should never take precedence over the function of a shoe. The fact is that a shoe will not prevent injuries associated with improper fit or function.

Designing great shoes is that designing with a decent blend of support, cushioning and style.

4.3.3.1. Heel Counter Material and the technology

Counters are usually made from fibreboard or heat moulded plastic. Foxing is an additional piece of leather that covers the counter externally. Sometimes a counter will extend medially to support the heel and prevent prolonged pronation. In some children's shoes and athletic footwear the stiffener is extended on the medial of the arch to provide an anti-pronatory wedge. The heel counter and vamp combine to provide lateral support and prevent rolling over the sole, both medially and laterally.

The original purpose of a heel counter was to help keep the shoe on the foot by grabbing the heel. In running shoes it has become the second most important component for **stability**. The most commonly used leathers are:

Leather

This material retains the top or outer membrane of the hide, which contains dense, tight fibres that are water-resistant and supportive. It conforms well to the foot over time, can be waterproofed, is abrasion-resistant, and will last for years when properly cared for. If this membrane faces outward, it is called "smooth-out." When it faces inward, "rough-out" leather protects the tighter fibres of the top grain from abrasion (giving the leather a longer functional life). Full grain leather can vary in thickness, depending on the starting thickness of the hide and on what part of the hide the leather is taken from. Thicker leathers require longer breaking in, but making a more durable, supportive boot. Some footwear is made with thicker leather only in the high-wear, high-support areas, and thinner, lighter, and more breathable leather in the remaining sections.

Figure. 4.65. Leather

Figure. 4.66. Tim Brennan-VIVO SHOES

Nubuck

A leather finishing process, but not a type of leather. It involves sanding the top grain leather surface which gives it a "fuzzy" appearance. This surface texture is sometimes mistaken for suede, but nubuck is actually a full-grain leather. It can be factory treated for waterproofness.

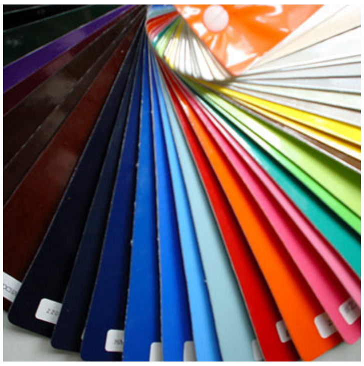


Figure. 4.67. Nubuck

Suede

There are two distinct layers in a leather hide; the outermost (top grain) layer and the lower (split) layer. Suede is created by sanding the split leather surface to roughen it up. It is generally less abrasion-resistant, more prone to stretching, and less stiff than full-grain leather. It also absorbs water more easily. Tanning processes or copious applications of goop can make suede waterproof, but it remains less appropriate for heavy-duty outings. Flexibility, breathability, and lower price make it a good choice for lighter use trips.

Fabric

Includes a wide range of materials used to construct mesh for high breathability and woven fabrics for greater durability. In general, lighter weight fabrics are more breathable, and easier to break in. Fabric is not as durable as leather, and is difficult to waterproof unless it is used in conjunction with a waterproof breathable membrane. It is often used with suede, leather, or synthetic reinforcing panels to construct footwear that achieves a good balance of support, lightness, and breathability.

Characteristics: Environmentally-friendly, good tensile strength, soft, lightweight, non-toxic, water-resistant, air permeable.

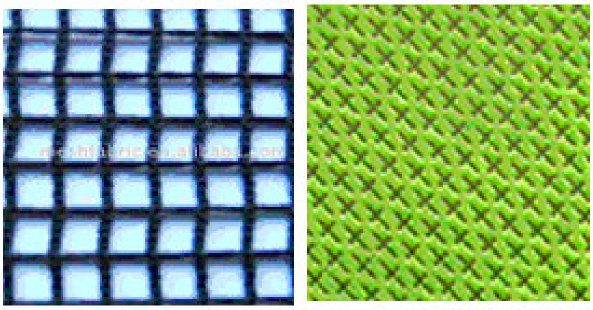


Figure. 4.68. Woven/Mesh Fabric and Cambrelle

Synthetic Nubuck

Synthetic fibers are bonded together and finished with a suede-like texture for added durability. Although it is less breathable and less waterproof than leather, it is much less expensive.

Plastics (or Nylon)

Plastic mountaineering boots provide absolute waterproofness and are extremely durable. The rigidity of plastic boots makes them well-suited to use with crampons in extreme conditions. Plastics, however, will not break in, and are used almost exclusively in "double" boots where a padded inner boot buffers the foot from the outer shell.

Figure. 4.69. Plastic used for heel and ball stabiliy

Plastic upper materials - in ever-increasing use, and have undergone considerable advances in recent years. The two main materials used are PVC and PU, both laminated to a textile backer. The best PU has the feel of leather and their surfaces are finished to give the look of fine leathers. While not necessarily cheaper than leather, they save labour in the factory and are more adaptable to mass production methods due to their homogeneity. In some cases they are hard to distinguish visually from leather, clues being a tendency for the stitches to sink into the material, and reluctance on the part of designers to leave edges raw. They hold their color better than leather. Disadvantages are their non- permeability, which can cause hot, and odorous feet, and a tendency to crack after extensive wear. They also do not keep their shape as well as leather.

Polyurethane (PU) upper material - thin sheet of expanded PU with a fabric backer. Usually used in its lighter weights for women's dress shoes as it has the appearance and even the feel of a good leather at a lower price.

PVC Polyvinyl chloride - A semi-rigid plastic whose strength attributes are used in components, particularly heel counters.

For example; thermoplastic heel counter is a PVC moulded under heat and pressure to give strength and support in the heel of the shoe.

Figure. 4.70. PVC used for heel and ball stability

Man made materials and fabrics are also used to make shoe uppers. The primary families of man made imitation leathers are vinyls and urethanes. Among the benefits of using man made materials are generally lower materials cost, good looks and easy maintenance. However, they have two primary disadvantages:

Inability to “breathe “– they don’t absorb and pass off foot moisture;

Memory retention – they return to their original shape after being worn.

In some shoes, primarily athletic foot wear, man made material is used in combination with fabrics which do breathe, thus giving breathability to the shoe.

4.3.4. Material Used in Footwear Sole

The selection of soling material by a manufacturer depends on the properties needed for a particular sole. The desired properties might be wear and durability, flexibility, traction, or insulation. In some shoes, the soles must be oil resistant, slip resistant, cushioned and/or modified for medical reasons. Most shoes today have soles made from various compounds, the mix of which depends on the properties needed for the shoe and its functions. Leather for soles has limited use and is found primarily in higher priced dress shoes and boots.

4.3.4.1. Midsole Material

The midsole is a cushioning layer between the outsole and the upper. The use of expanded polymer foam materials in the construction of footwear midsoles is widely accepted as a means of enhancing the level of comfort the shoe offers and, as such, is commonly recommended as a beneficial feature in footwear design. Subsequent investigations into material properties of footwear midsoles focused primarily on the ability of the material to reduce impact during walking. In this context, the hypothesis suggests that the use of thick, soft materials in footwear midsoles leads to instability, as the midsole material induces a state of “sensory insulation,” thereby reducing afferent input to the brain regarding foot position.

The majority of the midsole contains ethylene vinyl acetate (EVA) foam, polyurethane foam or a combination of the two (dual-density midsole) or rubber mixed with compounds, and other foam polymers, provides cushioning and shock absorption for the body. This is durable memory foam, which can resist up to one million compactions and in this portion of the shoe that many of the shock absorbing inserts such as air and gel are incorporated. EVA foam provides better cushioning but has less durability than polyurethane. In addition to foam, many companies have there own cushioning systems, such as air bladders, honey-comb cut foam, shock-absorbing gel materials and various other high-tech materials.

Figure. 4.71. EVA material

Other compounds like gel absorb, hydroflow, air, wave, grid, and adiprene are used to supplement the **cushioning,** but the EVA supplies most of it. Polyurethane was once a popular EVA like compound. Dual densities in the midsole help to guide the foot from strike to toeoff, to prevent or control pronation and instability. The firmer density is often highlighted by being a darker colour and is usually in the inside of the heel. Other bars and devices are used in the midsole to prevent compression and give **stability.** The EVA is injected into a mould under high pressure and temperature to reduce weight and increase durability. The top borders of the midsole are wrapped up to cradle the foot to improve **fit** and improve **stability**.

4.3.4.2. Outsole Material

The outsole is where the boot meets the trail. Available in different compositions of rubber with various tread patterns.

Leather has poor gripping capabilities and synthetic polymers are much preferred. There are also an infinite variety of surface designs. Extra grip properties can be incorporated in the form of a distinctive sole pattern with well-defined ridges. Alternatively they can be moulded with cavities to reduce the weight of the sole. These cavities need to be covered with a rigid insole or can be filled with light foam to produce a more flexible sole. In some cases two or more materials of different densities can be incorporated into the sole to give a hard wearing outer surface and a softer, more flexible midsole for greater comfort. Synthetic soling materials will off the physical property of dampening down impact levels (shock attenuation).

The traction pattern and materials of the outsole are specific for the playing surface. For example, a court shoe will be flat and flexible with a lot of traction, while a trail-hiking shoe will have a more rigid outsole with more aggressive traction pattern.

The outsole's function is to provide protection, traction, and durability. It can also play a role in flexibility, stability, and cushioning. Outsoles are most commonly made from rubber or compounds mixed with rubber. They also may be leather or polyurethane.

4.3.4.3. Insole Material

The insole board is necessary in shoes that are constructed using cemented or Goodyear welt techniques because it is the attachment for upper and lower components.

Figure. 4.72. Regions of foot base

The majority of insole boards is made of cellulose and is treated with additives to inhibit bacterial growth. Athletic footwear will often have a sock liner, a piece of material placed over the top of the insole board (glued in position or removable.

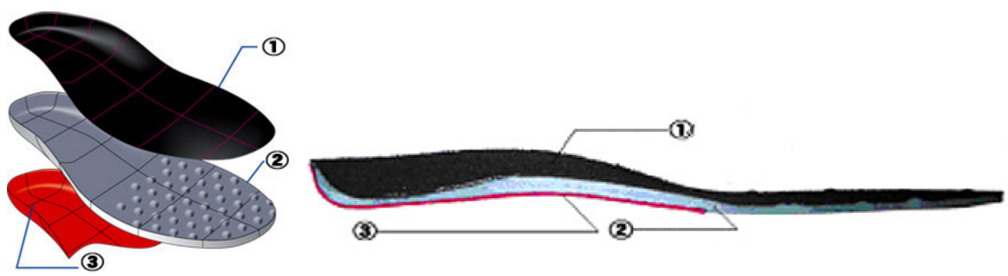


Figure. 4.73. An example of insole that stabilizes the heel

Good insoles are made from compressible foam that will mold to the contours of your feet. It should be noted, however, that most insoles that come with shoes will break down a lot faster than the shoe itself. There are a large variety of over-the-counter shoe inserts that can aid in prolonging the comfort and life of the shoe.

The insole's function is primarily for tactile comfort although it may add cushioning, moisture control, support, and guidance. Insoles are made from EVA, polyester, thermal plastic, graphite, and foam polymers.

Figure. 4.74. Eva insole

Figure. 4.75. Silicone Insole

This flexible material is used to design inner soles to fit easily into any type of shoe, boot, or sneaker to massage human feet.

Figure. 4.76. Gel Insole

These soft soothing liquid gel filled inner soles are designed to fit easily into any type of shoe, boot, or sneaker. The gel filled soles gently massage human feet, improving blood circulation, and relaxes your feet as you stand, walk, jog, or exercise.

4.4. Design analysis of NIKE and ADIDAS innovative solutions

ADIDAS T-MAC 4

Figure. 4.78. The Tracy McGrady signature shoe's innovative design goes without laces

The HUG consists of an inner bootie that's padded right on top of the foot. A wiring harness is anchored at the front of the shoe and the cables connected to the dial pull it tight. The concept uses the heel as a pivot point and so when you open the rear lever and pull it down, the system will come loose. It is only when you have adjusted the fit and re-raise that lever does the tightness settle in and lock down upon the foot.

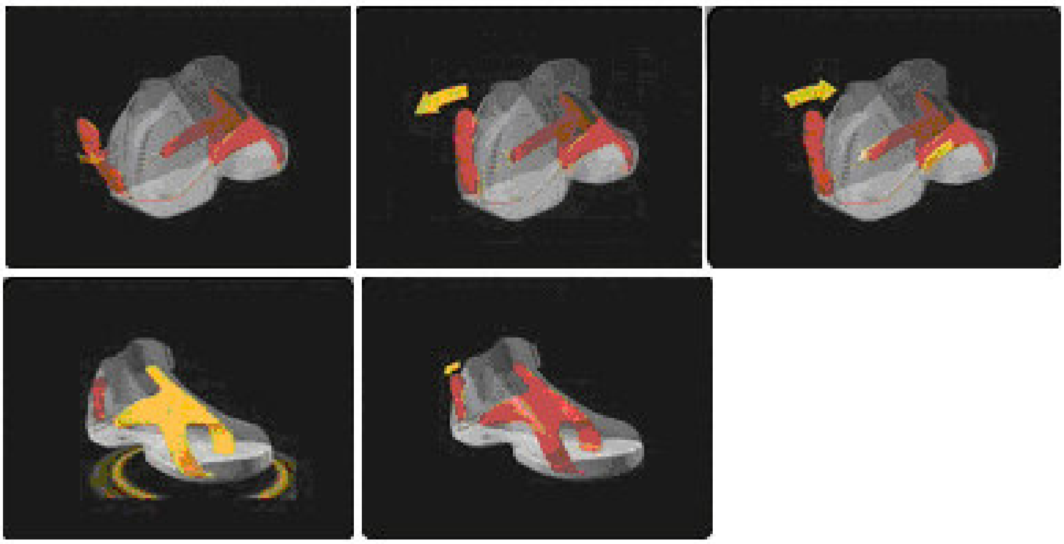


Figure. 4.79. The system inside

The advantage of this HUG technology is the elimination of pressure points that you usually get with the traditional lacing structure. There is now a larger surface area holding your foot down instead of narrower laces which spreads out the pressure over a larger surface area. The good news is that the TPU placed on top of the bootie won't stretch out over time, thus making your fit constant over the lifespan of the shoe. For micro-adjustability, you can always just readjust the dial over the course of a game. Hence, the technology and concept of HUG should accommodate any foot size and shape.

Figure. 4.80. How the system works

In this view, the lever is opened and we can peak inside at the wiring harness. Notice Tracy's signature at the heel tab and the #1 that is prominently displayed on the inside. hen opened, the dial can be seen where the adjustments can be made. Turn the dial to loosen or tighten the fit of the HUG system. The trick is merely a set of wiring cables that will pull the TPU down towards the foot.

Figure. 4.81. The design to control the system

ADIDAS _ 1

Figure. 4.82. Design a computer-based, dynamic cushioning system

In March 2001, three engineers at Adidas with no experience using electronics set out to pursue an idea considered to be more than a little out there: Design a computer-based, dynamic cushioning system to fit into the sole of a high-performance running shoe.

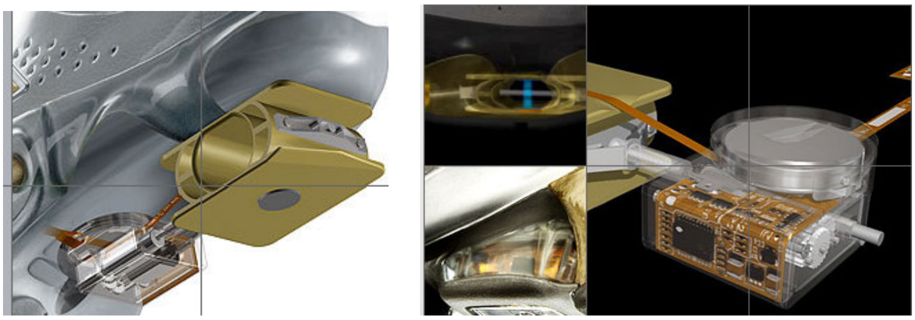


Figure. 4.83. System detail

Consisting of an 8-bit microcontroller (MCU) operating at 20 MHz, motor-controlled lead screw, Hall-effect sensor, and specially-designed plastic cushioning element, the system maintains the desired cushioning level by measuring the compression of the cushioning in the midsole and automatically adjusting it on the fly. The motor drives a series of gears with a 50:1 ratio, turning the lead screw. It expands or contracts a cable, altering the available space for the movement of the cushioning element, which features two concentric walls on each side to withstand shear force and provide stability. Typical compression in a 24-mm-high running shoe is 10 mm—or almost 50 percent.

The sensor is not only able to measure the distance that the cushion element has compressed, it also measures the time to achieve full compression—allowing the software to identify particular surface conditions.

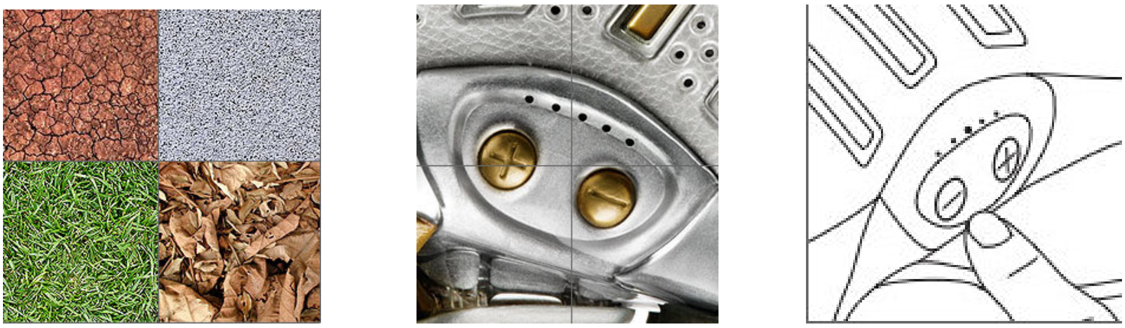


Figure. 4.84. Different ground characteristic and user interface design to adjust

The complicated design issues, for example the criteria for viewing the LEDs in the user interface called for a clean, crisp, and non-dispersed light that the runner could easily read from the side and above.

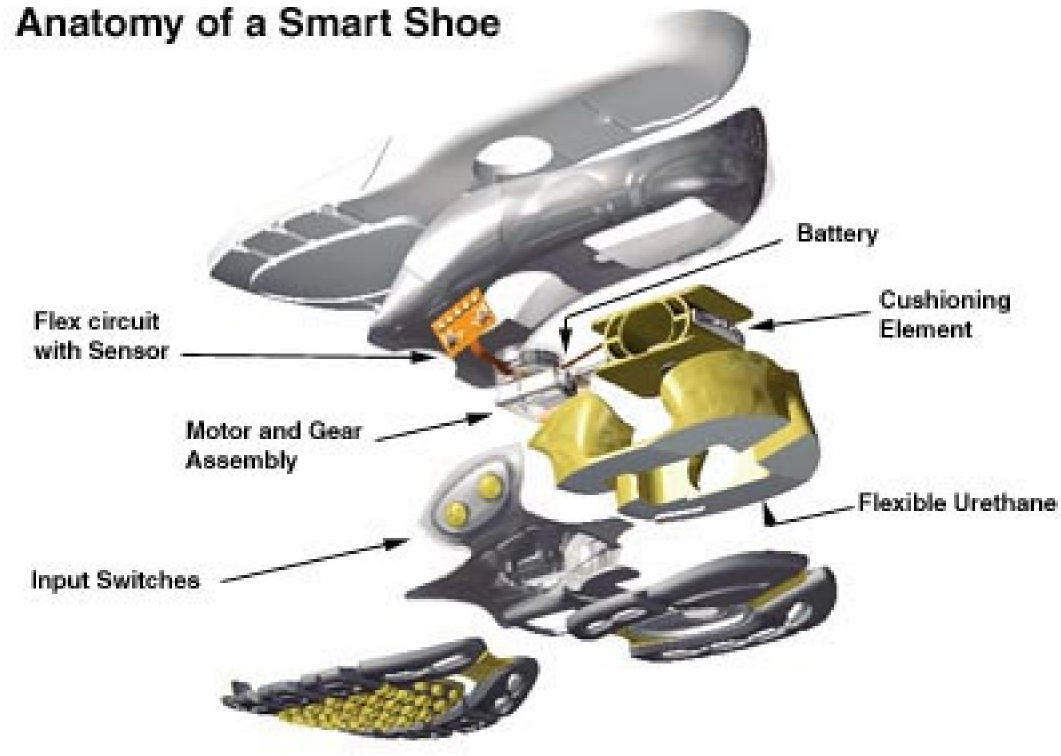


Figure. 4.85. Blow up of ADIDAS_1 design

A rigid, high-impact polycarbonate housing around the motor box protects it and maintains alignment for the parts inside it. This housing is then placed in a flexible

TPU. The shape and ribbing of this housing distributes the load around the motor and up into the shoe, providing a cradling effect for the foot.

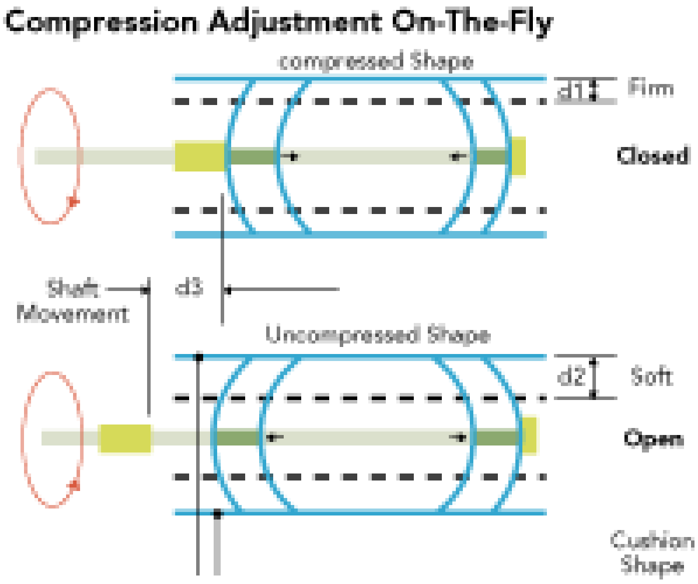


Figure. 4.86. Compression adjustment system detail graphics

How It Works: To adjust compressive force on the cushioning element, the motor drives a lead screw that expands or contracts a cable. This alters the space (d) available for movement of the cushioning element. As the screw turns, it expands or contracts a cable connected to a cushioning element in the heel of the shoe.

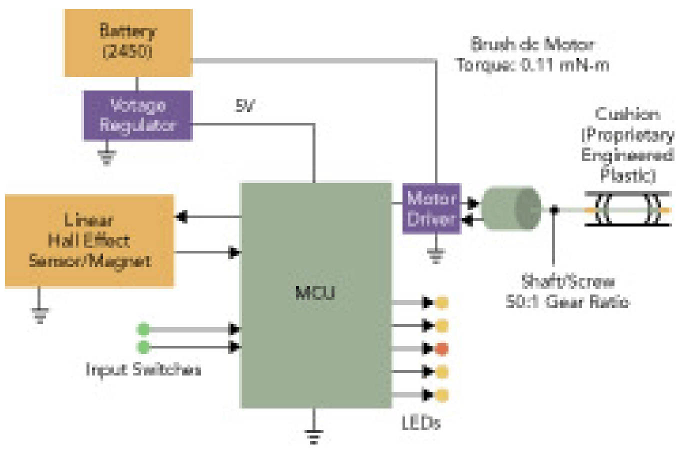


Figure. 4.87. System work of intelligent design

Minimum Impact: The dynamic cushioning system in the Adidas 1 running shoe consists of a microcontroller, brush dc motor and lead screw, cables, and Hall-effect sensor to automatically adjust the degree of cushioning. (www. Engineering Feat - 9-27-2004 - Design News - CA452888.htm)

NIKE FREE

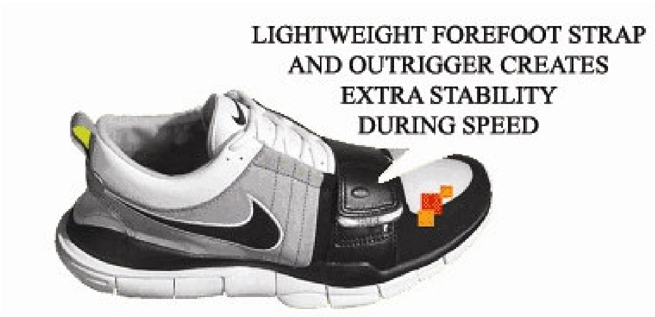


Figure. 4.88. Flexibility is the key factor for this footwear with deep cuts in the outsole.

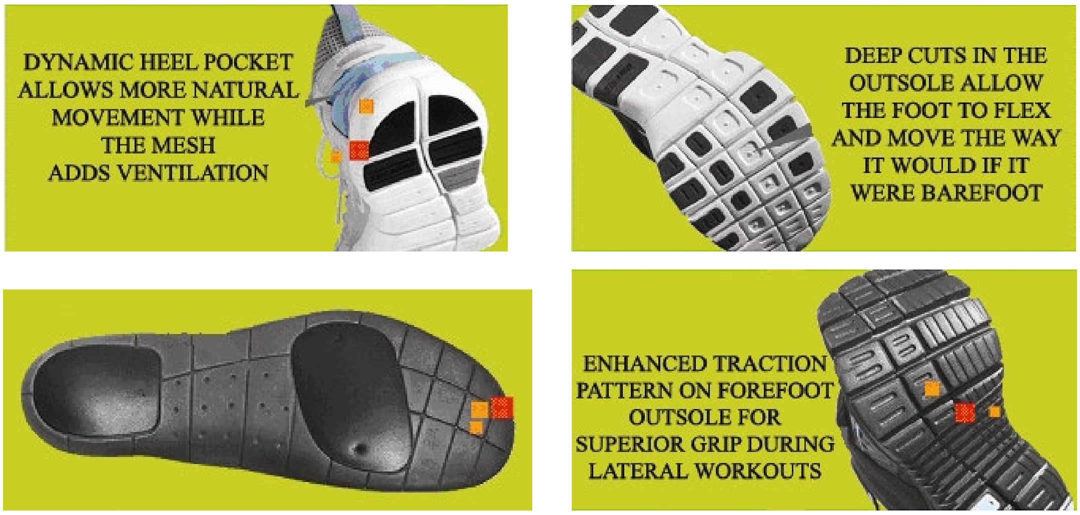


Figure. 4.89. For the insole design the cuts are also added for adaptation.

Figure. 4.90. Foot-footwear interaction

NIKE SHOX SERIES

The System: Two Pebax plates work interdependently with four columns to form the ultimate responsive cushioning system. The plates reduce peak pressure, deflecting it outward to the columns. They then quickly return to their original state - just like a trampoline. The entire system uniformly distributes your weight, releasing energy and propelling you forward.

NIKE Shox cushions AND stabilizes. The independent columns are made of a highly-resilient polyurethane foam that greatly reduces the stress of impact. The result: softer, more responsive landings on a stable platform.

Figure. 4.91. The SHOX columns on the SHOX in close-up.

An interesting aspect of the technology is that it can be tuned to the needs of specific sports and even specific athletes. The future potential of SHOX is very exciting. Where the SHOX columns meet the upper is the TPU (thermoplastic urethane) heel counter which provides heel support while also distributing the impact forces from the SHOX columns to the entirety of the heel. Each Shox unit is designed to be proportional to your bodyweight for maximum energy return.

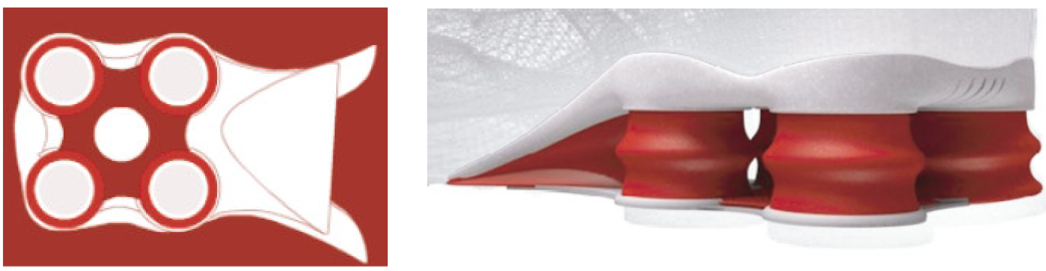


Figure. 4.92. Plan of system

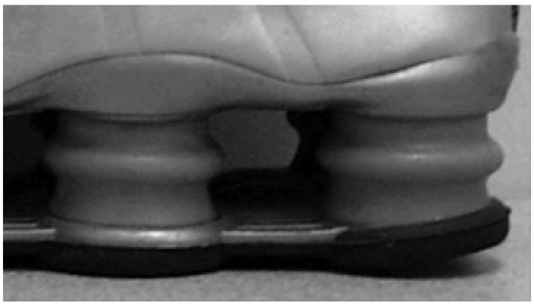
 

Figure. 4.93. Cushioning column systems for Shoe 1, top panel (*Shox*™, Nike Inc., Beaverton, OR) and Shoe 2, bottom panel (Iso-Dynamics Inc., Cleveland, OH). Each shoe is configured with four cushioning columns: Shoe 1 with high resilient urethane elastomer, Shoe 2 with thermoplastic polyester elastomer.

THE MIDSOLE: A built-in transitional wedge works together with a full-length Phylon midsole to enhance tortional stability. In other words, it guides you through every foot-strike. There's also a Poron insert in the forefoot for unsurpassed comfort in the foot-bed. It's made of a breathable, flexible mesh that stretches to accommodate a wide range of feet.

Figure. 4.94. ***34*** circular waffles fill lugs in the forefoot.

Each waffle has a recess around it that allows the lug to penetrate the internal midsole. So in effect, each lug works like an independent suspension. It's the complete package of durability, traction and road ride.

4.5. Case Study-1: Modular Insole Design

Insole is an interface design between foot and footwear. In this concept, to adapt to different types of foot different spherical modules designed in the purpose of changing according to need. This means; the insole can be matched to negative and positive errors of foot.

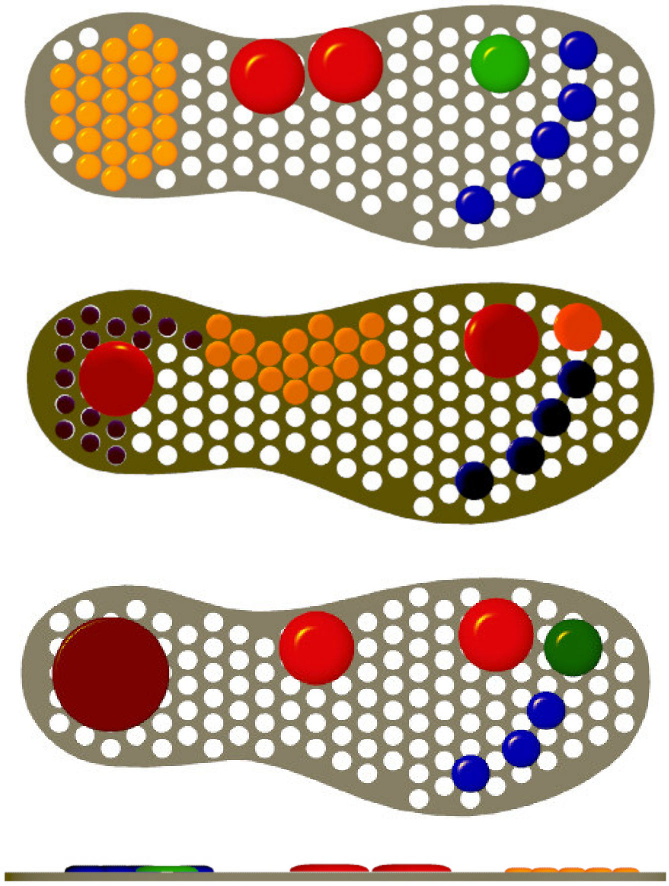


Figure. 4.95. The use of different modules

The foot's neural network characteristic is an important parameter which involves the whole body and lasts plantar, dorsal, medial and lateral parts of foot. According to this information called **reflexology**, this insole design aims to massage to different points of foot that consumer prefers. Modules are made of EVA foam with respect to supply suspension under the foot.

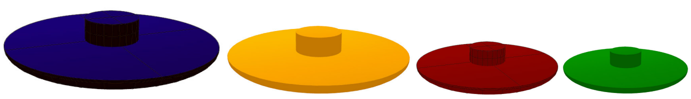


Figure. 4.96. Attachable modüles

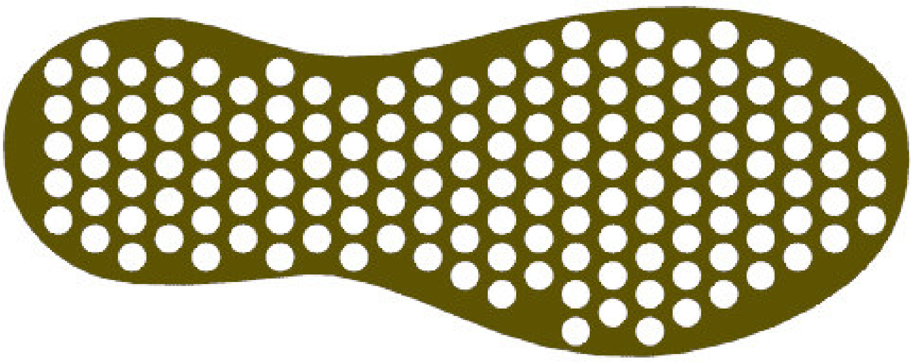


Figure. 4.97. The insole design with holes to attach the modules

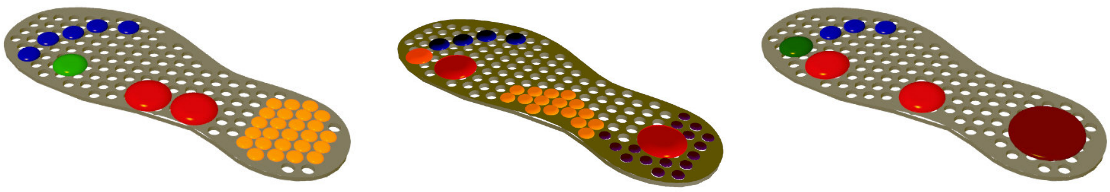


Figure. 4.98. Alternative use of insole design

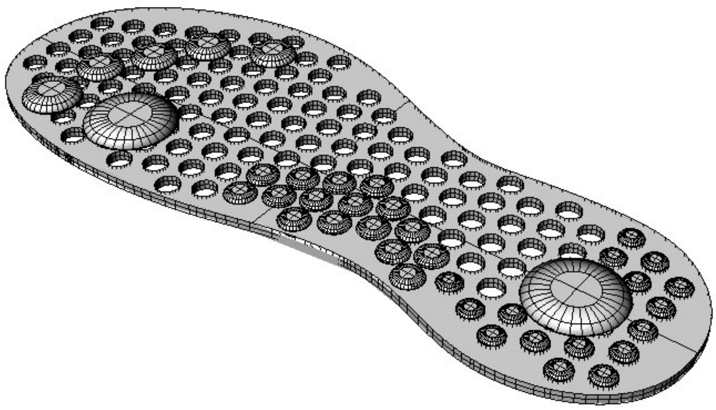


Figure. 4.99. The insole system

4.6. Case Study-2: A footwear design

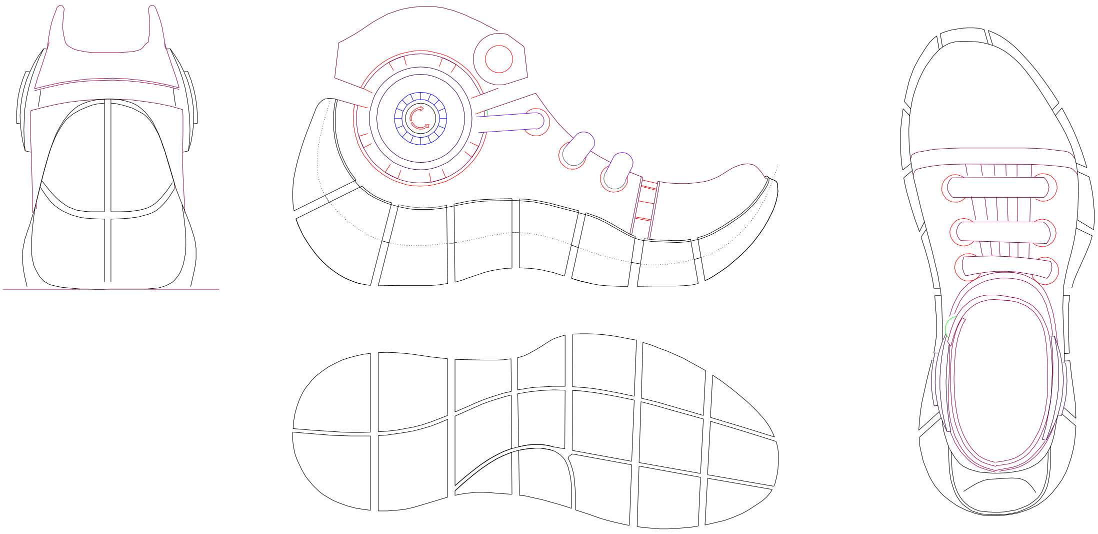
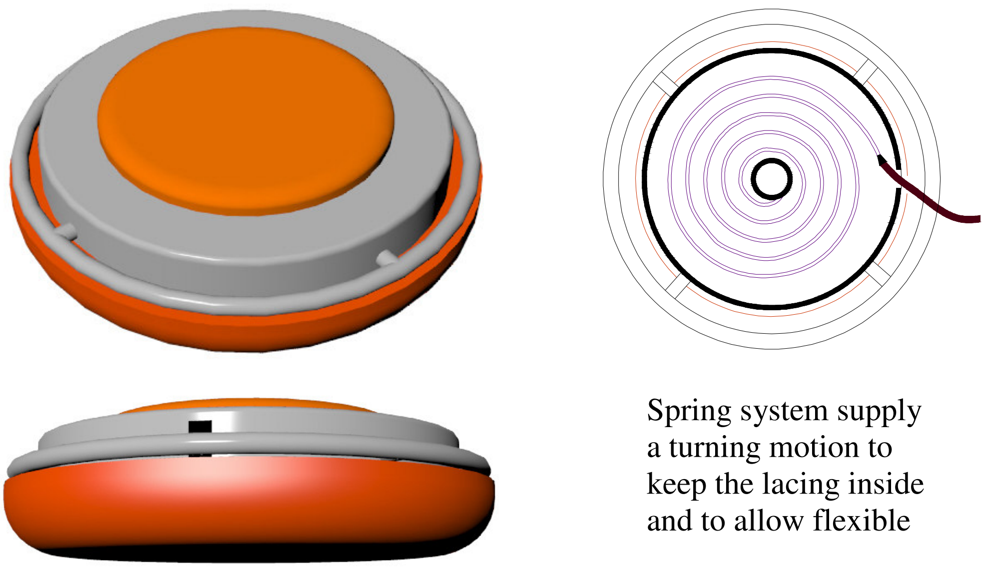


Figure. 4.100. Technical drawing of design

- Joint movement/ Flexibiliy
- Suspension by material phinomatic characteristic.
- Seperated parts in the upper
- Large areas for each gait phase,
- Stability in the heel counter
- Plantar arch definition
- Rocking sole design



Spring system supply
a turning motion to
keep the lacing inside
and to allow flexible

Figure. 4.101. Turnable lacing system

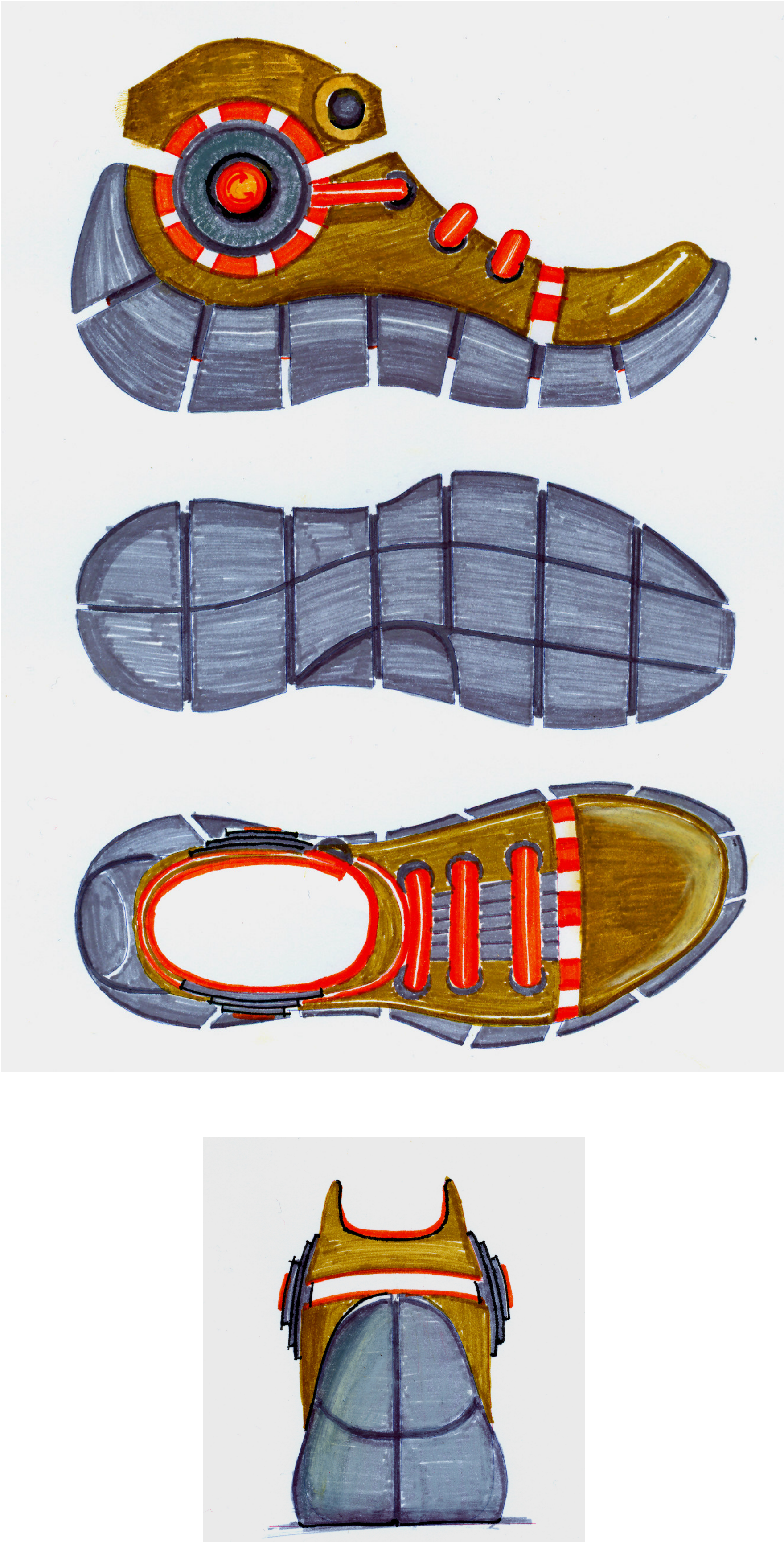


Figure. 4.101. New system application to flexible footwear design

CHAPTER 5

CONCLUSION

As designs become more detailed, the interaction between the human engineering and other disciplines becomes more advantageous. The implementation of the requirements needs to be verified, and additional design decisions need to be made as the design progresses. Designs will have to be reviewed for compatibility with human engineering requirements. The specific human engineering requirements, such as design requirements and human performance requirements, must be used to evaluate the designs. Especially some products like footwear directly interact with the human body. In this concept, the evaluation of footwear design could be possible by using the human engineering based knowledge. Incorporation of human engineering considerations systematically and effectively to footwear design, footwear will be user friendly, therapeutic, adjusted to foot biomechanics.

Since a person takes approximately 5,000-10,000 steps each day, mostly on hard surfaces, their entire musculoskeletal systems are being punished if their shoes do not fit correctly. Evaluating the shoe design solutions and fit using human engineering process will frequently provide comfort for the consumer and prevent being the source of their aching back, sore knees, and body fatigue.

All the different parts of the shoe have their own requirements, which are closely interrelated to the foot. If this interrelationship is ignored, the shoe will have a detrimental effect on the foot. The design of each component, the materials used, and the construction of the finished product all contribute to the shoes ability to meet human needs. For this reason studying the foot and its function during the gait cycle and interaction between the foot and the terrain in great detail is the heart of all well designed footwear. This knowledge allows a designer to develop a last that allows the joints of the feet to work naturally and unrestricted. Because, the form of footwear should conforms the nature of the foot.

The shoe is expected to wear well, feel well, keep its shape with wear, retain its style character, tread properly, allow for reasonable foot freedom, maintain both foot and shoe balance, remain structurally intact. These features are not always dependent on the quality of materials or components, or the manufacturing process. The design and multiple dimensions of the last provide the basis for the above but shoe stylists often pervert anatomy for the sake of style.

The body is exposed daily to transient forces due to the impact of the foot with the ground, in both walking and running. For well designed footwear, fitness, good shock absorption (cushioning), smooth tread, and a rocker sole design that encourages the natural roll of the foot during the walking motion, flexibility, control and stability in the heel counter area, lightness, and good traction, durability are the basic factors for the designer to consider and for the consumer to experience the comfort, safety, satisfaction and performance during use. Additionally, viscoelastic materials, both within the body and when used in footwear, are able to reduce these forces.

The right material makes the shoe flexible and also stable in the right places: the ergonomic design of the shoe protects the feet and joints. Leather, textiles and rubber have long since been replaced by functional plastics and shock-absorbing foams. The right material makes a product successful. In the future, material will play an increasingly important role. Modern materials help to make shoes more ergonomic. Shoes will have even better shock absorption and will become even lighter.

Due to the diversity of the human form, it is impossible to provide for the needs of each person on the planet. Shoe designers manage this overwhelming demand by supplying some standard, user-defined, foot-ground interface. Shoe design involves the complicated task of finding the most versatile specifications for the human performance through human engineering and biomechanical requirements.

On the basis of a review of the literature, it is clear that the wearing of footwear may influence postural stability in either a beneficial or detrimental manner.

Shoes alter the interface between the sole of the foot and the ground, both mechanically and neuro-physiologically. However, despite a number of published recommendations as to which features should be implemented in shoe design it appears that many questions remain unanswered regarding the influence of specific design features on postural stability. Appropriately designed shoes can reduce injury risk by moderating the effects of repeated impacts and adapting for the average or developing new solutions that fit to the different characteristics. Cushioned soles redistribute the loads on the foot, reduce the pressures on the plantar surface of the foot and attenuate the impact shock wave transmitted to the body or skeleton. Similarly, design features such as cushioning systems and mechanical stiffening elements can be used to control for balance and forces. Using objective measures design performance models can be developed or designed for the foot-footwear system which is aimed the natural function. It can be possible by analyzing the foot-footwear interaction through human engineering.

The influence of outer sole slip resistance is determined in this thesis because this factor needs to be considered with regard to the interaction between the shoe and the mechanical properties of the supporting surface and the friction to provide stability over a range of surfaces encountered in normal daily activities. The environment in which the foot interacts with the shoe, solutions should be conducive to maintaining any required clearance, as it can be extreme with high temperatures and high humidity levels during use.

It is clear that considering human engineering concept such as **anatomy, anthropometry**, **physical characteristics, biomechanics, and ergonomic** can drive the footwear industry to new heights. Consumers are looking for more comfortable footwear even at the expense of fashion and style especially those who need to be on their feet for long periods of time. Designing footwear to hold the foot in the right places while supporting the body weight at the right locations is the key to the development of footwear. Some recent studies are geared in this direction through Human Engineering, Human Factors and Ergonomics professionals to make footwear more user-friendly and comfortable. The important task is to design the right product that will have the right appeal and right fit. To furnish the necessary “comfort” to improve the human performance it is important to know the standards for comfort and even discomfort.

Concluding with the merits of the well designed footwear is dedicated to healthy child foot development. Designers should specially focus to the child foot and growing process because, this is the most important point to consider. Because child foot is shaped by the time they are growing up and mostly affected from the form and construction of footwear. So to prevent the result of foot and body disfiguring or altering usually self-imposed of natural shape of foot.

Knowing the shape of the foot outline will allow **designers** to incorporate the fashion components more effectively and efficiently. The use of flexible materials and innovative design features in footwear can compensate for such high variations. The locations of the relatively higher errors can provide footwear designers with important insights for not only shape but also materials, overlapping areas, stitching and so on.

Shoe designers can get details from human engineering researches, manufacturers and should have as much information as possible about the materials. In today's Information Age, customers want to know about technology, design, construction, components, soles, linings, waterproofing and other details that can help them select the most appropriate footwear for their needs. This is also a responsibility for designers to make the consumer more conscious about the critical points.

In Chapter 2, first of all, the concept of human engineering is defined. Then its role and perspective for the industrial design then the role and the responsibility of the designer is emphasized which is crucial for footwear design.

In Chapter 3, the foot structure is analyzed from the anatomical, morphological and biomechanical point of view to indicate and comprehensively bring to light the infrastructure of footwear design.

In Chapter 4, footwear design issues examined as a faulty of modern design comprehension and its discordant features and detrimental manner for the foot natural characteristics. In this direction, the fundamental for footwear design criteria discussed with respect to foot-footwear interaction and human engineering. Then the innovative and affirmative characteristic of modern footwear design is analyzed to encourage the designer to design the better products to drive the footwear design to new heights with respect to human nature using appropriate materials.

To designers, some research areas in footwear industry are suggested below;

- Research into novel and existing product attributes which can provide product differentiation and added product value e.g. comfort, easy-care, water resistance.
- Development of new materials, processes and technologies, as well as adaptation of materials, processes and technologies used in other sectors, to provide cost effective opportunities for product innovation.
- A comparative design analysis in the market today from the different point of view
- Reflexology based neurological approach to footwear design for medical care of illness
- The effects of manufacturing process to design solutions
- Aids to design innovation e.g. CAD/CAM, biomechanics. Tools to verify design with functionality and performance.
- Design and manufacture methodologies.
- Integrated design/information systems for concept-to-manufacture.

- Flexible production systems, particularly in the following areas: automated cutting, upper preparation and assembly, lasting and sole moulding/attaching.

These are all the responsibilities of designers to consider and to drive the footwear design to new heights with new concepts, such as intelligent design, user centered design and user interface design (to recognize the design and get some knowledge), computer based design information systems (CAD CAM systems to study different user characteristics to reach the knowledge of average values), human-footwear interaction for constitute a consciousness through human engineering and design relations.

Designers should focus on and concentrate on the possible future insight of footwear design as a responsibility in this consciousness. In the future, everyday shoes design will also be nourished from the high-tech developments of sports shoes. And meanwhile, sport shoes design will be taking progress with this consciousness.

The inclusion of human engineering criteria as a main part of the design process will be one of the most important developments in footwear design. Compared with the traditional design, human engineering considerations could be even more complex, but, it is the best way to find the right solutions for the footwear design.

BIBLIOGRAPHY

Abbott, John, 1964, "Footwear Evidence", Charles C. Thomas Publishing Company, (Springfield), pp. 19-23

Abboud, R.J.,Copyright, 2002, "Current Orthopaedics", *Elsevier Science Ltd.,*Vol. 16, pp. 165-179, available online at http://www.idealibrary.com

Adrian, K.C. 1991, "American Last Making: Procedures, scale comparisons, sizing and grading information, basic shell layout, bottom equipment standards", (Arlington, MA: Shoe Trades Publishing)

ANSVASTM F539.78 (1986). Standard for fitting athletic footwear, 229.235.

Barry, T.Bates, *1999*, "A Human Performance Model", B.S.E., Ph.D., FACFE, *Proceedings of the 64th Convention of the Oregon State Bar,.*

Bodziak, William J., 1990,"Footwear Impression Evidence", edited by Elsevier Series, (New York), pp. 4-5.

Bojsen-Moeller, 1978, "F. Biomechanic"*s VI-A*, Baltimore, IL: 261-266,

Byrne, M., Curran, M.J., 1998, "The development and use of a footwear assessment score in comparing the fit of children's shoes", *The Foot*, Vol. 8, pp. 215-218.

Cassidy, Michael J., 1980, "Footwear Identification", edited by Canadian Government Printing Centre (Canada) , pp. 109-122.

Cavanagh, P.R., 1980, "The Running Shoe Book", edited by Emmaus: Rodale Press, (Anderson World, CA: Mountain View)

Chang, W. and Seireg, A., 1997, "Frictional Properties of the Skin and Blister Formation", Third Symposium on Footwear Biomechanics, Tokyo, Japan

Chen, H.; Nigg, B.M.; Koning, J.D.E., 1994, "Clin. Biomec.., 9,6. 335-341.

Clarks, 1976, "Manual of Shoemaking", edited by Clarks Training Department (UK)

(Ceeny E The form of the foot in relation to footwear The Chiropodist 304-311

Choi, B.K. 1991, "Surface Modeling for CAD/CAM: Advances in Industrial Engineering", edited by Elsevier (Amsterdam)

Cheskin, M.P., 1987, "*The* Complete Handbook of Athletic Footwear", (New York: Fairchild Publications)

Corlett, E.N., 1989, "Ergonomics", *Applied Ergonomics*, Vol. 32, No: 3, pp.257-269.

Denvir, C., 1979, “The sports shoe” in *Baynes K & Baynes K (eds)* The shoe show: British shoes since 1790 Crafts Council

Dimaggio, John Dr., 1994, “The Foot and Shoe: an Important but Overlooked Identification Combination, International Association for Identification Annual Conference, Phoenix,

Downey, C.A., 1989, “Observational Gait Analysis Handbook”, edited by Professional Staff Association of Rancho Los Amigos Medical Center, pp. 252-256

Franke, E. H., 1951, “Mechanical impedance of the surface of the human body”, *Journal of Applied Physiology*, vol. 3, pp.582-590.

Fredrick, E.C., “The Running Shoe: Dilemmas and Dichotomies in design”, edited by Human Kinetics Publishers Inc. (Champaign)

Fredrick, E.C., 1984, “Sport Shoes and Playing Surfaces”, edited by Human Kinetics Publishers Inc, (Champaign)

Frey C., Thompson F., Smith J., Sanders M., Horstman H., 1993, "American orthopedic foot and ankle society women's shoe survey." *Foot & Ankle*; vol.14, pp.78-81.

Frey C., 2000, "Foot health and shoewear for women." *Clin Orthop*; vol. 372, pp.32-44.

Freychat P. and Bouche N. 1999, “Dynamic Arch Deformation and its Consequence on Shoe Design”, Footwear Symposium, Canmore / Canada, (August 5-7, 1999), Advanced Research Department**,** Decathlon Production, France, Vol. 25, p.650

Forner, A. García, A.C. Alcántara, E. Ramiro, J. Hoyos, J.V. Vera, P. 1995, “Foot Ankle Int.”, Vol.16, No:12, pp:778-786

Gage, J.R., 1990, “An overview of normal walking”. *Instructional Course Lectures,* vol. 39, pp. 291-303.

Gardener, R., 1856, “The illustrated handbook of the foot”, London

Goonetilleke, 2003, Ergonomics, vol.46, p.364

Goonetilleke, R.S., 1998, “Designing to Minimize Discomfort. Ergonomics in Design”, vol.6, No.3, pp.12-19

Goonetilleke, R. S. and Luximon, A., 1999, “Foot are and foot axis”, *Human Factors,* Vol. 41, pp.596-607.

Goonetilleke, R. S. and Eng, T. J., 1994, “Contact area effects on discomfort”, In Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting Santa Monica, CA: Human Factors Society, pp. 688-690

Goonetilleke, R.S, 1999, “Footwear Cushioning: Relating Objective and Subjective Measurements”, *Human Factors*, vol. 41, no.2, pp.241-256.

Goonetilleke, R.S. et. al., 2004, “Dimensional differences for evaluating the quality of footwear fit”, Ergonomics, vol.47, no.12, pp.1301-1317

Goonetilleke, R.S., Kwok L.T., Luximon A., 2003, “Foot landmarking for footwear customization”, Ergonomics, vol.46, no.4, pp.364-383

Goonetilleke, R. S., Luximon, A., and Tsui, K.-L., 2000, “The Quality of Footwear Fit: What we know, don't know and should know”, *Proceedings of the Human Factors and Ergonomics Society Conference*, 2000, San Diego, (July 29- August 4, 2000). Volume 2, pp. 515-518.

Greg T. Graglia, 2001, “Shoegear: The right shoe for the right activity”, *DPM, Madison VA Hospital,* (Madison, Wisconsin), vol. 1, no.5

Hamm, Ernest D., 1995, “Characteristics in Footwear Examinations”, European Meeting for Shoeprint and Tool Mark Examiners, (Vantaa, Finland)

Hanna A., 1985, “Design in strode: Explorations in shoe design Industrial Design”, Jan/Feb pp.40-45.

Hennig, A. Stacoff E., 2001, “Comparision of Foot-orthosis dimensions with an anthropometrical database of Children Healthy feet”, Proc. of the 5th Symp. on Footwear Biomechanics, (Zuerich / Switzerland), vol.38

Hennig E.M., 2002, “The human foot during locomotion - Applied research for footwear”, Wei Lun Public Lecture (10 October), Hong Kong: The Chinese University of Hong Kong;. pp.350-357

Henning, E. & Milani, T.L. 1995, "In-shoe Pressure Distribution for Running in Various Types of Footwear", *Journal of Applied Biomechanics*, Vol. 11, p. 299-310.

Hilderbrand, Dwane S., 1999, “Footwear-The Missed Evidence”, Staggs Publishing, Temecula, CA., pp. 7-8

Hilderbrand, Dwane, 2002, Four Basic Components of a Footwear Examination, The Magnolia Print

Ho, C.F., 1998, “3-Dimensional foot digitization”, Unpublished master's thesis, Hong Kong University of Science and Technology.

Holscher E.C. and Hu K.K. 1976, Detrimental Results with the common Inflared Shoe. Oithonedic Clinics of North America, vol.7, pp.1011-1018.

Horovitz, Z., *1991,* “Sole construction for footwear”, Andover MA, Composites, USA, (12 September 1989-2 March 1991), Volume 22, Issue, p.165

Hughes J.R., 1995, “Footwear assessment”, Merrimen LM, & Tollafield, (Ediburgh:Churchill Livingstone), pp.227-247

Janisse DJ. 1992, "The art and science of fitting shoes." *Foot & Ankle*; vol.13, pp.257-262.

Johansson, L., Kjellberg, A., Kilbom, A., and Hagg, G. A., 1999, Perception of Surface Pressure applied to the hand. *Ergonomics*, vol.42, no.10, pp.1274-1282.

Karwowski, W., 2000, “The science of an artifact-human compatibility”, Theoretical Issues in Ergonomics Science, vol.1, no.1, pp. 76-91.

Karwowski, P. Mondelo and M. Mattila All rights reserved, 2001, “Designing for Comfort: A Footwear Application”, Computer-Aided Ergonomics and Safety Conference '200, Edited by B. Das, W.

Kolarik, W. J., 1995, *Creating Quality*. New York: McGraw-Hill.

Kroemer, H., and Elbert, K. (1994). Ergonomics. How to design for ease and efficiency. New York: Prentice Hall.

Lemmon, D. et al., 1997, "The effect of insoles in therapeutic footwear – A finite element approach", *Journal of Biomechanics*, Vol. 30, No.6, pp. 615-620.

Liu, W., Miller, J., Stefanyshyn, D. and Nigg, B.M., 1999, “Accuracy and reliability of a technique for quantifying foot shape, dimensions and structural characteristics”, Ergonomics, vol.42, pp.346- 358.

Luximon A., Goonetilleke R.S., K.L, 2003, “Foot landmarking for footwear customization”, Ergonomics, 2003, Vol. 46, No. 4, pp.364-383

Manning J.R., 1966, “Size standardization”, Europoint The Chiropodist, vol. 21, no.6, pp.187-200.

Manning J.R., 1976, “Mondopoint: A metric system of shoe sizing and marking”, Australian Podiatrist, pp.102-103.

Martin D.R., 1997, “Athletic Shoes: Finding a Good Match”, The Physician and Sports Medicine, vol.12, no. 9,

McKenzie J., 1997, “The best in sportswear design”, (London:BT Batsford), pp20-23.

Naganoa A, Komurac T., 2003, “Longer moment arm results in smaller joint moment development, power and work outputs in fast motions”, Journal of Biomechanics, vol.36, pp.1675–1681

Nigg, Benno M., 1986, “Biomechanics of Running Shoes”, edited by Human Kinetics Publishers, (Champaign)

Nigg BM, Bahlsen HA., 1988, “Influence of heel flare and midsole construction on pronation, supination and impact forces in heel-toe running”, Int J Sports Biomechanics, vol.4, pp.205-219.

Nigg BM, Cole GK, Nachbauer W. Effects of arch height of the foot on angular motion of the lower extremities in running. J Biomech 1999; **26**: 909-916

Parham KR, CC Gordon & CF Bensel, 1987, “Gender and race differences in foot dimension”, American Journal of Physical Anthropology, vol.72, p.240

Parker, K. 1996, “Settling Footwear Complaints”, SATRA Technology Centre (Northants)

Rawling J.S. et al., 1981, “A manual of orthopedic shoe technology”, Precision Printing Co.

Roebuck J.A., 1993, “Anthropometric methods: designing to fit the human body”, Human Factors and Ergonomics Society, pp. 62-79

Rossi, W.A. and Tennant, R. 2000, “Professional Shoe Fitting”, Pedorthic Footwear, (New York), pp.103-118

Rossi W.A., 2000, “The complete footwear dictionary” edited by Kreiger Publishing Co., (Malabar)

Rossi W.A., 2002, “Children’s Footwear: Launching Site for Adult Foot Ills”, edited by Kreiger Publishing Co., Podiatry Management, (Malabar), pp.83-100

Rossi, William A, 1999, “Why Shoes Make “Normal” Gait Impossible ”, edited by Kreiger Publishing Co., Podiatry Management, pp. 50-61

Rossi W.A., 2001, “Footwear: The Primary Cause of Foot Disorders” edited by Kreiger Publishing Co., (Malabar), pp.129-138

Rossi W.A., 2001, “Fashion and Foot Deformation”, edited by Kreiger Publishing Co., Podiatry Management, (Malabar)

Rossi, W. A. (1988). “The futile search for the perfect shoe fit”, Journal of Testing and Evaluation, X, pp.393-403.

Sanders, M.S. and McCormick, E.J., 1987, “Human Factors in Engineering Design”, New York: McGraw Hill.

Segresser, B., 2001, “Injuries and Sport Shoe Design: Wish and Reality”, Footwear Symposium, Zurich, Switzerland, (5-7 July 2001)

Shackel, B.; Chidsey, K.D., Shipley, P., 1969, “Ergonomics”, vol.12, no.2, pp.269-306..

Stephen R. Lord, 1999, “Heel-Collar Height and Footwear and Postural Stability in Older People”, HYLTON B. MENZ, BPod (Hons), Volume 89 • Number :7 (July), pp.346-357

Yavatkar, A. S. 1993, “Computer aided system approach to determine the shoe-last size and shape based on statistical approximated model of a human foot”, Unpublished master's thesis, Tufts University, Medford, MA. 2-515

Woodson, W.E., 1954, “Human engineering guide for equipment designers”, University of California Press, (Berkeley)

Xia, B. and Robinson, J., 1997, “3D Kinematic Evaluation of Footwear Stability In Lateral Movements”, Third Symposium on Footwear Biomechanics, Tokyo, Japan,

Vass L. & Molnar M., 1999, “Handmade shoes for men” Cologne: Konemann.

Voloshin, A.; Loy, D.J., 1994, “Gait and Posture”, Vol.2, pp. 117-122.

Whittle, Michael. W, 1999, “Generation and attenuation of transient impulsive forces beneath the foot”, a review *Gait and Posture,* vol.10, pp. 264–275

Web Source:

WEB_1, 1999, "Anatomy of a Running Shoe”, Emmaus: Rodale Press, Runner's World Online: http://www.runnersworld.com/shoes/anatomy.html.

WEB_2, Carrozza, Paul, 1999, “A question of durability", Emmaus: Rodale Press, Runner's World Online: http://www.runnersworld.com/shoes/buzz1019.html.

WEB_3, 2004, Technical Group on Footwear Biomechanics: http://www.teleport.com/~biomech/sneakers.html

WEB_4, 2002, The Engineering Behind Shoe Design,İssue:iii Volume:5, "Anatomy of a Running Shoe." Runner's World Online:, Illumin. All Rights Reserved. Disclaimer http://www.runnersworld.com/shoes/anatomy.html,

WEB_5, Shorten, Martyn R. (Webmaster). "Technical Group on Footwear Biomechanics." International Society of Biomechanics.
http://www.teleport.com/~biomech/sneakers.html

WEB_6, N.J.Mills, C. Fitzgerald, A. Gilchrist, R. Verdejo, 2003, Polymer foams for personal protection: cushion, shoes and helmets, Composites Science and Technology, 63, www.elsevier.com/locate/compscitech

WEB_7, N.J.Mills, C. Fitzgerald, A. Gilchrist, R. Verdejo, 2003, Polymer foams for personal protection: cushion, shoes and helmets, Composites Science and Technology, 63, www.elsevier.com/locate/compscitech

WEB_8, Cooke, A and Dixon, 2001-2002, S., Sports Science and Engineering in Education: Sport Shoe Design, http://www.cookassociates.com,

WEB_9, Larsen, J., 1995-2002, Slam Dunk Science, A Sport Research Lab In the Classroom, http://www.scire.com/sds/sdsmenu.html, WEB_10, Emmaus: Rodale Press, 1999. Carrozza, Paul. "A question of durability." Runner's World Online: http://www.runnersworld.com/shoes/buzz1019.html.

WEB_11, FERNAND, 2002, TraceFeet. 21 June, http://www.fernandfootwear.com/html

WEB_12, 2002, Publishedby Elsevier Science Ltd. doi:10.1006/cuor.2002.0268, available online at , http://www.idealibrary.com

WEB_13, 2002, NIKE, (21 June 2002), http://nikeid.nike.com

WEB_14, 2000, Radovic PA: Feetfixer.com, http://www.nh.ultranet.com/~dd1822a/facts.html

WEB_15, 2004, Department of Podiatry, 13/10/2003, http://podiatry.curtin.edu.au/shoo.html#advice

WEB_16, http://www.nismat.org/ptcor/orthotics/

WEB_17, http://www.teleport.com/~biomech/sneakers.html

WEB_18, http://www.shoedoc.se/eng_menu.asp

APPENDIX A

VOCABULARY

Arch Height: Medial arch height of the insole.

Bespoke: Footwear made to measure to the highest specifications. In most cases a last is made especially to fit the wearer's foot, and stored by the bespoke maker. arch - part of plantar that does not touch the ground.

Arch Support: Area of insole built up and strengthened to support metatarsal arch, or similar support which can be inserted in the shoe separately.

Ball: The swelling at the inner side of the foot where the big toe joins the head of the first metatarsal bone. The main line of flexing of the foot, and hence of the shoe occurs across this point, which is herefore important in shoe fitting. This part of the foot is sometimes referred to as the joint.

Bones of foot: It is interesting though not essential for the shoe fitter to study the anatomy of the foot in detail. It is more instructive for him (or her) to understand how the bones move in relation to each other and the differing degrees of restricted movement between them. In a men's shoe with rather high cut quarters it is sometimes possible for the topline to press painfully on the outer ankle bones when the leg i.e. angled outwardly sideways with respect to the foot.

Brannock Device: A foot-measuring device having a slide piece adjustable to show the length of the foot and another slide piece which can be moved to show the distance of the ball of the foot from the heel. This measurement is used in conjunction with the foot length measurement to give the shoe size required. The device also indicates appropriate widths. The Brannock system is widely used in America, where it originated.

Bunion: An inflammation of the tissues over a joint, caused by pressure and/or friction. It most commonly develops over the protruberant metatarso-phalangeal joint of the big toe in cases of hallux valgus.

CAD - Computer Aided Design: A shoe design is prepared on the screen of a computer it is then put into the computer memory. It can then be modified and sectional patterns produced and all grading completed. Patterns can then be cut by laser water jet or mechanical cutter on instructions from the computer. Some systems can show 3D pictures of the designs.

Chiropody: Remedial care of the foot, especially dealing with corns, toe nail disorders and toe displacements (pronounce ky-rop-ody). construction - the basic method of making the shoe. In most cases this applies to the way the sole is attached to the upper.

Elasticity: the property of a body or material by which it stretches or under-goes other deformation under stress and resumes its original form when the stress is removed. If the stress continues beyond the limit of the material the material does not fully recover the original form. Elasticity is measured by the elastic modulus which is the ratio of stress to deformation.

Distribution of Measurements: Any distribution (set of measurements) can be represented by three statistics: mean (the average); median (midpoint at which 50% >, 50 %< than that point); and the mode (most frequently occurring number).

Ergonomlcs: The study of the working environment relative to work performance. Directed to the design of machines and factors in the environment to enable the individual to work most efficiently.

Flare: This describes the curve or contour of the last. The swing is determined by the position of the forepart when the last is bisected longitudinally forwards from the centre of the heel arc.

Footwear Forefoot Width: Width of the footwear in the forefoot region.

Footwear Heel Width: Width of the footwear in the heel region.

Footwear Length: Length of the footwear. (Mündermann, 2001, pp:40)

Forefoot Cushioning: Softness/hardness of the insole in the forefoot region.

Girth: The measurement round the wide part of the foot, namely the ball or joint. Used in several shoe fitting systems instead of simply the width. It is superior to the width system because it is possible for two people with the same foot width to have different joint girth measurements. The width system takes no account of the 'depth', that is the thickness of the foot a the forepart. The fitter takes account of it when he sees the customer's foot and suggests an appropriate width fitting.

Grain: The pattern of pores and other surface peculiarities, characteristic of the animal concerned, visible on the outer surface of a hide or skin after the hair or wool has been removed.

Heel Cup Fit: Fit of the insole in the heel region, i.e. whether the insole is loose or tight.

Heel Cushioning: Softness/hardness of the insole in the heel region.

Media-lateral Control: Position of the foot controlled by the footwear.

Outflare: This describes the last is the opposite with the swing lying to the lateral side of the forepart. Straights last describe neither an inflare or outflare preference. The long axis of the last when drawn through the bisection of the heel curve describes two equal longitudinal halves.

Overall comfort: Overall impression of the footwear.

Permeabillty: The ability of a material to transmit water or water vapour through its thickness. The comfort of a leather shoe is due in part to this property of leather.

injection mouldlng - a method of moulding a sole unit, for example, using PVC or other thermoplastic material, by melting the material in the heated barrel of an injection moulding machine and injecting it under pressure into the mould cavity. This is a cheap method of mass- producing shoes. The sole is flexible, waterproof long-wearing, with excellent adhesion, but tends to crack after a while.

plantar - the lower surface of the foot. Sometimes used to describe the insole.

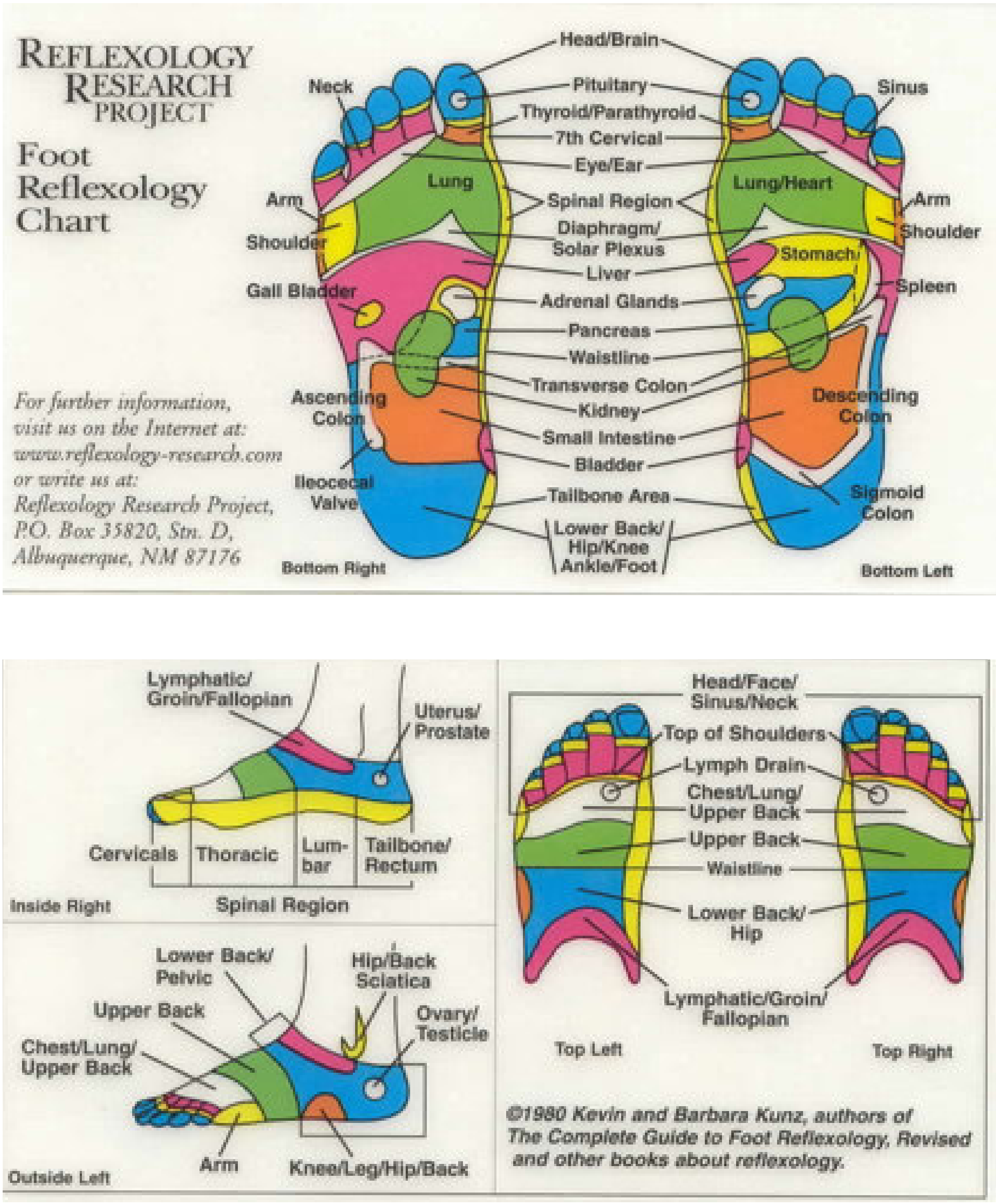
Plantar flex: Foot movement. To flex the foot downward so that the forefoot moves further away from the leg.

Platform: An extra component inserted between the insole and the outsole to add height to the wearer, or to give a chunky look to shoe design. The heel height has to be increased to accommodate the extra height. Platforms are made of various plastics, cork grain or even wood. In some cases they are moulded in one piece with outsole and heel.

polymer - a chain or other co-ordination of single molecules of a chemical compound.

Product Liability: The area of the law that deals with product safety and the legal liability resulting from the supply of unsafe goods.

Reflexology: It is foot's neurological system which contains the whole body neural network ends in and used in insole design.



SATRA: Shoe and Allied Trades Research Association, now known as the Satra Technology Center. It is an international center of shoe research, with headquarters and laboratories at Kettering.

Sizes: It should be remembered that there are two different size measurements. (1) foot length and (2) last or internal shoe length. The differences between lasts are quite large and it is best to rely on the skill of a qualified shoe fitter rather than to rely totally on the information from a size-stick or measuring device. These should be considered as a useful first indication. See also paris points and mondopoint. Further complication arises when shoes made on European lasts are imported into the UK. English sizes stamped on the shoes can never be accurate because English size interval of one third of an inch is different from the Paris Point increment of 0.66 cm; thus sizes get out of step.

Straight axis: The normal foot has a straight axes and lasted shoes can be worn on either foot.

Tread: This describes the width across the sole under the ball of the last and it should correspond to the dimension of the feet. The tread point on the last represents the bottom forepart just behind the ball and in contact with the base plane.

Vulcanized Construction: Construction in which rubber pellets are heated in a mould to form the bottom or a string lasted shoe. This construction is cheap and produces a flexible comfortable product, but it can only be used on rough materials like suede or fabric. It is not suitable for smooth leathers.

Virtual Reality: Advanced computer based 3-D graphics system with which the user can interact.