AN ABSTRACT OF THE THESIS OF

Elizabeth Ashley Halbauer for the degree of Master of Science in Design and Human Environment presented on May 2, 2014.

Title: Design Criteria of Minimalist Running Shoes

Abstract approved:

_____________________________________________________

Kathy K. Mullet

Much research has been conducted to determine the difference between running barefoot versus the traditional heel strike running style. Each style of running requires parts of the foot to strike the ground differently. Shoe companies have addressed these differences by designing different styles of shoes for each running style. This study looked to evaluate the design criteria of running shoes, to see if the current criteria are appropriate so that the shoe emulates the biomechanics of running. To do this a content analysis of running shoe reviews was done on a neutral, stability, minimalist, and racing flat shoe. This information was then compared to the biomechanics of barefoot running to see what design criteria were needed to emulate barefoot running.

The design framework for this study was reverse engineering. This concept relies on understanding the product, and the needs or problems which each component in the product meets. The idea is to find the components which are most successful in order to use those components to design another product which has similar needs.

Data were collected that allowed the researcher to define the problem that needed to be solved. This was done in the form of analyzing blog reviews of male runners. Blogs were read
and coded to evaluate what male runners thought about the characteristics of neutral, stability, minimalist, and racing flat shoes that are currently on the market. It was assumed that runners would be more likely to express their satisfaction or dissatisfaction with a particular shoe in blog as opposed to a survey.

Physical requirements were defined using the information collected from the blogs along with consideration of the biomechanics of barefoot running information that was found during the review of literature. Once physical requirements were defined, market research was done to see if there was currently a shoe being sold that had all of the requirements defined by the study. Finally the final shoe criteria was evaluated to be sure that it solved the problems determined from the blog data.

The success of this study provides a method by which shoe manufactures can use publicly available information to develop design criteria, based on current user needs.
Design Criteria of Minimalist Running Shoes

by
Elizabeth Ashley Halbauer

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented May 2, 2014
Commencement June 2014
Master of Science thesis of Elizabeth Ashley Halbauer presented on May 2, 2014

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

____________________________________
Elizabeth Ashley Halbauer, Author
ACKNOWLEDGEMENTS

I wish to express my sincerest appreciation to my advisor, Dr. Kathy Mullet, for all of her support and enthusiasm. To all the members of my committee I wish to express my gratitude for their guidance and their willingness to go above and beyond.

I would also like to thank my parents for making graduate school at Oregon State a possibility, for helping me move from Illinois to Oregon on a week’s notice, and their continuing willingness to help make my ever changing life goals happen. It’s been an adventure! To my big sister, Sarah I have endless gratitude for being there for me always and whenever I need you.

To my officemates, your advice and friendship has meant so much to me you truly got me through this last year.

And last, but definitely not least, to the boys who befriended me when I knew no one. Your friendship, support, and willingness to change a bike tube has meant the world to me. Without you kids I would not have made it two years in this rainy state.
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Chapter 1

INTRODUCTION

Humans started running over two million years ago. The earliest humans who ran did so barefoot. It is estimated that about 30,000 years ago humans started to use protective coverings on their feet (Rixe, Gallo, Silvis, 2012). Previous to the development of modern day running shoes, people mostly ran barefoot. The first modern day running shoes were not developed until the 1970’s (Lieberman, et al., 2010). In 1971, the first modern day running shoes were created by Bill Bowerman using his wife’s waffle iron as the mold for the shoes sole. The company that formed to sell these innovative shoes is now the leader in running shoes, Nike (Moore, 2006).

Recently minimalist running has become a popular trend. Today, if you look at any major athletic shoe brand such as Adidas, Asics, Brooks, or Nike, all offer a shoe that claims to simulate a barefoot-like ride. Whereas most runners are not ready to take the leap into running completely shod free they are interested in what barefoot running has to offer them. As a compromise to running unshod, most runners interested in the barefoot trend will try minimalist running shoes. Today companies are devoting time and effort into the research and development of these types of running shoes (Novacheck, 1998).

Barefoot running is just like it sounds. An athlete who is a barefoot runner runs without any foot covering, or unshod. The popularization of barefoot running has come about because experts in the field have found that barefoot running may reduce the risk of running related injuries. While research supports the idea that barefoot runners may be less likely to have running related injuries, it is still unclear if the minimalist running shoes developed to simulate a barefoot-like ride actually do simulate barefoot running (Murphy, Curry & Matzkin, 2013).
Traditionally exercise sport and athletic trainers have been interested in studying activities or how to prevent injuries. However, few have studied the influence of clothing on the activity. The purpose of this study was to review existing biomechanical literature related to understanding the mechanics of running and compare this information with what is known about barefoot running. Running shoes were then compared to determine what features of a shoe supports the biomechanics aspect. From this data, a shoe for barefoot running or walking can then be designed based on the biomechanics data and the design specifications.

**Purpose of the Study**

The purpose of this study was to understand the design criteria that are needed for a minimalist running shoe that truly gives the runner a barefoot-like ride. This study aimed to find out if there was a method that can use the biomechanics data of the foot while running to develop a shoe design. Using the method of reverse engineering, current shoe designs were evaluated to determine what design characteristics supported the biomechanics aspect of running. The biomechanical aspect of barefoot running was then compared with current minimalist shoes to determine if the design criteria were met.

**Objectives of the Study**

The objectives of the study were:

1. To identify the differences between the biomechanics of the foot while running in traditional running shoes as well as the biomechanics of the foot while running barefoot.

2. To identify running shoes styles which were evaluated as satisfying the needs of runners.

3. To compare running shoes to determine design criteria which support the biomechanical aspect of barefoot running.

4. To establish design criteria which could be used to evaluate or design a running shoe.
5. To evaluate current shoes on the market to determine if any shoes meet the specified criteria established in Objective 4.

**Limitations of the Study**

As I will be looking at shoes from all brands and cost brackets of running shoes in order to get a comprehensive idea of what current running shoes on the market, I will not be able to personally study, inspect, run in, nor review all of the running shoes. I will therefore rely on expert reviews and analysis of the shoes in order to collect data for my research. Other limitations include not being able to obtain a comprehensive list of every blogger that reviewed the shoe which lead to a fairly small sample size. Finally being able to build an actual prototype of the minimalist shoe with the criteria that was identified in this study is not possible and therefore testing the final design criteria was not possible.

**Assumptions**

This study was completed with the following assumptions. First it was assumed that the specification information about the selected shoes were correct. Second it will be assumed that the information that bloggers reported in their review was their truthful and honest opinions about each shoe.

**Rationale**

There is much debate about whether or not running barefoot reduces injuries. While some studies conclude that running barefoot is beneficial for a runner, others have concluded that barefoot running will increase injury, still others have concluded that the benefits of barefoot running depends on the biomechanics of the individual (Murphy, Curry & Matzkin, 2013). As
the popularity of barefoot and minimalist running has increased, it is important to know whether or not a minimalist running shoe gives the same ride as running barefoot. Since some studies show that minimalist running shoes are more akin to wearing traditional running shoes, it is important to find out if this is a fact and if so how can the shoe be redesigned to fit the activity.

**Definition of Terms**

**Anterior** - In medical terms refers to front of the body

**Anterior tibialis** - Muscle that runs from the top of the shin down and inserts into the base of the first metatarsal

**Barefoot Running** - Running with no protective covering or support for the foot

**Dorsiflexion** - Flexion in a dorsal direction; especially: flexion of the foot in an upward direction

**Foot strike** - Where the foot has initial contact with the ground during a gait cycle. The three types of foot strike include fore, mid, and heel

**Gait Cycle** - the period of time between when one foot hits the ground and when the same foot hits the ground again

**Ground Reaction Force (GRF)** - An external force that is the ground acting upon the runner

**Kinematics** - a branch of physics that deals with aspects of motion apart from considerations of mass and force

**Kinetics** - A branch of science that deals with the effects of forces upon the motions of material bodies or with changes in a physical or chemical system

**Lateral** - In medical terms refers to the area closer to the outside of the body

**Medial** - In medical terms refers to the area closer to the middle line of the body
**Minimalist** - A type of running shoe that is light weight and flexible. The shoe simulates running barefoot while still offering protection from the road and elements.

**Plantar flexion** - Movement of the foot that flexes the foot or toes downward toward the sole.

**Posterior** - In medical terms refers to back of the body.

**Pronation** - Rotation of the medial bones in the metatarsal region of the foot inward and downward so that in walking the foot tends to come down on its inner margin.

**Shod** - The action of wearing shoes.

**Supination** - A corresponding movement of the foot and leg in which the foot rolls outward with an elevated arch so that in walking the foot tends to come down on its outer edge.

**Traditional running** - Running with a heel strike gait cycle.

**Traditional running shoe** - Shoes which have been developed for running with a heel strike.
CHAPTER 2
REVIEW OF LITERATURE

The purpose of this study is to understand the design criteria that are needed for a minimalist running shoe. The review of literature will discuss design processes, the use of a needs assessment to determine design criteria and reverse engineering to support the proposed design framework for this study. The review of literature will also discuss the biomechanics of running, the biomechanics of barefoot running, and the characteristics of a traditional running shoe.

Design Processes

There are several traditional models that are useful to the process of designing a functional product. One such model is the three step design process (Solkowoski & LaBat, 1999). In this design process the three steps used are problem definition and research, creative exploration, and implementation. During the problem definition and research step, an initial problem definition is made. Research is then done to identify user needs, function, aesthetics, and economics. Market research is conducted to identify products that are currently on the market and what the current competition is. The final sub step in this process is to take what the research shows and create a working problem definition. The second step in the model is creative exploration. During this step, the researcher comes up with preliminary ideas, not containing themselves by any requirements in order to come up with an expansive variety of solutions. Next the researcher must refine ideas using user constraints such as function, economic, and aesthetic aspects as well as product constraints which include factors such as cost of production, time of production, method of production, and potential to be sold. Once designs are refined a prototype
can be developed, the design for the prototype is decided upon by taking into consideration design criteria (customer requirements) and workable ideas. The final sub category of this step is to evaluate the prototype. The product would first be evaluated by the researcher and then given to the customer for evaluation. The final step of the three step design process is implementation. During this step production is refined taking into consideration production constraints. The product can then be immediately produced or further evaluation can be done. However if further evaluation is done, then the production of the product will be held up.

A similar design process is discussed in Watkins (1988), “Using the Design Process to Teach Functional Apparel”. This design process is similar to Sokolowski and LaBat’s three step design process. This model uses seven steps to aide in the creative process the seven steps include: acceptance, analyze, define, ideate, select, implement, and evaluate. The acceptance stage asks the designer to accept the problem and the challenge to finding a solution. During the analysis step, extensive research is done so the designer can understand all aspects of the problem. The define stage asks the designer to identify the most important aspects of the problem and create a definition of the problem to come back to during the evaluate stage. During the ideate stage, the designer comes up with as many solutions to the problem in order to have a large sample of solutions to choose from to solve the problem. The selection stage asks the designer to choose the solution that best solves the problem. The implement stage is where the ideas become a prototype. The evaluate stage analyzes the idea that was chosen. To evaluate whether or not the final idea was a success, the designer looks back at the definition of the problem created during step three to see if the design solves the problem that was designed. In each of these two design processes; design criteria are established and then used to evaluate the final product. In order to develop the design criteria, a needs assessment is the first step.
Needs Assessment

A needs assessment is part of the functional design process. A needs assessment is conducted to identify problems with a current product. To complete a needs assessment research might include reading articles, and examining the product in person. Often “experts” or people who are experienced users of the product are questioned to find what needs are being met to optimize the functionality of a garment.

Cho (2006) redesigned hospital gowns. The researcher uses a needs assessment to identify the problems with existing hospital gowns. To identify problems, the researcher recruited volunteers to take a survey about their thoughts on current hospital gowns. Former patients were asked three main questions about the gowns including design features of the gown they wore during their hospital stay, what activities they did in the gown and any problems they encountered in performing these activities, and finally what they thought were important features to include in a functional hospital gown. In addition to former patients nurses were also surveyed. Nurses were asked questions such as “what are current design features in hospital gowns”, “what their activities were”, and “if they had a suggestion to improve upon current designs” (Cho, 2006 p.??).

Black and Cloud, (2008) assessed functional clothing needs of bicycle patrol officers. The researchers use a needs assessment to identify problems with bike patrol officer uniforms. To do this they sent out questionnaires to a sample of police patrol officers in order to collect their data. The results of the data were analyzed to find what officers thought needed to be improved upon in their uniforms. In this needs assessment most officers were neutral or happy with their uniform. The researchers suggest that this information can be used in the future to redesign and optimal uniform for bike patrol officers.
In the article “Problem Structure Perceived: Dance Practicewear Needs of Adult Female Dance Students”, a questionnaire was used to survey dancers of all commitment levels on their preferences in practice wear (Mitchka et., al 2009). The questionnaire was arranged in four parts the first asking about commitment to dance, the second asked about dance wear expectations, the third section asked about dance wear attributes, and the fourth section asked the person being surveyed to rate eight common garments worn during practice for satisfaction with selection. The data was then statistically analyzed. Findings on what different dancers thought was important or what they expected from their dance practice wear varied among commitment levels. The researchers suggest that the study will help inform the rest of the design process for the improvement of dance practice wear.

**Design Criteria**

Customer or physical requirements are made apparent through a needs assessment. The needs assessment gives the researcher information and data that they can analyze in order to come up with what the customer/physical requirements.

“Customer requirements”, “design criteria”, “physical requirements” are used to describe the problem or needs identified in a needs assessment. This interchange of terms was reported in a study which looked to solve was that there were no clothes small enough for neonates to wear when they were born. The researchers went about solving this problem in six steps. The first step of the process was interviewing hospital directors and making observations. The researchers defined six criteria/concerns that needed to be taken into consideration when designing the garments. These included comfort, safety, adjustability, accessibility, aesthetics, and production. These six criteria were then used as a basis to design the garment. An interaction matrix was developed to see which, if any of the requirements would come in conflict with one another.
Researchers then used this information to design the garment including as many of the requirements as possible. Prototypes of the garments were made. To evaluate the prototype garments, the garments were to two hospitals along with questionnaires for nurses who work with neonates to fill out. (Bergen, Capjack, McConnan & Richards, 1996)

**Reverse Engineering**

Curtis, Hartston, and Mattson (2013), define reverse engineering as “the process of extracting information about a product from the product itself” (p.1). Reverse engineering has three stages. During the first stage, the product is studied taking into account the customer needs. The researcher usually has hands on experience with the product they are looking to redesign. The researcher may also disassemble the product in order to see all of the parts of the product. During this stage, manufacture analysis are done as well as a functional analysis. A final design is generated and the design specs are created. A prototype is actually created and experimentation is done on the prototype. In the final stage, a final product is created based off of the information procured during the first two stages (Otto and Wood, 1998). The reverse engineering process should be completed many times in order to increase accuracy of the data (Curtis, Hartston, & Mattson, 2013).

In summary the Reverse Engineering and Redesign Method steps are:

1. Formulate customer needs
2. Reverse engineer
3. Creating functional model through teardowns
4. Specifications that match customer needs
5. Depending on redesign scope new features are possibly perceived
6. Models of specs are developed to optimize
7. New product form is built and further optimized using design experiments
Combining the Design Process and Reverse Engineering

In general, design processes have started with a problem or needs assessment in order to develop a new product. In each of the processes implementation and evaluation of the final product are suggested. This study proposes to use the technique of reverse engineering to evaluate the final product and proposes that this reverse engineering of one product can be used to implement or evaluate a product which has been developed with known customer needs. Figure 1 illustrates this process of starting with the design process and then through reverse engineering to evaluation of a new product.

The proposed design process combines aspects of the seven step design process and the method of reverse engineering. When designing a functional garment one must take into consideration several steps in order to have a final product that is functional for its intended use. In order to design a product that is optimal for the intended use one must consider a needs assessment, problem definition, design criteria, implementation and evaluation.

In reverse engineering, the process works on the premise that a product is successful at satisfying a problem or need. Being able to understand the successful component or design criteria of the existing product, it stands to reason that component or design criteria can be used to design another product.

For this study, the physical needs of the runner are determined through a review of literature on the biomechanics of runners. Shoes that are evaluated as being successful in satisfying these physical needs are then identified. Design criteria are determined through reverse engineering the identified shoes, and these become the criteria for evaluating or designing a new product.
Figure 1 shows the combine design process and reverse engineering. While I used four products in this study two products are shown for simplified explanation. First, a needs assessment is done on each product. Through a needs assessment design criteria are identified. The design criteria that is identified as satisfying the problem are then chosen and put together to make a new product. The new product is then evaluated to see if the new product satisfies the user needs.

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Figure 1: Reverse Engineering Design Process

**Biomechanics of Running**

In order to understand barefoot running and how a minimalist running shoe can best simulate it, we need to understand the differences between traditional running and barefoot running. As running becomes more popular companies are putting more time and money into researching the mechanics of running in order to design more effective shoes.
Running occurs when a person’s feet both leave the ground for a period of time. In contrast while walking one foot is always in contact with the ground at all times. (Novacheck, 1998). A gait cycle is the period of time between when one foot hits the ground and when the same foot hits the ground again. A gait cycle consists of five stages; 1. Heel strike 2. Fully loaded foot 3. Heel lift 4. Toe off 5. Heel strike. These five stages are broken up into two phases, stance and swing. Mid stance occurs during just after toe off. The mid stance is characterized by supination at the subtalar joint which gets the foot ready for propulsion. Propulsion takes place during the stance phase as well, during propulsion the heel lifts and the stage concludes with the toe off. The swing phase starts at the toe off and the foot pronates and dorsiflexes in order for the foot to pass over the ground. The foot then resupinates at the end of the phase in preparation for the beginning of a new gait cycle (Prost, 1979). During a runners gait cycle both feet do not come in contact with the ground at the same time, in fact, there are two periods of time that neither foot is in contact with the ground. As a runner starts their gait cycle their body is tilted forward, this is so that the runner does not fall backwards from the ground reaction force being placed on their body. When the runner reaches their maximum velocity their body starts to straighten up. There are two parts to a gait cycle the stance and the swing. The stance occurs when the runner is preparing to take off. The swing is the start of the toe off as the foot prepares to leave the ground (Rothschild, 2012).

As the runner goes through a gait cycle the runner must land on their feet. This is called the foot strike. In running biomechanics there are three types of foot strikes, the fore foot strike, the mid foot strike, and the heel strike. A forefoot strike occurs when the runner lands on the ball of their foot and rolls down. A mid- foot strike occurs when the runner lands flat on their feet. A rear foot strike occurs when the runner lands on the heel of their foot (Lieberman et al., 2010).
Eighty percent of distance runners strike the ground with a rear foot strike, however the faster a runner runs the more likely they are to change to a forefoot strike (Novacheck, 1998).

While running there are two types of forces being acting upon the body, these two forces are internal and external. An internal force comes from within the body and cannot be measured. Internal forces can only be estimated. External forces come from outside the body. External forces can be measured (Nigg, 1986). Ground reaction force is an example of an external force because it is the force of the ground, something that is outside of the body, acting on the body. As discussed earlier ground reaction force affects a runner’s gait while they are gaining speed. Other external forces that act upon a runner are body weight and air resistance. Both external and internal factors affect a runner’s gait cycle.

**Biomechanics of Barefoot Running**

While many of the terms are the same in the biomechanics of running shod and barefoot the actual mechanics vary greatly. A barefoot runner runs with a shorter stride length and a higher cadence. A shorter stride length means the runner has a decreased vertical movement. A decreased vertical movement potentially reduces the initial impact forces on the body (Rothschild, 2012). It is advantageous that initial impact forces are reduced because most running injuries occur when the impact of the body hits the ground (Lieberman et al., 2010).

A study by Squadrone & Gallozzi (2009) looked at sixty consecutive steps that each participant took. It was concluded when looking at these sixty consecutive steps that flight time in barefoot running reduces impact peak and therefore reduces high impacts of mechanical stress. These findings reinforce that of Rothschild (2012) and Lieberman et al. (2010) (Divert et al., 2005).
In a study looking at the difference in foot strikes it was concluded that out of the four
different foot strikes they identified, toe, fore, mid, and heel, a runner has the least amount of
ground contact time when they land with a toe or fore foot strike (Nunns et al., 2013) The
forefoot strike of barefoot running allows the ankle to plantar flex which lowers the body in a
more stable controlled fashion (Rothschild, 2012). The mid foot strike and the forefoot strike
unlike the heel strike, which is associated with running in traditional running shoes, reduces
stress put on the heel (Squadrone & Gallozzi, 2009).

Other mechanical differences between barefoot and shod running include lower peak
torques at the hip knee and ankle in barefoot runners (Rothschild, 2012). A barefoot runner has a
greater ankle excursion which means the ankle is going to absorb more impact.

A barefoot runner fore foot striker has a loading rate three times less than that of a
habitually shod heel striker. Loading rate is defined as a runners landing force divided by landing
time (Murphy and Curry et al., 2013). A lower loading rate means less force is put on the body
when landing.

Leg stiffness is maximum vertical ground reaction force divided by leg compression
(Blum, Lipfert and Seyfarth, 2009). The leg can be thought of as a spring with the muscles
tendons and ligaments all working together. When the leg gets ready to hit the ground all of these
elements compress together like a spring. This gets the leg ready to push off of the ground to
take another step. Greater leg stiffness means that there is a shorter contact time with the ground
(Farley and Morgenroth, 1999). The same concept of the spring also applies to the ankle (Butler,
Crowell III and Davis, 2003).

The biomechanical characteristics of barefoot running are summarized as:

1. Shorter stride length, higher cadence
2. Fore or mid foot strike
3. Impact transient of ground reaction force is insignificant
4. Loading rate is 3 times less than a shod heel striker
5. Lower leg and ankle stiffness.

Barefoot Running vs. Traditional Running

There are many differences in the biomechanics of a shod and a barefoot runner. One of the most studied differences between shod and barefoot running is the foot strike of the runner. A shod runner most often hits the ground with a heel strike this means that the heel hits the ground first. A barefoot runner hits the ground with a mid or fore foot strike (Rothschild, 2012). Foot strike affects a runner’s stride length and cadence, a barefoot runner has a shorter stride length and a higher cadence. Since a barefoot runner typically lands on their fore foot this means that the part of the foot that will need to be protected most is the fore foot, unlike in a traditional running shoe where the heel is significantly cushioned. As discussed above a barefoot runner has a shorter stride length and a higher cadence than that of a shod runner. This means that a barefoot runner gets less vertical movement when they run. The higher a person jumps off of the ground the higher the force being place on the body when they come back down. Since a barefoot runner has as much as three times less of a loading rate the body does not have as much force acting on their body when they land. This would reduce the amount of aide they would need from cushioning they would need to absorb force. When running a barefoot runner has a lower leg and ankle stiffness. A lower leg and ankle stiffness means that the lower muscles, tendons and ligaments are more relaxed when they are in motion and coming in contact with the ground. A lower leg and ankle stiffness leads to less ground contact time. Finally it is intuitive that a barefoot runner is going to be able to move more freely and feel every bump and texture of the ground that the runner is running on, while a runner that is running in a traditional running shoe
is going to be protected from the elements and won’t have the same freedom and tactile experience as that of the barefoot runner.

**Characteristics of Shoes**

In order to understand the design criteria which are influenced by the biomechanics of different running styles. It is important to understand the various components which are used in running shoes. A traditional running shoe will be analyzed to provide a context for further discussion of shoe components that will be established as design criteria.

**Traditional Running Shoes**

There are three characteristics that one should look for in a traditional running shoe: one that reduces impact forces, controls pronation, and controls supination on takeoff (Nigg, 1986). A high impact runner is someone who hits the ground hard with their feet. You can tell if you are a high impact runner by listening to see if your foot makes a noise when coming in contact with the ground. A low impact runner lands more lightly on their feet and will not make noise when their feet come in contact with the ground. Whether you are a high or low impact runner is dependent on how much cushioning one should look for in a running shoe. A high impact runner needs a shoe that offers more cushioning to absorb the impact of the ground reaction force being placed on their body. A low impact runner in contrast, does not need a lot of additional cushioning because the ground reaction force being placed on their body is not that great (Nigg, 1986). A running shoe is made of three parts: the insole, mid-sole, and outsole. In a traditional running shoe the major variation is in the midsole of the shoes cushioning, here there
is room for variation in use of foam, gel, air, etc. to be used for cushioning (Murphy & Curry et al., 2013).

Figure 2 and Table 1 provide an overview of the parts of shoes and purpose or activity which the components support in running.

Figure 2: Parts of a Traditional Running Shoe (Nigg, 1986)

<table>
<thead>
<tr>
<th>Shoe Part</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe spring</td>
<td>Allows foot to rock forward</td>
</tr>
<tr>
<td>Inserts</td>
<td>Change the way the foot lays in the shoe. A heel insert lifts the heel. An arch insert supports pronation.</td>
</tr>
</tbody>
</table>
### Table

<table>
<thead>
<tr>
<th><strong>Item</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heel</td>
<td>Holds the heel of the foot in place.</td>
</tr>
<tr>
<td>Toe box</td>
<td>Contains spread of the foot</td>
</tr>
<tr>
<td>Last</td>
<td>The general shape of the shoe that contains the foot.</td>
</tr>
<tr>
<td>Vamp</td>
<td>The region where the shoelaces are</td>
</tr>
<tr>
<td>Insole</td>
<td>A piece of cushioning added for extra cushioning and support.</td>
</tr>
<tr>
<td>Outer sole</td>
<td>The portion of the shoe that is found above the outer sole. Impacts the amount of ground reaction force on the joint.</td>
</tr>
<tr>
<td>Midsole</td>
<td>The portion of the shoe that comes in direct contact with the ground.</td>
</tr>
<tr>
<td>Upper</td>
<td>Encloses the foot into the shoe.</td>
</tr>
<tr>
<td>Heel counter</td>
<td>A running shoe may or may not have a heel counter. The heel counter is found in the upper of the shoe. Its function is to offer motion control to the back of the foot.</td>
</tr>
<tr>
<td>Collar</td>
<td>Stitching around opening of the shoe.</td>
</tr>
</tbody>
</table>

### Summary

In this review of literature design processes as well as biomechanics of running were research. Design processes included Solkowoski & LaBat three step design process, 1999, as well as Watkins seven step process, 1988. Needs Assessments were then looked at in order to understand where design criteria comes from. Design criteria are used to describe the problem or
needs identified in a needs assessment. Reverse engineering was looked at to combine with the traditional design processes. As defined by Curtis, Hartson, & Mattson, 2013 reverse engineering is “The process of Extracting information about a product from the product itself”.

In addition to looking at design processes the biomechanics of traditional and barefoot running were studied as well as the significant differences between the two. These characteristics included a shorter stride length and higher cadence in barefoot running while a traditional shod runner has a longer stride length, and a lower cadence. A barefoot runner strikes with a fore or mid foot strike while a shod runner strikes with the heel. Impact transients of ground reaction force is insignificant for a barefoot runner while in a traditional shod runner impact transients affect the body. The loading rate on a barefoot runner is three times less than a shod heel striker. Finally a barefoot runner had lower leg and ankle stiffness than a traditional shod runner.

Finally through the review of literature, characteristics of a traditional running shoe were researched. It was found that one should look for three major characteristics in a traditional running shoe including: one that reduces impact forces, controls pronation, and controls supination on takeoff (Nigg, 1986).
CHAPTER 3

METHODS AND PROCEDURES

The purpose of this study was to determine the design criteria for a minimalist running shoe that would truly simulate a barefoot like ride for a runner. To do this, I used the stated objectives to lead the research.

Objective 1

To identify the differences between the biomechanics of the foot while running in traditional running shoes as well as the biomechanics of the foot while running barefoot.

This objective was implemented using a review of literature, and the differences between the two running styles are discussed in the results section. The biomechanics of the two running styles have been well documented. However, understanding the shoe design criteria which support each running style has not. This objective is to accomplish steps 3 and 4 of the Reverse Engineering process, in which specifications which match customer needs (biomechanical needs) are created from “teardowns” of existing product.

Objective 2

To identify running shoes styles which were evaluated as satisfying the needs of runners.

In the majority of apparel design studies, the objectives have been to interview and observe the customer in order to establish the needs or problems. In this study, the purpose is to identify products that have already been produced and evaluated them to determine what design specifications have been incorporated to satisfy known customer needs.
For this study, data were collected from two sources. First, shoe styles that were evaluated by an “expert” were identified. The second step was to conduct a content analysis of online blogs and reviews that was used to establish the ratings of the expert as well as identify design criteria.

The writers of Runners World was selected as my “expert”, for identifying the shoes styles which were evaluated in this study. This magazine has been in circulation since 1966, the magazine has a current readership of over 3 million people, and the website has over 22 million site hits (Runners world media, 2013). Runner’s World has had reviews on hundreds of running shoes throughout the years. To narrow it down to four shoes I looked at their “Editors Choice” shoes from the last ten seasons. I then compiled a list below (Figure 3) of the “Editors Choice” shoes. To evaluate current running shoes on the market I chose four different types of running shoes from the following categories; stability, neutral, minimalist, and racing flat. A stability shoe is for a mild to over pronator, who has low or normal arches. A neutral shoe is defined as a shoe that has maximum midsole cushioning with minimal medial support. A neutral shoe is generally best for a mid to fore foot striker who has normal to high arches. A minimalist shoe is for a biomechanically efficient runner, meaning the runner has no biomechanical problems for the shoe to correct. A minimalist shoe is responsive and stripped down, however it still offers some cushioning to protect the foot from the ground. A racing flat is also for a biomechanically efficient runner. Most runners will only use it for races as it is light weight, and offers minimal cushioning and support (Runner's World, 2014). To narrow the list (Figure 3) to one shoe from each category I chose the shoe that appeared on the list the most often, meaning if the shoe had more than one iteration it was chosen. The iteration was randomly chosen. If there were multiple shoes but no repeats, I picked a shoe at random. The neutral shoe I chose was the Brooks Ghost 5, the stability shoe I chose is the New Balance 860 V2.
To choose the minimalist shoes I needed to use a different list than the Editor Choice list. No minimalist shoes appeared on the “Editor’s Choice” list that I compiled (Figure 3). In order to choose the minimalist and racing flat I looked at Runners world “Let it Be” list. This is a list of shoes that they believe have performed well over the years and that the editors believe should not be changed. From this list I pulled all of the minimalist shoes (Figure 4). From this list I chose the Nike free 5.0. As there were no repeats on this list the Nike Free was chosen because it was the most visible minimalist shoe on the market and would therefore be more likely to be reviewed by more people. The second shoe I chose from the list is the Mizuno Wave Universe 5 this was chosen at random between the other racing flat on the list.
In order to establish the design criteria of traditional and minimalist running shoes currently available on the market, a content analysis of blogs was done. When saturation of criteria was reached, data collection was considered finished.

**Content Analysis**

A content analysis is conducted to examine content in documents or other communicative medium (Neuman, 2006). To perform a content analysis, the researcher first identifies the body of work. The researcher then must create a way to record the content that they are analyzing. This is done by identifying units of analysis, whether they be a word, sentence, or paragraph. Instrument categories are then identified. Once they have done this, the researcher goes through the documents and collect data using the identified units of analysis and the instrument categories. Once the body of work has been exhausted, and the data has been systematically recorded the findings are analyzed. The findings are often expressed in chart or graph form (Neuman, 2006).

In order for a content analysis to be considered a good piece of scholarly work it must consist of a few key components. First the analysis must be reliable. This means that every time the analysis is performed the same results are able to be procured. The next thing that a content
analysis must be is valid. Validity is making sure that the study is really testing what the researcher wants is to test (Neuendorf, 2002). The goal of this study is to use content analysis to collect quantitative data that will enable the researcher to use the collected data to evaluate design criteria for minimalist running shoes. From the content analysis “counts of key categories and measurements of the amount of other variables” are collected as data (Neuendorf, 2002). According to Neuendorf, there are eight steps to a content analysis they include; theory and rational, conceptualizations, operationalization, coding schemas, sampling, coding, final reliability, and tabulation and reporting.

During the theory and rational step content is chosen to analyze. In order to analyze content there must be a valid reason to do so and a research question behind it. In the conceptualization step variables are identified. During the operationalization step the researcher needs to decide what unit of measure will be used. In order to maintain reliability the measure must be measuring the concept that was decided upon. Next one must create a coding scheme. In the sampling step the researcher needs to figure out how they are going to get a random sample to analyze and then define how they chose that sample and why. During the coding stage dictionaries are used to come up with frequencies within the data. Finally during the tabulation and reporting stage results are reported (Neuendorf, 2002)

**Steps Used in Content Analysis**

1. Content to analyze is chosen
2. Identify units of analysis
3. Decide what unit of measure will be used
4. Coding scheme (what categories were used)
5. Coding
6. Data are tabulated, analyzed, and reported

Through a web search using google.com and google.com/blogsearch, the running blogs of male runners were identified to be coded. The only requirements for the blogs were that they
reviewed the male version of the shoe that data was being collected on. Given the fact that the runner had a running blog it was assumed that the writer believed they had enough expertise to give an opinion on a running shoe.

The unit of analysis used was written text. If a word or sentence mentioned from one of the instrument categories it was marked down and included in the frequency count under the appropriate category.

Categories were then developed. These categories included: Toe box, sole thickness, sole flexibility, sole cushioning, heel, heel outer, collar, lining, fastening, cushioning, tongue, weight, upper, mid foot, fore foot, midsole, and inserts. Subcategories were added in order to make coding possible. For example, sole thickness would be coded based on the thickness of the sole mentioned (i.e., thick or thin). Finally, the data were coded using a spread sheet to record. The data were analyzed and frequencies were reported.

Thirty-one blogs of male runners that review running shoes were used in order to gather my data on features of the different running shoes styles.

**Objective 3**

To compare running shoes to determine design criteria which support the biomechanical aspect of barefoot running.

Frequencies from the data obtained from the content analysis of the four running shoes were compared with the information on the biomechanical aspects of barefoot running in order to determine design criteria that would create a shoe that allows a runner to have the same biomechanics as if they were to run barefoot.
Objective 4

To establish design criteria which could be used to evaluate or design a running shoe.

Finally design criteria were decided upon and weighted. Weighting of the design criteria was decided by looking at the aspects of biomechanics that were the most significantly different between shod and unshod running. Criteria were also weighted by looking at the frequencies of the different aspects of minimalist shoe criteria and what design criteria was most frequent.

Objective 5

To evaluate current shoes on the market to determine if any shoes meet the specified criteria established in Objective 4.

To do this I reviewed shoes that are currently coming onto the market for spring 2014. Using runnersworld.com the “new” shoes were evaluated against the criteria established in Objective 4.
CHAPTER 4
RESULTS

The purpose of this study was to determine the design criteria that are needed for a minimalist running shoe that will truly simulate a barefoot like ride for a runner. The following objectives explain the results of this study.

Objective 1

To identify the differences between the biomechanics of the foot while running in traditional running shoes as well as the biomechanics of the foot while running barefoot.

Data supports the idea that barefoot running and shod running are significantly different (Bonacci et al., 2013). Table 2 provides a comparison between barefoot running and traditional running biomechanics. One of the most notable differences between shod and barefoot running is the initial contact of the foot with the ground during a gait cycle. While a shod runners foot initially comes into contact with the ground with their heel (a rear foot strike), barefoot runners usually adopt a mid foot or forefoot strike (Rothschild, 2012). Different foot strikes affect stride length and cadence. Barefoot runners have a shorter stride length and a higher step frequency than runners shod in traditional running shoes (Rothschild, 2012).

Bonacci et al (2013) looked at differences in ground reaction force and kinematics in three different styles of running shoes as well as having the participants run barefoot. The three styles of running shoes that the participants ran in were minimalist, racing flats, and the usual athletic shoes of the participants. Among the three styles of shoes the researchers found no difference in ground reaction forces or kinematics. However, the difference between a shod runner and a barefoot runner was significantly different. Major differences were found in the kinematic and kinetic data. Barefoot runners had less flexion during mid stance, peak internal
knee extension was decreased by 11% and abduction moments were decreased by 24%, the ankle was less dorsiflexed at initial ground contact and there was a 14% increase in peak power generation and 19% increase in work done.

In their paper *The Barefoot Debate: Can Minimalist Running Shoes Reduce Running Related-Injuries?*, Rixe, Gallo, & Silvis (2012) summarize the differences between shod and barefoot running. They state that barefoot runners have decreased abnormal joint torque as compared to shod runners at the hip, knee, and ankle. Barefoot runners have a greater ankle motion in stride as compared to shod runners who have less. Barefoot runners have greater “braking and pushing” impulses while shod runners have lower impulses to do this. A barefoot runner evenly over time and over the foot surface distributes plantar pressure while a shod runner had plantar pressure at the heel at the moment of impact and does not spread out the pressure. A barefoot runner upon impact has a plantar flexed foot, using a mid to fore foot heel strike contrastingly a shod runner dorsiflexes and hits with a heel strike. A barefoot runner has an increased foot with in comparison to a shod runner. A barefoot runner had decreased contact time with the ground and decreased flight time in comparison to a shod runner that is increased. Leg stiffness in barefoot running is decreased while a shod runner is increased. A barefoot runner has an increased net running efficiency compared to that of a shod runner. Peak tibia internal rotation was not research for barefoot runners however for shod runner it is decreased for runners who wore a stability shoe and has low arches. For barefoot runners the calf muscle reactivates more than that of a shod runner. Stride frequency is increased a barefoot runner compared to a shod runner. However, the stride length of a barefoot runner is decreased. Tibia shock/acceleration are decrease in both types of running. Toe movement is normal in barefoot running and restricted in shod running. The final difference between the two is the decrease vertical impact forces in barefoot running as compared to the increased ones of the shod runner.
Table 2: Shod vs. Barefoot Biomechanics

<table>
<thead>
<tr>
<th>Barefoot Running Biomechanics</th>
<th>Traditional Running Biomechanics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shorter stride length, higher cadence</td>
<td>Longer stride length, lower cadence</td>
</tr>
<tr>
<td>Fore or mid foot strike</td>
<td>Heel strike</td>
</tr>
<tr>
<td>Impact transient of ground reaction force is insignificant</td>
<td>Impact transient of ground reaction force is significant</td>
</tr>
<tr>
<td>Loading rate is 3 times less than a shod heel striker</td>
<td>Loading rate is 3 times higher than unshod mid or fore foot striker</td>
</tr>
<tr>
<td>Lower leg and ankle stiffness</td>
<td>Higher leg and ankle stiffness</td>
</tr>
</tbody>
</table>

In another study conducted by Frank (2013), the researcher looked at the limb variability in males who ran in their own running shoes and then again in a pair of minimal running shoes. Within the parameters of the study it was concluded that there was no lower limb variability when comparing traditional running shoes to minimalist running shoes.

In summary, there are many differences in the biomechanics of a shod and a barefoot runner. Many studies about barefoot running biomechanics and how they differ from the biomechanics of traditional running focus on the foot strike of the runners. A shod runner most often hits the ground with a heel strike. This means that the heel hits the ground first. A barefoot runner hits the ground with a mid or fore foot strike (Rothschild, 2012). Foot strike affects a runner’s stride length and cadence. A barefoot runner has a shorter stride length and a higher cadence while a traditional shod runner had a longer stride length and a shorter cadence. Since a barefoot runner typically land on their fore foot this means that the part of the foot that will need the most protection is the fore foot, unlike in a traditional running shoe where the heel is significantly cushioned. As discussed above a barefoot runner has a shorter stride length and a
higher cadence than that of a shod runner. This means that a barefoot runner gets less vertical movement when they run. The higher a person jumps off of the ground the higher the force being place on the body when they come back down. Since a barefoot runner has as much as three times less of a loading rate the body does not have as much force acting on their body when they land. This would reduce the amount of aide they would need from cushioning they would need to absorb force. When running a barefoot runner has a lower leg and ankle stiffness. A lower leg and ankle stiffness means that the lower muscles, tendons and ligaments are more relaxed when they are in motion and coming in contact with the ground. A lower leg and ankle stiffness leads to less ground contact time. Finally, it is intuitive that a barefoot runner is going to be able to move more freely and feel every bump and texture of the ground that the runner is running on, while a runner that is running in a traditional running shoe is going to be protected from the elements and won’t have the same freedom and tactile experience as that of the barefoot runner.

The finding of these two studies suggest that minimalist running shoes are not doing what they promise to do ,which is to offer a runner a similar experience to barefoot running. Instead the runner is getting a similar experience to that of a traditional running shoe.

**Objective 2**

To identify running shoes styles which were evaluated as satisfying the needs of runners.

For this study, data were collected from two sources. First, shoe styles that were evaluated by an “expert” were identified. The second step was to conduct a content analysis of online blogs and reviews that was used to establish the ratings of the expert as well as identify design criteria.

Figures 5,6,7,& 8 show the specifications of the four running shoes for which a blog review content analyses were completed. Figure 5 shows the specifications for a minimalist
running shoe, the Nike Free 5.0. The Nike Free 5.0 according to specifications is the second lightest shoe out of the four analyzed. The Mizuno Wave Universe 5, a racing flat is the lightest out of the group. The New Balance 860 V2, a stability shoe is the heaviest of the group. The Brooks Ghost 5, a neutral shoe, is the second heaviest. It is not surprising that the 860 V2 and the Ghost 5 weigh more as they provide significantly more cushioning and stability features. The drop, or difference in profile height from heel to toe, in the Wave Universe 5 is the least. The 860 V2 has the next lowest drop however the heel and forefoot profile are the highest out of the four shoes. The Ghost 5 has the highest drop.

The lightest of the shoes is the Wave Universe 5, followed by the Free 5.0, Ghost 5, and the 860 V2. The same order is true of the heel cushioning, forefoot cushioning, profile height, and stability features. The Wave Universe 5 is the least stiff followed by the Free 5.0, the 860 V2, with the Ghost 5 being the stiffest.

The specifications obtained from Runners World explain all technical construction pieces of the shoe. Weight is reported in ounces. This gives the runner an idea of how heavy the shoe is going to be on the foot. Heel profile is the measurement of the heel at its highest point. This is measured in millimeters. Forefoot profile is the measurement of the heel at its highest point. This is also measured in millimeters. The heel profile as well as the forefoot profile give the runner an idea of how much cushioning and rubber is in the sole of the shoe. The drop is the difference in height between the heel and forefoot. This is also measured in millimeters. The drop measurement gives the runner an idea of how high the heel is raised. A shoe with zero drop would have no difference between the heel and forefoot profile.

Some shoe specifications are given using percentile rankings these include weight, heel cushioning, forefoot cushioning, profile height, stiffness, and stability features. All of the following explanations on percentile rankings were found on Runner's World & Running Times,
2014. Weight is taken using a size nine men’s shoe. The shoes are ranked on a zero to one hundred scale with one hundred being heavy, fifty being average, and zero being light. Heel and forefoot cushioning are both tested the same way. The shoe is tested with an impact testing machine, this machine specifies how soft or firm the cushioning is. Force of impact and midsole compression are taken into consideration for this ranking. On a scale zero to one hundred zero is hard, fifty is average, and one hundred is soft. Stiffness measures how much the shoe flexes or resists flexing on the toe off portion of the gait cycle. For this scale, pliability is measured, one being pliable, fifty being average, and one hundred being stiffer. Profile is a measurement of how tall the shoe is minus the upper. Again this scale measures one being the lowest profile height, fifty is average, and one hundred is tallest.

The specifications for each shoe were obtained from runnersworld.com, which as previously discussed in the methods and procedures sections was identified as an expert that could provide such information. The graphs following the specification sheets (Figures 5, 6, 7 & 8) report the frequencies for shoe characteristics that were reported by the running bloggers in which the content analysis was conducted on. Some of the graphs do not report characteristics this is because they were not reported by the blogger. It is assumed that these pieces were seen as insignificant and not worth commenting on for the specific shoe.
Nike Free 5.0
Minimalist

Weight: 8.3 oz
Profile (Heel): 27.7mm
Profile (Forefoot): 17.1mm
Drop from heel to forefoot: 10.6mm

Percentages out of 100
Weight: 23
Profile height: 20
Heel cushioning: 22
Stiffness: 15
Forefoot cushioning: 25
Stability features: 58

Figure 5: Nike Free 5.0 (Minimalist)
Brooks Ghost 5
Neutral

Weight: 11.3oz
Profile (Heel): 34.7mm
Profile (Forefoot): 23.8mm
Drop from heel to forefoot: 10.9mm

Percentages out of 100
Weight: 73  Profile height: 65
Heel cushioning: 83  Stiffness: 66
Forefoot cushioning: 53  Stability features: 67

Figure 6: Brooks Ghost 5 (Neutral)
Mizuno Wave Universe 5

Racing Flat

Weight: 2.9 oz

Profile (Heel): 12.4mm

Profile (Forefoot): 10.3mm

Drop from heel to forefoot: 2.1mm

Percentages out of 100

<table>
<thead>
<tr>
<th>Weight</th>
<th>Profile height</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heel cushioning</th>
<th>Stiffness</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Forefoot cushioning</th>
<th>Stability features</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 7: Mizuno Wave Universe 5 (Racing Flat)
New Balance 860 V2
Stability

Weight: 11.6 oz
Profile (Heel): 36.5 mm
Profile (Forefoot): 26.9 mm
Drop from heel to forefoot: 9.6 mm

Percentages out of 100

Weight: 82  Profile height: 92
Heel cushioning: 77  Stiffness: 37
Forefoot cushioning: 92  Stability features: 90

Figure 8: New Balance 860 V2 (Stability)
**Objective 3**

To compare running shoes to determine design criteria which support the biomechanical aspects of barefoot running.

Through the content analysis of thirty-one blog reviews of male runners I was able to obtain their thoughts on design criteria of running shoes. Eleven categories were identified for analysis within the blog reviews. The categories were toe box, sole thickness, sole flexibility, tongue, weight, upper, mid foot, forefoot, midsole, sole cushioning, and heel structure.

As expected many of the reviewers commented on similar features or had similar comments on the design features that were being looked at. This reinforced the design criteria that were viewed as important or not important.

**Toe box**

The first category that was looked at was the toe box (Figure 9). Of those who talked about toe box in their review of the Ghost 5 more reviewers reported that the toe box was wide, while there were no reports that the toe box was narrow. This is not consistent with running biomechanics of a runner in neutral or stability running shoes. The Ghost 5 is a neutral shoe in which a runner would be running with a mid foot strike, which does not need a wide toe box. The 860 V2 was reported by one reviewer to have a slim and shallow toe box (Clyatt, 2014), while another review reported just a slim toe box (bahaistudy.com, 2014). For a stability shoe this holds consistent with the running biomechanics. Runners who are running in a stability shoe will strike the ground with a heel strike. This means that the toes are not spreading out as much and do not need a larger toe box to contain them. The Free 5.0 were reported to be narrow (ProShoeologist, 2014). As the Free 5.0 is a minimalist running shoe the report of a narrow toe box is not consistent with the biomechanics of a barefoot runner. As a barefoot runner is striking the ground with a forefoot strike the toes are going to splay out more upon impact, this means that
shoe needs a wider toe box to accommodate the toes upon impact. Conversely one reviewer stated that the Free 5.0 had a toe box that was wide and shallow, which would not hold consistent with the biomechanics of barefoot running. The Wave Universe 5 was reported to be wide (Pang, 2013) which is consistent with the biomechanics of a barefooted runner because as stated before the width gives the runners toes room to splay out with the use of a forefoot strike.

![Figure 9: Toe Box data](image)

**Shoe Sole**

Sole thickness was the next design characteristic that was analyzed (Figure 10). Few reviewers commented on the thickness of the sole of the shoe that they were reviewing. Of those who responded all responses were consistent with the biomechanics of barefoot running. The Ghost 5 and the 860 V2 were both reviewed to have a thick sole. For a neutral and a stability shoe the sole of the shoe should be thicker. A runner who is running in a neutral or stability shoe is running with a mid or heel strike. The extra thickness in the sole protects the runner’s heel from higher impact transients being placed on the body (Lieberman, 2014). The Free 5.0 and the
Wave Universe 5 were reviewed as having a thin sole; this holds consistent with biomechanics of barefoot running, because of the lower force being placed on the body when running there does not need to be as much cushioning to aide in reducing and displacing forces being put on the body.

Figure 10: Sole Thickness data

The next design characteristic that was analyzed was sole flexibility (Figure 11). All of the reviewers who did mention sole flexibility while reviewing the Ghost 5 stated that the sole is flexible. This is not fully consistent with the biomechanics of a runner in a neutral shoe. A flexible sole allows the foot to move freely. When running barefoot the lower leg and ankle has a lower stiffness this means that they move more freely, a flexible sole would allow the foot to do this, however, a neutral runner only needs a small amount of flexibility in the sole of their shoe. Too much flexibility will not give the neutral runner the support they need. The 860 V2 had one reviewer remark on the flex grooves in the sole (My Running Addiction, 2012), which like the Ghost 5 is inconsistent with biomechanical aspects of a shod runner. Of the eleven reviews
analyzed about the Free 5.0 eight commented that the sole was flexible. Six of these reviewers pointed out the specific design feature, the siping, as the reason that the sole was flexible. This is consistent with biomechanics of barefoot running because the lower leg and ankle stiffness associated with barefoot running means that the muscle, tendons and ligaments in the lower leg and ankle are more relaxed this leads to the foot moving more freely and less rigidly while running. One reviewer commented on the Wave Universe 5, stating that it did have a flexible sole (Pang, 2013) which holds consistent with barefoot biomechanics for the same reasons as stated with the Free 5.0.

Figure 11: Sole Flexibility data

**Shoe tongue**

Reviewers did not comment on tongue design features frequently (Figure 12) however, they will be discussed briefly as the design of the Free 5.0 was significantly different than that of the other three shoes. Of the Ghost 5 one reviewer noted that the tongue was cushioned
The Free 5.0 was reported to have an attached tongue by two reviewers (Figure 12). One reviewer said that the fit was better because of the gusseted tongue (Nike Free 5.0, 2014). This potentially could help a foot that has a lower leg and ankle stiffness stay in the shoe better without slipping around. Neither the Wave Universe 5 nor the 860 V2 reported any review on the tongue.

Figure 12: Tongue data

**Shoe Construction**

How the shoe was constructed and the materials used are important components to the design criteria. Shoe weight, upper construction, midsole, forefoot are discussed.

The next design feature analyzed was weight (Figure 13). The Ghost 5 was reported as being light by three reviewers and medium by two others. There was no reviewer that commented on the weight of the 860 V2. All of the reviewers who commented on the Free 5.0 agreed that the shoe was ultra light weight. The Wave Universe 5 all reviewers stated that the
shoe was ultra light. While weight is not a mechanic it does affect mechanics. Having a lighter weight shoe makes it easier and less cumbersome to move feet. This can help with the higher cadence that a barefooted runner has. A lighter weight shoe makes it easier to move the feet more quickly.

![Weight data](image)

**Figure 13: Weight data**

The next design characteristic that was analyzed was the upper (Figure 14). The reviews about the uppers of each shoe were not very cohesive. Reviewers of the Ghost 5, the Wave Universe 5, and the 860 V2 spoke about the upper being made of mesh. This is a traditional material for a shoe upper to be made of, it makes the shoe light weight. Having the upper made of mesh rather than a material such as leather makes the shoe lighter weight and easier for the foot to move. One reviewer commented on the structural overlays on the Ghost 5 and how they gave the shoe structural integrity (Fonger, 2012). Structural overlays may lend support to the foot would be consistent with the biomechanics of shod running and the need for a shod runner to have more stability features. One reviewer commented that the upper of the Free 5.0 was breathable, usually breathable fabrics are lighter and would be in line with the biomechanics of
barefoot running (Boles, 2005). Another reviewer commented that the upper did not stretch very much (Larson, 2014). An upper that does not stretch helps the shoe stay snug against the foot making it like a second skin.

The next design characteristic analyzed was the mid foot (Figure 15). The Ghost 5 was commented upon having a firm middle biomechanically this is consistent with a neutral runner that would have higher leg and ankle stiffness. The reviewer who talked about the Ghost 5’s firm mid foot said it gave the “ability to limit excess mid foot motion and provide light stability” (Green, 2014). The Free 5.0 was said to be roomy (Larson, 2014), while four other reviewers commented on the flywire technology that was used in the Free 5.0 mid foot. All of the reviewers who commented on the flywire technology stated that it made the shoe have a secure fit. One reviewer said it best stating that “flywire created a secure fit [in the mid foot] without being too restrictive” (Cho, 2014). Biomechanically the use of flywire to keep the foot secure is not consistent with barefoot running, while running the barefoot runner has nothing to support the foot except for the muscles, tendons and ligaments.
The next design characteristic that was analyzed was the forefoot (Figure 16). The forefoot of the shoe was not highly commented on amongst reviewers. The reviewer that did speak about it in their review of the Ghost 5 stated that the shoe forefoot was firm (Bestrunningshoesforhigharches.com, 2014), which holds consistent with the heel to mid foot strike that a neutral runner would be using. The Free 5.0 forefoot was commented on as being flexible by one reviewer (Larson 2014), this holds consistent with the biomechanics of barefoot running. As the bare foot runner would strike with a forefoot strike the forefoot of the shoe should be bendable to allow the foot to move as though it is not be contained by a shoe. In the reviews of the Wave Universe 5 there were no comments on forefoot characteristics. A reviewer of the 860 V2 (My Running Addiction, 2012), commented on the asymmetry in the materials of the forefoot stating it “offers additional foot freedom”. Additional foot freedom is not consistent with the biomechanics of a stability runner. Since a stability runner has something wrong with their biomechanics their shoe should offer them support and not freedom for the foot to move around.
The next design characteristic that was looked at was the midsole (Figure 17). Two reviewers commented on the midsole cushioning of the Ghost 5 stating that the midsole was firm but cushioned (Sportsfootwearreviews.com, 2013, Fonger, 2012, and Jun, 2014). A well cushioned midsole holds consistent with design criteria that would be best for a neutral to stability runner. The extra cushioning helps disperse the force that is being placed on the body when it lands during the gait cycle. No reviewer commented on the midsole of the Free 5.0. Reviewers of the Wave Universe 5 stated that the midsole was cushioned, both pointing out that the midsole was made of U4ic, a material created by Mizuno that was designed to absorb shock while still being incredibly light (Mizunousa.com, 2013). The light weight cushioned midsole is more consistent biomechanically than other shoes, however a shoe that truly offered a barefoot like ride would not provide any sort of cushioning to absorb impact forces. 860 V2 reviewers specifically mentioned the technology Acteva lite as being the technology used in the midsole. The technology is a light weight foam that is made to handle being compressed really well.
Biomechanically the extra cushioning would be able to handle the higher impact transients of the stability runner.

Figure 17: Midsole data

**Sole cushioning**

The next design characteristic that was analyzed was the sole cushioning (Figure 18). All of the reviewers who talked about the Ghost 5 talked about the lateral sole cushioning. Specifically each reviewer talked about the technology that Brooks used in the Ghost 5 called the caterpillar crash pad. The caterpillar crash pad “is constructed of high-density rubber and blown rubber on the outside with deep grooves to allow for flexibility” (Roy, 2014). The crash pad offers lateral cushioning for heel and mid foot strikers to disperse forces on the body. One reviewer states that the Free 5.0 may have too much sole cushioning to give someone looking for a barefoot running experience a barefoot like run in the shoe (Cho, 2014). Of the Wave Universe 5 one reviewer stated “The sole is surprisingly cushioned ("cushioned" being an extremely relative term) for how little there is there” (Klein, 2014, para 5). Biomechanically for a barefoot
like ride there should be no cushioning. However, out of the four shoes the Wave Universe is described as having the least amount of cushioning to aide in the dispersion of forces being placed on the body. One Free 5.0 reviewer says that the sole cushioning was medium- “soft but not too soft” (Larson, 2014, para 4). As the Free 5.0 is a minimalist shoe this is not biomechanically consistent with barefoot running. Another Free 5.0 reviewer commented on the additional cushioning of the Free 5.0, the waffle pistons, which are protrusions of extra rubber in higher impact areas (Haulingmycarcass.com, 2013).

\[ \text{Figure 18: Sole cushioning data} \]

**Heel**

The heel structure was the last design feature that was analyzed (Figure 19). The Ghost 5 was said to be semi flexible (Fonger, 2012). Biomechanically a neutral runner usually has few to no pronation problems. The flexibility of the heel would allow the runner to have a little bit of freedom while running while still getting help from the shoe if the runner does has pronation problems. The Free 5.0 was said to be snug, unstructured, and having no heel counter (Figure
The unstructured fit would be consistent with the biomechanics of a barefoot runner, as would be the lack of heel counter. A barefoot runner does not have anything to support the foot while running. The snug fit seemingly would go against the biomechanics of a barefoot runner. However, if the snug fit is not providing support, the close fit makes the shoe become one with the fit and potentially reduce weight of the shoe. Similar to the Free 5.0 the Wave Universe 5 also was said to have no heel counter (Klein, 2014). Additionally the Wave Universe 5 was said to have a contoured heel cup (Pang, 2013), which would provide the runner with a close fitting shoe which makes the shoe feel part of the foot.

![Heel Structure data](image)

**Figure 19: Heel Structure data**

**Data Summary**

Eleven categories were looked for and analyzed in the blog reviews. The categories were toe box, sole thickness, sole flexibility, tongue, weight, upper, mid foot, forefoot, midsole, sole cushioning, and heel. The following is a summary of the data collected on each design criteria. There was no consensus amongst reviewers on the toe boxes of each shoe except for the Wave Universe 5 which was said by all reviewers to have a wide toe box. Minimalist and racing flats were said to have thin soles while the neutral and stability shoe were said to be thick. Sole
flexibility was talked about more in the review of the Free 5.0 where eight out of the eleven reviewers commented and the Wave Universe 5 where one out of the three commented. Sole flexibility was less of a talked about topic in the neutral and stability shoe the Ghost 5 where only four commenter’s commented and no reviewers commented on the sole flexibility of the 860 V2. Only three out of all twenty eight reviewers commented on the tongue of the shoes. Two reviewers stated that the Free 5.0 had an attached tongue while another reviewer stated that the Ghost 5 was cushioned. When reviewers talked about weight there was a consensus among those who mentioned weight that the Free 5.0 and the Wave Universe 5 were both ultra light. Brooks Ghost 5 reviewers said that the shoes were light to medium. Reviewers of the 860 V2 did not comment on the weight of the shoe. Uppers there was no consensus among reviewers. Reviewers of all of the shoes except for the Free 5.0 commented on the mesh material of the upper. One commenter of the Ghost 5 commented on the structural overlays of the upper. The mid foot of the Free 5.0 was said to be secure by four out of the six reviewers. While there were not many reviewers that commented on the forefoot the Ghost 5 was said to be firm by one reviewer, while the Free 5.0 was said to be flexible by one reviewer. Sole cushioning was a widely commented on design criteria. The Ghost 5 reviewers commented on the lateral cushioning in five out of the fourteen reviews. The Wave Universe 5 had only one reviewer comment on cushioning. The Free 5.0 was said to be cushioned by three reviewers had have at least medium cushioning by one reviewer. Finally heel structure was commented on mostly about the minimalist Free 5.0 and the racing flat Wave Universe 5. The Free 5.0 was said to be snug, unstructured, and having no heel counter. The Wave Universe 5 was said to have no heel counter and contoured to fit the heel. No reviewer commented on the heel structure of the 860 V2.
Objective 4

To determine design criteria which could be used to evaluate the design of a running shoe.

The design features that were compared to the biomechanics of running are: toe box, sole thickness, sole flexibility, tongue, weight, upper, mid foot, forefoot, midsole, sole cushioning, and heel. Taking into account the biomechanics of barefoot running and the comments of reviewers of the four different types of running shoes the following design criteria for a minimalist running shoe with a barefoot like ride was created (Table 3).

Table 3: Design Criteria for a Minimalist Running Shoe

1. Toe box: Wide
2. Sole thickness: Thin
3. Sole flexibility: Super flexible
4. Tongue: Attached
5. Weight: Ultra light
6. Upper: Unstructured
7. Mid foot: Snug to foot
8. Forefoot: Flexible
9. Midsole: Light weight (no excess cushioning)
10. Sole cushioning: Zero drop
11. Heel structure: Unstructured and contoured

The toe box should be wide to allow the toes to spread upon a forefoot strike. The sole should be as thin as possible. As there are lower forces being placed on the body of a barefoot runner the shoe does not need to offer additional cushioning to absorb and disperse higher forces that are associated with traditional shod running. The sole should be as flexible as possible because the lower leg and ankle has a lower stiffness than a traditional shod runner this means that the foot moves more freely while running. A flexible sole allows the foot to move freely. The tongue should be attached to the upper of the shoe. This allows the shoe to fit closely to the foot. Eliminating excess bulk and making the shoe fit closely helps make the shoe feel inconspicuous on the foot. A minimalist running shoe should be ultra light weight. An ultra light shoe helps to not weigh down the runner. It also aids in allowing the runner to run with the
higher cadence associated with barefoot running biomechanics. The upper should be unstructured with no additional foot support. The mid foot should be close fitting to the foot, not stiff and should not provide any support. The close fit helps reduce bulk and makes the runner feel as though they have nothing on their foot. The forefoot of a minimalist running shoe should be flexible. As a barefoot runner strikes with a forefoot strike the shoe should not restrict this movement. The midsole should be lightweight as to support the runner’s ability to run with a higher cadence. There should not be additional sole cushioning; this reduces unneeded bulk and because of the decreased force placed on the body during barefoot running extra cushioning becomes unnecessary. The heel should be unstructured and should contour to the heel. The unstructured heel gives the foot the freedom to move as if it were unshod and the contoured heel cup helps make the shoe sit more closely to the foot of the runner which gives the foot the feeling of wearing nothing. The final design criteria is the weight of the shoe. The shoe should be made to be as light weight as possible. Reduced weight allows the runner not to feel bogged down by heaviness and will allow the runner to run with the shorter stride length and higher cadence that is associated with barefoot running.

**Objective 5**

To evaluate current shoes on the market to determine if any shoes meet the specified criteria established in Objective 4

To research current running shoes on the market I once again used runnersworld.com as an expert source. Each season Runners World creates a guide of new shoes on the market. At the time of this thesis the most current list of new shoes available was from Spring 2014. Table 4 provides a list of the new shoes on the market for Spring 2014.

Table 4: New Shoes for Spring 2014

1. Adidas Supernova Glide 6
2. Brooks PureFlow 3
3. Under Armour Speedform Apollo
4. Sketchers GORun Ride 3
5. Hoka One One Conquest
6. Asics Gel-Kayano 20
7. Saucony Triumph 11
8. Saucony Hurricane 16
9. Brooks Ravenna 5
10. Nike Lunar Eclipse 4
11. Zoot Ultra Kalani 3.0
12. Mizuno Wave Inspire 10
13. Saucony Mirage 4
14. Asics Gel- Electro 33
15. Nike Flyknit Lunar 2+
16. Mizuno Wave Rider 17
17. Scott T2 Palani
18. New Balance Fresh Foam 980
19. North Face Ultra Smooth
20. On Cloudracer 2
21. Adidas Adizero Adios Boost
22. Vibram FiveFingers Bikila EVO
23. Brooks Transcend

Each shoe was individually evaluated using specifications by runnersworld.com. This was done by comparing the specifications provided by runners world to the eleven design criteria: toe box; wide, sole thickness; thin, sole flexibility; super flexible, tongue; attached, weight; ultra light, upper; unstructured, mid foot; snug to foot, forefoot; flexible, mid sole; light weight (no excess cushioning), sole cushioning; zero drop, heel structure; unstructured and contoured. Each shoe was put into a chart like the one in Figure 20 they were then compared to Runners World specifications all similar to the one in Figure 21. If the shoe specification agreed with the design criteria it was marked “yes” it met the criteria. If the shoe specification disagreed with the design criteria it was marked “no” it did not meet the criteria. If the shoe received any “no” marks it was not considered an optimized minimal running shoe. In order to be considered an optimal minimalist running shoe the shoe needed to have “yes” marks to all eleven design criteria. Therefore, once there was a conflicting design criterion listed the shoe was no longer analyzed. In order to decide if a shoe received a yes or a no the percentile rankings were used. As
there were no reviews of the new shoes at the time of this study, the design criteria for the toe box could not be evaluated for the shoe. Sole thickness looked at the percentile ranking profile height, if this number was in the zero to forty nine range it was considered as meeting the design criteria, however if it was fifty and above it was considered as not meeting the design criteria. Sole flexibility looked at the percentile ranking stiffness if this number was in the one to forty nine range it was considered as meeting the design criteria, however if it was fifty and above it was considered as not meeting the design criteria. While there was no specification information given about the tongue a picture was included with the specification, from the photograph it could be determined whether or not the tongue was attached or not. Weight looked at the percentile ranking weight if this number was in the zero to forty nine range it was considered as meeting the design criteria, however if it was fifty and above it was considered as not meeting the design criteria. Again no specification information was included about the upper or the mid foot and therefore the shoe could not be evaluated on whether or not it met the design criteria. Forefoot looked at the percentile ranking stiffness if this number was in the one to forty nine range it was considered as meeting the design criteria, however if it was fifty and above it was considered as meeting the design criteria. As no specification information was included on the mid sole, sole cushioning, or heel structure they were unable to be evaluated

None of the shoes on the list of the new twenty three shoes on the market for Spring 2014 were identified as being optimized.
Summary

Differences between the biomechanics of the foot while running in traditional running shoes as well as the biomechanics of the foot while running barefoot were looked at the
following list of differences were found. A barefoot runner runs with a shorter stride length and a higher cadence while a traditional runner runs with a longer stride and a lower cadence. While a barefoot runner strikes the ground with a fore of mid foot strike a traditional shod runner hits the ground with their heel. Impact transients of ground reaction force are insignificant on the runner while they are significant on the body of a traditional shod runner. A barefoot runner had a loading rate that is three times less than that of a heel strike traditional runner. Finally a barefoot runner has a lower leg and ankle stiffness than that of a traditional shod runner.

Running shoes styles which were evaluated as satisfying the needs of runners were identified. This was done through a systematic search using Runners World, as experts who were able to identify shoes that satisfied the needs of runners. The four shoes identified were the Brooks Ghost 5; neutral, Nike Free 5.0; minimalist, Mizuno Wave Universe 5; racing flat, and New Balance 860 V2; stability.

Running shoes were then compared in order to determine design criteria which support the biomechanical aspects of barefoot running. A full summary of the completion of this objective can be found at the end of the results section under objective 3.

Finally design criteria which could be used to evaluate of design a running shoe was determined. To do this design features were compared to the biomechanics of running and the following eleven categories were identified: toe box, sole thickness, sole flexibility, tongue, weight, upper, mid foot, forefoot, midsole, sole cushioning, and heel.

It was determined that the Vibram Bikila Evo shoe came closest to satisfying the design criteria established from reverse engineering the current shoes on the market. This is because it fit all of the requirements the closest of all the shoes that were evaluated.

Sole thickness looked at the percentile ranking profile height as this number was two the shoe met the requirements for a minimalist running shoe. Sole flexibility looked at the percentile
ranking stiffness the number was seven which is in the one to forty nine range so it was considered as meeting the design criteria. While there was no specification information given about the tongue a picture was included with the specification, from the photograph it could be determined whether or not the tongue was attached or not, the tongue of the Vibram Bikila Evo was not attached and therefore did not meet the design criteria. Weight looked at the percentile ranking weight if this number was one as the number was in the zero to forty nine range it was considered as meeting the design criteria. No specification information was included about the upper, the mid foot and therefore the shoe could not be evaluated on whether or not it met the design criteria. Forefoot looked at the percentile ranking for stiffness this number was two which fell into the one to forty nine range therefore it was considered as meeting the design criteria, however if it was fifty and above it was considered as meeting the design criteria. As no specification information was included on the mid sole, sole cushioning, or heel structure they were unable to be evaluated. From the given specifications it was determined that the Vibram Bikila Evo met four out of the eleven design criteria, did not meet one and five were unable to be determined without reviews. Additionally percentile numbers were taken into consideration. While many of the shoes met the design criteria the Vibram Bikila Evo had the lowest percentile rankings in all categories which means that it best fits the given design criteria.
CHAPTER 5
SUMMARY AND RECOMMENDATIONS

Summary

The purpose of this study was to understand the design criteria that are needed for a minimalist running shoe that truly gives the runner a barefoot-like ride. This study aimed to find out if there was a method that can use the biomechanics data of the foot while running to develop a shoe design. Using the method of reverse engineering, current shoe designs were evaluated to determine what design characteristics supported the biomechanics aspect of running. The biomechanical aspect of barefoot running was then compared with current minimalist shoes to determine if the design criteria were met.

Through a review of literature design processes were identified, the biomechanics of traditional shod running and barefoot running and the differences between the two were studied, and the characteristics of a traditional running shoe were identified.

Using Runners World as an expert, running shoe styles were identified as satisfying the needs of runners. The four shoes identified were: the Brooks Ghost 5; as a neutral shoe, Nike Free 5.0; as a minimalist, Mizuno Wave Universe 5; as a racing flat, and New Balance 860 V2; as a stability shoe. Running shoes were compared to determine design criteria which support the biomechanical aspects of barefoot running. To do this a content analysis of running shoe reviews was done on a neutral, stability, minimalist, and racing flat shoe. This information was then compared to the biomechanics of barefoot running to see what design criteria was needed to emulate barefoot running. A list of design criteria was then created and current shoes on the market evaluated to determine if there is a shoe with the determined design criteria exists on the market.
During the time of the study only shoe specifications of the spring 2014 shoes were available. Reviews were not available because shoes were not available to the public yet. As reviews were not available, shoes could not be evaluated fully. However, as it would only take a shoe not meeting one of the design criteria, it can be said that none of the shoes met all of the established design criteria. This was determined from using information given in the Runners World specification sheets.

Application of Reverse Engineering

This study provided an example of an application of reverse engineering as applied to the development of a minimalist running shoe. During a needs assessment, data were collected that allowed the researcher to define the problem. In this study a needs assessment was done in the form of analyzing blog reviews of male runners. Blogs were read and coded to evaluate what male runners thought about the characteristics of neutral, stability, minimalist, and racing flat shoes that are currently on the market.

Once the problem was defined, design criteria of a minimalist running shoe could be developed. Design criteria were defined using the information collected from the needs assessment along with consideration of the biomechanics of barefoot running information that was found during the review of literature. Eleven categories were looked for and analyzed in the blog reviews. The physical requirements included: toe box, sole thickness, sole flexibility, tongue, weight, upper, mid foot, forefoot, midsole, sole cushioning, and heel.

Once physical requirements were defined, market research could be done to see if there was currently a shoe being sold that had all of the requirements defined by the study. Through this process of reverse engineering, new design criteria for the minimalist shoe were established and the criteria can then be used to evaluate future shoe designs.
Limitations

This study had many limitations. The first was that I was unable to hold, inspect or test any of the shoes myself. I had to rely on expert reviews and analysis of the shoes in order to collect data for my research. Other limitations included not being able to obtain a comprehensive list of every blogger that reviewed the shoes that I had chosen to review. This lead to small sample sizes especially for the Mizuno Wave Universe 5 and the New Balance 860 V2. As shoes were chosen before looking for reviews it was difficult to obtain many reviews for the less popular Mizuno Wave Universe 5 and the New Balance 860 V2. While I could have chosen popular shoes it was my purposeful intention not to do this and rather look at reviews of shoes that experts identified as a good running shoe. The final limitation of the study was that I was not able to create an actual prototype of the minimalist shoe with the criteria that was identified through the study, which made it not possible to evaluate the design criteria.

Recommendations and Future Research

A recommendation and further research which would support the findings of this research would be to produce a prototype and evaluate its performance against the criteria established. The method used in this study can be used and applied to discover if current products are performing properly for their intended activity. From the findings of this study any functional product could be tested and potentially redesigned to optimize the functionality of the product using the proposed model.

Future Research could include:

1. A study could be done using the same methodology for evaluating the design criteria of any other type of athletic shoe.
2. A study could be done using the same method to evaluate any type of functional product.

3. A component could be added looking at the comments of people on the bloggers review to see whether they agreed or not with the review.

**Conclusion**

From this study a model was created that could reverse engineer a running shoe, identifying design criteria that would create the ideal minimalist running shoe. The specifications for the ideal shoe using all eleven design criteria are shown in Figure 22. While many studies do needs assessments, they stop after they create a new product. This study creates a new product with criteria that is proven to work in existing products and then evaluates to see if the new product that was pieced together works better than existing products. For a designer looking to design an optimized functional products I would suggest that they look at several product reviews that are as similar as possible to what they are designing. By doing this the best design characteristics can be chosen.
Figure 22: Minimalist Shoe Specification
REFERENCES


Appendix A:

Shoe Review Data