

CONVERTIBLE HIGH HEEL DESIGN

by

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Abstract

Many women feel pain and discomfort when wearing high heels to certain events. This is a problem because it can lead to a variety of health issues. It would be beneficial and convenient if a woman could remove the heelpiece from her shoe while still wearing the same product. However, there is currently no popular high heel that can convert to a flat shoe on the market today. Our goal was to perform an in depth human factors analysis with regards to high heel use and formulate a solution to these problems. After reviewing literature, conducting a survey, and analyzing current materials used in shoe making, we proposed a solution and created a prototype that demonstrates how a heelpiece can detach from a shoe converting it into a flat. This proposed design had to be durable, convenient, and aesthetically pleasing in order to realistically expect demand for such a product. We discovered solutions that address these issues along with a viable mechanism for connecting and disconnecting the heelpiece. Further research in the manufacturing of such materials could definitely lead to the production of an exceptional product.

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Introduction

In today's society, many women wear high heels for different reasons: some wear them to parties and events while others wear them to work or even casually. Regardless of the situation, women want a shoe that will be able to provide comfort, stability, ease of use, and of course, aesthetics. It may be very difficult to find that "perfect" shoe because they come in many different shapes, sizes, heights, and materials. The user will often have to buy multiple pairs that she may not even know will be compatible with her foot. Buying so many products is costly and inefficient both personally and environmentally.

All of these observations about high heel users are important to consider when fulfilling the objectives of this project. Likewise, they all play a role in the negative stigma that every female has at least once attributed to wearing high heels. The problem with regular high heel shoes is that many females find it difficult to wear them for long periods of time due to pain and discomfort.

The idea of this project was to design a detachable high heel shoe that can be worn comfortably as a flat shoe as well. With this in mind, the project objectives were as follows:

- Conduct a survey that will give feedback about comfort and stability among various high heel users
- Perform research on topics related to ergonomics and human factors and high heels in order to make the most comfortable and user-friendly design
- Consider possible alternate solutions to creating a high heel that can convert into a flat shoe
- Create a rough prototype of the best possible solution while keeping comfort, stability, durability, and aesthetics in mind

The survey consisted of 43 females that all answered (the same) various questions based on their experience with high heels. More information about the survey can be found in the

appropriate section later in this report. However, the survey results did give a sense of direction with regards to where to spend further time researching ergonomic solutions.

In order to develop the best mechanism to attach the heel to the sole, it was imperative to explore possible alternatives to figure out which methods really worked best. Much can be learned from understanding what has succeeded and failed in the past. Principles from each of those successes and failures can be applied to this project in order to make it complete and accurate.

Creating a prototype was originally sought out to be challenging and costly considering it could take multiple machining and tooling attempts to seek the desired end result. It was necessary to meet with others who have experience in this field including teachers, students, and locals that were willing to offer their services. Once the concept had been solidified, we used Pro Engineer (a CAD program) to accurately dimension the necessary parts of the high heel shoe. Since the final prototype was made out of plastic, it is only precise in demonstrating the mechanism used to attach the heel to the sole.

In order to ensure that all objectives were met, we followed a schedule and were aware of the necessary deadlines throughout the duration of the project. We met with our technical advisor as needed to ensure the appropriate steps and progress was being met.

One may be wondering how such an idea came to light. It is not specifically one particular event that led to this idea, but an accumulation of events. When one wakes up in the morning, he or she faces the predicament of what to wear. Unaware of what the rest of the day entails one has to decide whether to dress for comfort or elegance. In regards to shoe selection, women generally have to decide whether to wear high heels or not. If they do indeed choose to wear them, then the next decision is what heel height to select. However, in today's society, there is added pressure to choose elegance over comfort. In addition, more and more women are required to wear high heels to work. Unfortunately, once this decision is made, the person must live with this decision for the rest of the day. Women that choose elegance over comfort by selecting to wear high heels may be

stuck wearing these high heels for long periods of time. Consequently, this day commonly ends with sore and achy feet. However, if there was a high-heeled shoe that could convert to a flat shoe, women could choose elegance without the consequence of being entitled to live with that decision for the rest of the day.

In addition, living in a college town, I, Tyler Shelton, notice how much people travel by foot. On the weekends, several people walk to and from social events. Many of the women who go to these social events wear high-heeled shoes. After a long night of walking, standing, and dancing in high heels, these women may still have a long walk home ahead of them. Before the walk even begins, fatigue, soreness, and aching of the foot already begin setting in. These women then face a difficult predicament, either continue to walk home or to a distant parking lot in the high heels and add to the fatigue, soreness, and aching; or take the high heels off and walk barefoot, risking injury from stepping on glass or stubbing a toe. In addition, what woman wants to walk barefoot on the dirty, rough concrete? I understand this predicament because my girlfriend and several female friends are victims of these high heel consequences every weekend. Wouldn't it be great if a woman could conveniently have both elegance and comfort? What if a high heel user could simply remove the heel to convert to a flat shoe when fatigue began to set in? These experiences and situations are what led to the idea of a converting shoe.

Background

In this era, high heels are very common. There are several types of high-heeled shoes for various types of occasions. Each type of shoe has a different connotation for what it is trying to represent or symbolize. Today, high-heeled shoes are often seen on a woman in a dress in an attempt to display elegance and sophistication. However, high-heeled shoes were originally developed for a different reason. They were first seen being worn by the upper classes on Egyptian murals dating back to 3500 B.C. In contrast with the present purpose of heels, the original purpose was for functionality. In fact, Egyptian butchers originally wore heels in order to walk above the blood from the dead animals they had been working on [1]. However, the use of heels varied depending on occupation and global location. In Ancient Greece and Rome, Actors wore platform sandals called Kothorni, later known as buskins, of varying heights to indicate different social statuses or importance of characters. Kothorni, or buskins, were shoes with high wood or cork soles. During the Middle Ages, both men and women wore Pattens, which had a purpose similar to that of the Egyptian butcher's heels. Pattens, or wooden soles, would attach to fragile and expensive shoes to keep them above the mud and dirt when walking outside [2]. This functionality allowed user's to keep the shoes clean and elegant. Chopines, created in Turkey in the 1400's and popular throughout Europe until the mid 1600's, had the same functionality as Pattens. However, Chopines were worn entirely by women and would range in heights of 6 inches, 8 inches, and even 30 inches [3].

By the time the 1500's came around, heels grew in popularity among both male and female horseback riders. Although the heels were only 1 to 1 ½ inches high, they functioned as a mechanism to keep riders from slipping from their stirrups. However, this is also the era where the purpose of heels began to evolve. Catherine de Medici (1519-1589) is credited with making heels more fashionable rather than functional by creating elegance through higher and thinner heels.

However, Catherine de Medici had a purpose of this change in heel design. Being only 14 years old, and just under the height of 5 feet, Catherine de Medici felt young and insignificant. She needed to create a way to catch the eye of her fiancé, the future King of France. At the time, he had been intrigued and focused on his favorite, and significantly taller, mistress. In an attempt to recapture his focus, she created heels two-inches high that gave her a more astounding physique and an elegant motion when she walked [3].

In the early 1700's, France's King Louis XIV would often wear heels as tall as five inches. These heels, called "Louis heels," were often seen decorated with small battle scenes. He decided that only nobility could wear red heels and that no one could wear heels taller than his. This inspired a heel revolution where heel heights grew and became more slender. The Puritans in the New World noted the desirable and sexual nature of these new heels. In fact, the Massachusetts Colony even passed a law banning women from wearing high heels with the intention to intrigue men. If a woman was found guilty, she would be tried as a witch [4]. High heels were also banished in 1791 when Napoleon attempted to bring equality. This banishment led to the demise of the "Louis" high heel. In fact, in the 1790's, the heels diminished so much that there was barely a small wedge in place of the heel. From this period until the 1930's there were four types of heels used on Western Women's shoes: the knock-on, stacked, spring, and the re-emergence of the "Louis" heel [3].

In the 1860's, the invention of the sewing machine really sparked high heels as fashion again by enabling a larger variety of heels to be constructed at higher quantities. By this time high heel users became more comfortable walking in higher heels. Advertisers tried to intrigue customers by promoting that high heels help alleviate back pain and stooping, and made walking less tiring. However, critics reassured that high heels encouraged a more sexually aggressive walk that intrigued insensitive men [5]. Ignoring the criticism, America opened its first high heel factory in 1888. The twentieth century strongly influenced high heel demands based on the several events

that took place. Women demanded more comfortable heels, until the higher hemlines of the roaring twenties encouraged higher, more fashionable heels. In the 1930's and 1940's, The Great Depression and WWII minimized the supply of luxury items. High heels were categorized as one of these luxury items; and therefore, a shorter wider heel was in demand. However, once the war ended in the 1950's, high heels made a strong comeback. This comeback was largely due to the collaboration of Christian Dior and Roger Vivier to create stilettos, a low-cut vamp shoe with an exaggeratedly slender, narrow heel [6]. In addition, in the 1960's, the invention of the miniskirt enabled the attachment of stilettos to boots to enhance the vision of bare legs.

The 1970's brought back the popularity of platform shoes. This was an era where both men and women basically dressed to shock, wearing bright and exuberant colors. However, the 1980's brought a completely new feel to high heels. This era began the idea that fashion, specifically sexy shoes, was beneficial to women [7]. Women now began to wear heels to feel better about themselves. It not only made them taller, but also gave them the feeling of power and authority. However, in the late 1980's and early 1990's, as women in the workforce increased, more flat-heeled shoes began to be worn in the corporate culture.

Literature Review

Current Patents/Designs/Problems

When women consider which heeled shoe to wear, the height and style mostly come into play. A tall, narrow heel is generally worn to represent elegance. In contrast, a short, wide heel is generally chosen for comfort and mobility. Active lifestyles often involve long periods of standing and walking, which demands a need for flexible shoes that can accommodate these active lifestyles. Although attempts have been made to create a shoe with variable heel height and style, no design has proven successful in addressing the need of aesthetic appeal, ease of use, comfort, simplicity of design, and sturdiness.

US Patent No. 5133138 discloses a shoe with a replaceable high heel. However the design of this heel has several drawbacks. Typically, the greatest stress in a heel lies at the top of it where there is an attachment to the sole [8]. Therefore, having a wider attachment point of the heel to the sole greatly helps the shoes stability. However, on this patent the fixed-heel insert attached to the sole is narrower than the top surface of the detachable-heel, and consequently provides less strength than a normal high-heeled shoe. In addition, a slight movement of the heel relative to the sole would create a gap between the sole and the top edge of the detachable-heel. Therefore, a retractable pin would be required to manually secure and release the detachable-heel. This pin makes detachable-heel replacement uncomfortable for the user.

Patent W091108685 discloses a shoe with a detachable heel as well. This design contains all the drawbacks that US Patent No. 5133138 has except there is no retractable pin required [8]. This design uses a magnetic attachment for the detachable heel. One major issue with using a magnetic bond is that a slight variation in mechanical tolerances (such as temperature and moisture) of the

metallic insert or its housing will result in either an overly tight or overly loose attachment, resulting in less stability [8].

There must be ways to bond the fixed heel or socket to the sole of the shoe. In these designs, the heel is bonded to the sole with nails and adhesive. Alternative methods of attachment would work as long as it attains a secure and durable bond. The sole is constructed with materials that allow flexibility within the sole to provide proper foot position and support. A material commonly used to accommodate the needs of the sole is flexible leather [8]. However, alternative materials, such as flexible rubber could also be used to accommodate the needs of the sole. When the shoe converts from a higher heel to a lower heel, the front portion of the insole must be flexible enough to adjust to the flexing sole. The most commonly used material to accommodate the upper portion of the shoe is a combination of Lycra and leather. This material must be flexible, yet sturdy enough to hold the foot in place. Some alternative materials that could also be used are any flexible leather, cloth, or any other material permitting flexibility to help enable proper foot position and support [8].

The fixed heel part of the shoe is composed of ABS plastic injected around the upper magnet. The surface shapes of the attachments should be shaped according to its matching part that it will be attached to so that they can be flush with one another. This will also help increase stability. The interchangeable low heel part, which is fixed to the shoe, is composed of molded polyurethane plastic injected around the lower magnet. Also, the interchangeable high heel part is composed of molded ABS plastic injected around both the lower magnet and the metal cylinder core. In addition, the interchangeable heel has a conical shape that allows for minimal friction and rubbing between the socket wall and the interchangeable heel surface as the user inserts the heel until it is fully inserted and the magnets come into contact [8]. Some alternative plastic types can be used for the construction of the heel as long as they are lightweight but strong. The magnets used are solid

neodymium magnets, which permit a compact design that are strong enough to securely attach the interchangeable heel; yet, it just takes a quick tug to detach the interchangeable heel.

In addition, the shape of the detachable heel and the socket which the heel enters for attachment both have somewhat of a square cross-section to eliminate rotation of the detachable heel once it is attached [8]. This eliminates the need for a notch and key guide, therefore improving simplicity for the user and manufacturer, as well as increasing the aesthetics. By producing a highly accurate mold, the fixed heel and interchangeable heel parts should become flush with one another creating more stability and a nearly undetectable joint. This would hide the mechanics of the shoe; and therefore, add to the aesthetics of the shoe. Also, by housing the socket in the fixed heel part (attached to the sole) of the shoe, it allows for an exponential thinning of the heel; therefore enabling a narrower more elegant design of the heel balancing aesthetics with stability. This also enables for a greater surface joining area to account for the greatest stress point of the shoe. Furthermore, in a past study, an MIT student designed three prototypes of a “detachable” high heel shoe [9]. In each of the cases, there was some type of key and slot mechanism that made the heel attachable and detachable. Designating the detachable heel as the male oriented part allows for a smaller, more portable detachable heel, which the user can easily fit into a purse or small bag.

Human Factors/Convenience

One of the most important aspects of such a design in this case is human factors. Not only does the high heel need functionality and aesthetics, it also needs to be comfortable for all types of potential uses. It can be noted that “wearing high-heeled shoes may be a contributing factor with respect to the development of patellofemoral pain (PFP)” based on the fact that “peak patellofemoral joint stress was found to increase significantly with increasing heel height” [10]. A

detachable high heel shoe must have the same comfort as any other high heel shoe product on the market in order to avoid that the connotation that detachable heels create more discomfort and pain than normal high heels. In order to make a product that can flex and function as a regular shoe, it seems that it may be easier to work with a shorter heel because of the angle associated with the sole is small; and therefore, the sole requires less flexibility.

When it comes to the materials that make up the product, it will be important to select something that offers comfort and support. This is the case for both the exterior and interior of the shoe. In a recent study, thick, soft foam inserts proved to be the most effective method in decreasing pressure and force on the foot [11]. Both the material properties and thickness of the foam inserts proved to be important factors that contributed to the amount of peak plantar pressure. Therefore, the correct thickness of material must be found in order to increase comfort and maintain support. It would be beneficial to explore many materials that have similar properties in order to find the perfect mix of where cost effectiveness meets comfort.

Wearing high heels inevitably makes the user less stable and more prone to injury. In fact, human feet account for about 10% of the total surface area of the human body [12]. Of that 10%, less than half is in contact with the ground. However, when a high heel is worn, the surface area of foot that touches the ground is essentially cut in half again due to the nature of the foot [12]. These constraints can make walking a struggle, especially if the heels are very tall. For example, say that an average woman only really needs to wear a pair of high heels 25% of the time at a certain event. This is assuming that they will wear them while getting ready to go out, driving in the car, walking to the desired destination, or taking them off before they even leave the event. If these women were able to wear some type of flat shoe for the remaining 75% of the time that they have a product on their foot then they could limit their risk of major injury that could be caused by the shoe.

In a past study, the energy cost and the lower extremity mechanics in shoes of different heel heights (1.25 cm, 3.81 cm, 5.08 cm, and 7.62 cm) were examined in 15 female subjects [13]. Heart

rate and oxygen consumption were monitored as the subjects walked 4.2km/hr on a treadmill. Analysis of the biomechanical data revealed that ankle plantar flexion, knee flexion, vertical ground reaction force, and the maximum anteroposterior braking force increased as heel height increased [13]. In addition, the timing of the subtalar and knee joint action is not synchronized as heel heights increase. Heart rate and oxygen consumption also increase with heel height. According to the data, to maintain comfort and decrease the risk of injury, women may be advised not to wear shoes with a heel height greater than 5.08 cm [13]. Considering women often wear high heels to working environments, they must deal with the consequences of their choice in heel height for the rest of the day.

Astonishingly, Osteoarthritis of the knee is twice more common in women than it is in men. To investigate this problem, a study was done at Harvard Medical School. Twenty healthy women walked in their own high heels and then barefoot [14]. Data were plotted and qualitatively compared. However, major peak values for high-heeled and barefoot walking were statistically analyzed. Measurements showed an increased force across the patellofemoral joint and a greater compressive force on the medial compartment of the knee when walking in high heels versus barefoot. In fact, on average there was 23% greater force created when walking in high heels [14].

In a different survey of 200 young women wearing high heels, there were frequent complaints of leg and lower back pain. Therefore, a study was done to examine the biomechanical effects of three heel heights (0, 4.5, and 8 cm). This study examined five healthy, young women while standing in the heels versus walking in the heels [15]. The four major biomechanical effects observed were the trunk flexion angle, tibialis anterior EMG, low back EMG and the vertical movement of the body center of mass. Consequently, the trunk flexion angle decreased, while the other stresses increased significantly when wearing high heels. The decrease in the trunk flexion angle creates a more unstable posture because of the increase in the height of the center of body mass. In addition, this decreasing angle creates additional compressive forces in the lower lumbar

spine because of the change in the lumbar lordosis [15]. Also, in order to maintain the abnormal posture, the back must over compensate. All these effects can significantly increase discomfort and fatigue levels in those wearing high heels especially at work [15].

Using CAD for Design

Inevitably, the costs of manpower and resources will constantly increase over time. Because of this, the use of computer aided process planning (CAPP) has also increased. This includes the use of computer-aided design (CAD) and computer integrated manufacturing (CIM) in order to help develop the product. Many companies in Europe began to use this process once they were exposed to higher manufacturing prices. “The purpose of CAPP is to automate process planning so that process plans can be consistently generated. Process planning, including the manufacturing process and the sequences, manufactures products economically and competitively” [16]. Using CAD and CIM programs to aide CAPP will be very helpful in defining exact measurements and tolerances for every arch, crack, tread and crevice in each type of sole. Using a CAPP system will allow for a complicated process to be standardized and cost effective in the long run. The start up cost for using such tools can be quite high considering needs for CAD software, lab/machine space, the machine itself, and many materials to create prototypes. But in the long run CAPP will reduce production time, provide consistency, minimize error, and set standards among various types of high heel shoes in the industry. Developing a CAPP system is out of the scope for this project, however certain aspects of it may be very valuable when designing and manufacturing a prototype.

Design

Survey Results and Analysis

The idea of creating a high heel shoe that can convert into a flat possessed many challenges. One of these was the fact that the founders of this project are both male, and subsequently were not users of any high heel products. In order to understand what the “high heel experience” was like, it seemed necessary to create a survey that asked simple, yet significant questions directed towards females that may or may not use the product. One hundred and fifteen females ranging from ages 20-23 were invited to participate in a survey that was set up and conducted through Survey Monkey. Of those one hundred and fifteen females, forty-three participated. The survey was taken online and each user remained completely anonymous. It was set up in the following manner: there were seven multiple choice questions, participants were not allowed to skip any questions, each participant was instructed to answer each question as honestly as possible. Listed below are the questions with their corresponding answers that were listed on the survey.

- Question 1: How often do you wear high heels?
 - Less than once a month
 - A few times a week
 - 1-3 times a week
 - 4-6 times a week
 - At least once a day

- Question 2: Which part of your foot/ankle feels the most discomfort when wearing heels?
 - Heel
 - Toes
 - Arch of foot
 - Top (from straps)
 - Ankles

- Question 3: Would you pay more for high heels that could guarantee comfort?
 - Absolutely, comfort is most important
 - Probably, as long as its within reason
 - Maybe
 - No, I feel fine in all the heels I buy

- Question 4: How important is comfort to you when wearing heels? (1 least important, 6 most)
 - 1
 - 2
 - 3
 - 4
 - 5
 - 6
- How important are the aesthetics/looks of your heels? (1 least important, 6 most)
 - 1
 - 2
 - 3
 - 4
 - 5
 - 6
- How important is stability when wearing heels? (1 least important, 6 most)
 - 1
 - 2
 - 3
 - 4
 - 5
 - 6
- How aware are you with the possible long-term physical health issues related to wearing high heels?
 - Very aware, I try to wear heels only when necessary
 - Pretty aware
 - I've maybe heard a thing or two about it
 - I didn't know high heels could cause long term issues

In addition to some of the results being discussed here, full summary tables of the participants' answers can be found in the Appendix.

The answers received on these questions can be considered valuable since 72 percent of those females who took the survey wear high heels at least a few times every month. One can assume that they have the experience to be able to give feedback on the subject. An overwhelming 70 percent agreed that their toes feel the most discomfort when wearing heels. Because of this, something had to be done in the toe region of the proposed model in order to alleviate that discomfort. Several options were taken into consideration including changing the shape of the toe area, having some sort of padded material insulate the entire toe covering, and gel pads placed in specific areas. Eighty eight percent of participants agreed that they would be willing to pay more for

shoes that can offer greater levels of comfort as long as those costs can be justified. This was great to hear because naturally, by owning and wearing more comfortable high heels, there will be a reduced amount of injury that coincides with using the product.

It is no surprise that the participants felt that comfort, stability, and aesthetics were all important qualities in a high heel shoe. A whopping 91 percent of the females responded with either a 5 or 6 when asked how important the aesthetics were. After seeing these numbers, it became a necessary goal to make sure that the proposed high heel can look just as good as popular heels out on the market today.

On the contrary, it was interesting to see that 70 percent of participants were either completely unaware or had maybe heard something once or twice before about the possible long term physical health issues related to wearing high heels. This is definitely a problem that needs to be addressed and fixed. If a female wears her high heels in such a way with frequent repeated use, then she will likely have complications in certain parts of her foot or leg at some point in her life. Being unaware of these issues is like smoking cigarettes without knowing that they can harm you. Every user of a high heel product deserves to know that it is not the best thing for their physical health, and that there are alternatives to help prevent injury.

Human Factors: Ergonomics

According to dictionary.com, ergonomics is “the technology concerned with the design, manufacture, and arrangement of products and environments to be safe, healthy, and comfortable for human beings.” Ergonomics can be applied in several ways to this shoe design in order to maximize the comfort, usability, and safety. Several problems that high heel users face come from the rubbing of certain parts of the shoe against the foot. According to the Mayo Clinic, such problems include corns, calluses, and blisters. Corns and calluses are hardened, thick layers of skin formed in areas where rubbing between the shoe and foot occur [17]. In addition, pump bump or Haglund’s deformity can also occur due to the rubbing from the rough rigid straps of the shoes [17]. This deformity is a bony enlargement that generally forms on the back of the heel. One solution to these problems is the application of a clear gel padding that attaches to the inside of straps or any other point of friction and irritation. Two major points of friction in which this solution can be applied can be seen at points 1 and 2 on Figure 1 [18].



Figure 1



Figure 2

Figure 2 displays the gel pad and how it can be applied to the inside of a heel strap in order to minimize irritation from the strap slipping off the foot [19].

Another issue that high heel users face is from the pressure applied to the balls of the feet and toes. When the heel is raised, more weight is distributed to the front of the foot. This additional weight forces the foot to move forward causing the toes to constantly be pressed against the front of the shoe. Ultimately, this issue leads to health problems such as hammertoe,

bunions, Neuromas, toenail problems, and even stress fractures. Hammertoe is an unnatural bending of the toes often caused by a foot being pressured up against the front of a shoe. Bunions are bony bumps that form at the base of the big toe generally from tight fitting shoes [17]. Similarly, joint pain can also occur at the ball of the foot. Neuroma, a growth of nerve tissues, causes a sharp, burning pain in the ball of the foot along with a stinging numbness in the toes [17]. In addition, nail fungus and ingrown toenails can form due to the toes constantly being pressed up against the front of the shoe. Although somewhat of an extreme case, stress fractures, or tiny cracks in the bones of the foot, can occur from the added stress high heels inflict on certain parts of the foot. Figure 3 displays the highest pressure point areas in red from a person wearing high-heeled shoes [20].

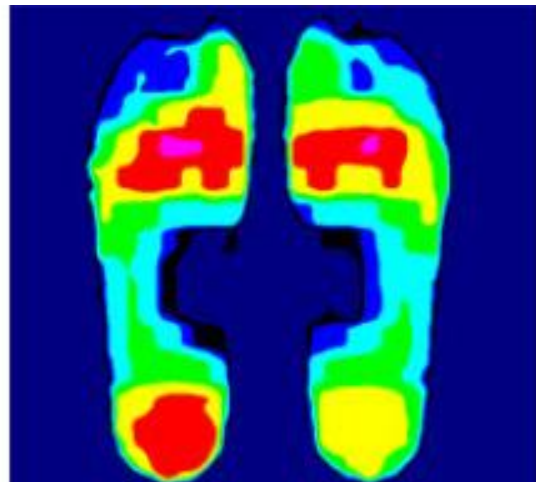


Figure 3

One solution to minimize these issues is to apply an orthopedic memory foam pad to the higher pressure points on the shoe. By applying the material used in orthopedic floor

mats (as seen in Figure 4) to the shoe in the areas of the ball of the foot and the heel, the user will feel more comfort [21]. Figure 5 shows the pain reduction in the knees, back, and foot during Insole Pilot Test Programs with various Fortune 500 companies [22]. These Insole Pilot Test Programs showed an average of 30% less pain received within a span of 3 weeks and a 95% acceptance rate [23]. This material will absorb the pressure applied from the foot instead of inflicting that pressure back on the foot. In addition, this absorption of pressure will keep the foot from sliding forward, thus pressing the toes against the front of the shoes. This material will also encourage blood flow



Figure 4



Figure 5

throughout the foot [24]. By alleviating pressure from the foot, blood can flow more freely, minimizing swelling within the foot. The aesthetics of the shoe can be maintained by applying these orthopedic memory foams to only the areas of the toes and heel. The arc of the foot is the narrowest part of the foot. It is the part of the shoe that is most visible when being worn. By not placing orthopedic memory foam in this location, the original aesthetic design of this portion of the shoe can still be seen. In addition, this particular material deters the absorption and accumulation of bacteria from sweat. Implementing this material will deter the formation of bad odors.

Alternative Designs

In order to find the optimal shoe, several designs had to be considered. Each design experimented with a different heel attachment mechanism. The first alternative design taken into consideration for the detachable heel was a pin mechanism. This shoe consists of a fixed socket in which the heel can be inserted. A pin is then inserted through a hole, enabling the user to adjust and fix the heel at a desired height. The socket and heel structures would be composed of ABS Plastic injected. However, the heel would consist of ABS Plastic injected around a cylindrical metal core. This material would be durable enough to contain the weight and strain that the user applies to the shoe, yet light enough so that each step isn't a burden due to heavy shoes. In addition, the pin would be constructed out of steel in order to be strong enough to hold the heel and socket together. In order to have a strong connection point between the sole and socket, both nails and adhesives would be used. However, there are several problems and drawbacks to this design. One drawback is that the shoe is not as aesthetically pleasing since holes must be punctured along the heel height in order to allow the heel to be adjusted and removed. Another issue hindering the shoes aesthetics is that a pin will be constantly visible on the exterior of the shoe. In addition, the socket in which the heel is inserted must be large enough to maintain stability. The more heel height there is inserted into the socket, the more friction and grip the socket will have on the heel to increase stability. The problem with this design is that there will always be a fixed socket height. Therefore, if the heel is removed the shoe can never be converted to a flat shoe since the socket height is permanent. Being unable to convert the shoe to a flat shoe limits the amount of pressure reduction and comfort of the foot. Also to maintain stability, there must be very small tolerances between the socket and heel, and hole and pin. These small tolerances lead a higher manufacturing cost due to a required high precision manufacturer.

Another alternative design taken into consideration for the detachable heel was a magnetic attachment design. Much like the previous alternative design, there is a fixed socket in which a heel can be inserted. However, on this design there is a magnet that lies on the top surface of the heel and the upper surface of the socket. This mechanism would allow the user to remove and insert different heels with varying heights. The user would easily be able to remove the heel with a quick tug. The socket and heel would have a square shape, which would disable the heel from turning or rotating within the socket. This would eliminate the need of a notch and key mechanism. Similar to the previous alternative design, the socket and heel structures would be composed of ABS Plastic injected. However, this heel would also be ABS Plastic injected around a cylindrical metal core. This material would be strong and durable, yet lightweight. Lightweight material is important in order to limit the user's energy usage when wearing the shoes. The socket would also be bonded to the sole using both nails and adhesive. The magnet used would need to be strong enough to hold the heel in place, yet not too strong so that the user can easily remove and replace the heel. However, there are also several flaws and drawbacks in this detachable heel design as well. One drawback is that the environmental conditions, such as temperature and moisture, can affect the properties in the magnet. This variation of properties can create either a loose or tight connection depending on the environmental conditions; ultimately, varying the stability of the shoe. In addition, in order to change the heel to the desired heel height, the user must possess the different heel sizes at the time of detachment. Also comparable to the previous alternative design, the socket in which the heel is inserted must be large enough to maintain stability. The more of heel that lies in the socket, the more friction and grip the socket will have on the heel to increase stability. The problem with this design is that there will always be a fixed socket height. Therefore, if the heel is removed the shoe can never be converted to a flat shoe since the socket height is fixed.

In order for the high-heeled shoe to convert to a flat shoe once the heel is removed, there must be some thought put into how the shoe will bend at the connection point between the balls of

the foot and arc of the foot. Therefore, some alternative designs for the bending point were explored. One method of bending was the implementation of a hinge mechanism. A metal hinge would be attached between the arc and the ball of the foot area. This hinge would be attached with nails and adhesive. It would allow the shoe to bend and convert when changing from a high heel to a flat shoe and a flat shoe to a high heel. As one may have already guessed, there are some drawbacks to this bending mechanism. One drawback is that the attachment of the hinge to the sole would be difficult to create a strong bond. Furthermore, the technicality of this design would create higher manufacturing costs. In addition, this design has only one fixed hinge point, which isn't very adaptable to varying foot shapes and sizes. Not all bending points of each user's foot will be positioned at the same location, even when given the same shoe size.

Another alternative design for a bending mechanism was to apply a thin strip of rubber between the arc of the foot and balls of the foot. This strip of rubber would allow for enough flexibility at the bending point. It would also be flexible enough to adapt to different feet shapes and sizes since it can slightly stretch and adjust. However, there are some drawbacks to this design as well. One drawback is that the best way to bond this rubber to the shoe is by thread. This thread could tear through the rubber creating a weak, unstable bond. In addition, this strip of rubber may not be durable enough to maintain its elasticity and last for a decent amount of time. Most rubber of this nature can be easily worn out and may not handle certain environmental conditions as the rest of the materials on the shoe. A balance between flexibility and durability would be difficult. If the strip is too durable then it won't properly bend to the shape of the foot. If the strip is too flexible then the front part of the shoe will bend downward when the ground exerts no force and the person is in mid-stride. Similar to the previous bending mechanism, this design is fairly technical which, again, leads to a higher manufacturing cost.

Proposed Design

There was one detachable heel design that was chosen as the proposed design. It was chosen because it adequately balances style with comfort. The proposed design consists of a hook and eye bracket attachment mechanism. The eye bracket has a female orientation and is bonded to the top of the cutout in the bottom of the outsole. The eye bracket is attached using small screws and E-6000 industrial strength adhesive. The outsole of the shoe is thick enough for the screws to be inserted into it. This adhesion is very important because this particular location of the shoe experiences one of the highest amounts of stress. The outsole is shaped according to the shape of the upper part of the sole. Therefore, the outsole and heel will match up with one another's semi-oval shape, enabling the heel and outsole to be positioned completely flush to each other. The outsole and heel have been cut at an angle towards the front of the shoe in order to maintain the same design that current high heels possess, as well as to account for the conversion to a flat shoe. Therefore, when the shoe is converted from a high heel to a flat, the arc curve will be minimized and the user will still be able to walk comfortably. On the other hand, the hook bracket is located on the top of the heel. This bracket will also be bonded to the heel using screws and adhesive. This bond is also very important considering it experiences the same amount of stress as its counterpart, the outsole. The hook bracket is oriented on the top of the heel with the insertion slip facing the back of the shoe. Therefore, when the heel is attached to the shoe, it will be inserted into the cut-out of the sole approximately .5-.75 inches just before the eye bracket, then slid towards the back of the sole enabling it to hook onto the eye bracket; thus holding the heel in place. This will allow for each attachment and removal of the heel. The hook bracket is oriented in this direction in order to keep the heel from falling out with each step forward. When the user takes a step forward, a force is applied to the heel in directions up and toward the back of the heel. Each step the user takes will push the heel back and up into the eye bracket; ultimately, keeping the heel stable and secure. The

eye and hook brackets are made out of a strong metal that allows the shoe to maintain a high level of stability. In addition, since the brackets are located on the inside of the shoe, the aesthetics of the shoe can be maintained, and from the exterior the convertible shoe looks like a normal high heeled shoe.

The heel is composed of an ABS Plastic injected mold. This allows the heel to be durable enough to withstand the pressure and weight that the user applies to this portion of the shoe, yet lightweight to minimize energy used by the user when walking. The heel is wide at the base and tapers thinner as it reaches the contact point with the ground. This provides extra support at the attachment point with the outsole, yet provides the heel with aesthetics as it tapers. As mentioned in the literature review, thin narrow heels represent aesthetics, while thick wide heels are designed for stability. By combining both these elements into the heel, both aesthetics and stability are achieved. The outsole is composed of sturdy yet flexible leather. The leather is thickest at the heel region in order to provide maximum support. As the outsole approaches the front of the shoe it becomes thinner. This design allows for more flexibility within the outsole as it approaches the front of the shoe. This increased flexibility will enable the shoe to bend where necessary while adapting to the user's foot. Unlike the alternative bending mechanisms mentioned in the previous designs, the proposed design doesn't have one single hinge point. Therefore, the outsole can better mold and adapt to the user's foot. Naturally the foot doesn't arc downward and drastically bend at one point to become flat at the balls of the foot, so why design a shoe around that? The design better meets the shape of the foot and the natural flow of a person's walking motion.

When a high-heeled shoe is worn, the center of mass is raised to a higher position. This is the reason several lower back and abdominal issues can occur. This heel is designed and positioned to be in the center of the user's heel. If the heel placement were located too far forward on the shoe then more of the user's mass would shift behind that point of stability. This would inflict more stress on the lower back and abdomen in order to counteract that shift in mass to stand at a more

erect and correct posture. In contrast, if the heel were positioned too far back on the shoe, then the user would find herself fighting from leaning forward. More pressure would be forced upon on the front of the foot and the user would place more stress on the lower back and abdomen in order to stand in a more erect and healthy posture.

Proposed Design vs. Prototype

After determining the nature of the proposed design, the idea of a prototype became an important aspect of the project. After numerous hours designing a high heel in the drafting program, Pro Engineer, the file was saved and formatted to be compatible with a 3D printing program. However, it should be noted that due to time, material, and manufacturing knowledge constraints, the prototype that was created to supplement this project was for demonstration purposes only. The entire heel and sole portions were constructed with the use of a 3D printer that injects layers of ABS plastic over several hours. In the proposed model, the high heel would attach to the sole with a single, thick, sturdy hook and eye bracket. Unfortunately, this bracket with the desired specifications could not be found given certain time and resource constraints. Instead, two



Figure 6

smaller brackets were used to represent the same idea of how the connection point works in the proposed model. Since these hooks were smaller than expected, the cutout located near the heel in the bottom of the sole was too deep to house them. The prototype was modified to

contain two smaller hook and eye brackets as seen in Figure 6. The female portions of the bracket (located in the sole cutout) were set on top of a layer of glue to raise them about .2 inches. After the glue dried, each bracket was secured with two screws that are similarly used in eyeglass products. This modification allowed for the female bracket to be nearly flush with the outer edge of the sole making the alignment match up correctly for insertion. The combination of the industrial strength glue and the screws ensure that the bracket connection points are durable enough to withstand large amounts of force. Refer to the Appendix for more figures of the prototype.

Material Analysis

The proposed converting high heel (not the prototype) is composed of fifteen different parts. The heelpiece is made of a lightweight yet durable plastic. It is 3.5 inches tall and possesses the shape of what most people would consider a normal high heel. One hook (male piece only) bracket is connected at the center of the heel with the insertion slit facing the back of the heel. This bracket is held on with an industrial strength adhesive and two small stainless steel screws.

The outsole is made of a strong yet flexible leather material that ranges from .667-.750 inches thick at the heel, and gradually gets thinner until it reaches its thinnest point at the ball of the foot where the user's toes bend flat. The purpose of the outsole getting thinner as it progresses toward the toes is so that it will bend much easier when converting into the flat shoe. On the thick heel section of the outsole, there is a small square cutout that houses the eye (female piece only) bracket. The eye bracket is bonded to the outsole with industrial strength adhesive along with two small stainless steel screws.

The insole is a thin layer of three different materials: a gel pad strip, memory foam, and leather. The gel pad strip is for different locations depending on the type of heel being produced. If

the high heel design follows one of that seen in figure 1A, then the gel pads would be placed at points one and two. However, if it is a strap high heel design, then the two gel pads would be placed inside of the straps that go over the top of the user's foot holding it in place. The memory foam is located at the inside of the front third region of the foot, providing comfort for the toes and ball of foot. The leather is one piece connecting the heel to the memory foam, basically under the arch region of the foot.

Cost Analysis

Attempts to contact manufacturers for an approximation of material and manufacturing costs were made; however, feedback from these manufacturers deemed unsuccessful. Material costs slightly vary depending on shoe size. In addition, these costs of materials will vary depending on quantity purchased per order due to promotions or specific quantity discounts. In order to minimize materials costs, more materials should be ordered at a time. Manufacturing costs are dependent on the complexity of the product and process of manufacturing. There are different processes to cure the leather in order to satisfy the needs of the material. For example, the process required for the leather of this shoe would involve drying, tanning, and glazing. Depending on the emphasis of each step, the leather will be as flexible, durable, and lightweight as necessary. Without confidence in accurate cost values for the materials and manufacturing necessary for the production of this shoe, no cost conclusions will be made.

Environmental Impact

It is important to consider the environment and the lives of those that may be affected by designing and manufacturing a new product. It should be a goal set by every company to produce as little waste and be as eco-friendly as possible. The materials used in our proposed design are set to be as environmentally friendly as possible. All plastics, metals, and adhesives are as natural as possible. Any product that uses additional chemicals that may harm the environment has not been used. Consider the following scenario: our product becomes popular in today's market. Assume that every female owns at least two pairs that she enjoys to wear at some casual and most fancy occasions. For these situations, she essentially has four pairs of shoes that only consume the material used in two pairs by having a product that can simply convert into a comfortable, versatile flat shoe. A lot of material would be saved if this became the standard in the market.

In addition to the points listed above, a converting high heel product would greatly increase the health and safety of the user over a long period of time. The risk of rolling an ankle, forming blisters, bruises, or other sores would be minimized. Since spraining or breaking a foot/ankle is a realistic possibility when wearing heels, medical bills could rise for those who wear high heels on a regular basis. These medical costs would be widely decreased in response to the reduced risk from having a product that can convert into a regular shoe when the user becomes uncomfortable or tired.

Conclusions

Many females enjoy wearing high heels to weddings, work, or even casual events. Some of these events require an abundance of standing or walking. The problem is that many females find it difficult to wear high heels for long periods of time due to discomfort. Throughout the years more women have evolved away from the household duties and into career jobs. Due to media and public critique, women feel pressured to wear high-heeled shoes in order to fit the mold of “the ideal beautiful woman.” However, there are many long and short-term health risks associated with high-heeled shoes. The objective of this report was to find a solution to this problem in order to increase comfort and minimize high-heel related health risks. It became apparent that the best way to maximize comfort and minimize health risks was to decrease the amount of time women wear high heels. Style and fashion are very important aspects when it comes to high-heeled shoes; therefore, a balance needed to be found between style and comfort. The smaller the heel height, the less pressure there is applied to the balls of the foot and toes. With that being said, the optimal design must contain a shoe that would be stylistic and elegant, yet could somehow convert to a shoe with as small a heel height as possible. This is when the idea of a detachable heel was discovered.

Several designs for a detachable heel were explored but most of the designs consisted of a fixed heel socket that would limit the high-heeled shoe from converting to a flat shoe. In addition, there were several more drawbacks included in each design. The only way to convert the high-heeled shoe to a flat shoe was to get rid of the fixed heel socket. In order to solve this problem, several alternative attachment mechanisms had to be investigated. After much discussion and trial by error, one attachment mechanism finally seemed to solve the problem while maintaining aesthetics. The proposed design consists of an attachment mechanism that uses eye and hook brackets. A rectangular cutout was made in the bottom of the outsole of the shoe. The eye bracket is bonded within this cutout using screws and adhesive. Its counterpart, the hook bracket is bonded to

top of the heel using screws and adhesive as well. This became the optimal attachment method because it increased stability and functionality while maintaining aesthetics by housing the attachment method internally. The method of attachment is not visible on the exterior of the shoe and from an observer's point of view this convertible high heel looks like an ordinary high-heeled shoe.

Now that there was a detachable heel mechanism in place that enabled the removal of the whole heel, there needed to be a mechanism designed to allow the heel to bend down into a flat shoe. This bending mechanism would need to be placed just behind the balls of the foot where the arc of the foot begins. Several options were explored; however, all the options had too many associated drawbacks. The proposed design consists of a sturdy yet flexible leather outsole that gradually becomes thinner as it approaches the balls of the foot and toe region. This design allows for support and flexibility where necessary. Not all feet are shaped or sized the same; therefore, this design slightly adapts to the variances in location of the bending point on each user's foot. The foot itself doesn't have one single bending point, so why should the shoe? This design allows the outsole to better mold to the user's foot by imitating the user's natural walking motion. Ultimately, this design met its objectives by allowing the user to wear high-heeled shoes and convert them to flat shoes at any moment. By limiting the amount of time a user must wear high-heeled shoes, the associating health risks can be minimized and comfort can be maximized.

Recommendations

A lot of time and energy was put into this report and design. However, there are several procedures that could've been done differently in order to complete this project as efficiently as possible. One problem faced was that the design was completed prior to fully understanding which materials would be used. Therefore, a search for materials that would adapt and accommodate the design had to be done, instead of finding the materials and creating the design around those materials. This became an issue when constructing the prototype. Brackets for the heel attachment could not be found in the size necessary to accommodate the prototype. The cutout in the outsole of the design was made deeper than the height of the purchased bracket. This, in turn, led to a great deal of customization had to be done to the prototype in order to make the heel attachment come together successfully.

In addition, when designing and developing a new product, one must allocate a lot of time to this procedure. It is important to allow enough time to create a prototype for each alternative created. In this project, a sample prototype was created in plastic using a 3D printer in order to display the heel attachment mechanism. Large amounts of research had to be done in order to theoretically determine which methods would work best for the design. However, with more time full prototypes can be created using the designed materials. Given more manufacturing resources, the designs can be manufactured into actual high-heeled shoes that can then be tested by potential users. After accomplishing this, the shoe design could then be proven successful or unsuccessful, and could be adjusted and modified from there.

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Appendix

Survey Results

How often do you wear high heels?	People	Percent
Less than once a month	12	28%
A few times a month	15	35%
1-3 times a week	14	33%
4-6 times a week	1	2%
At least once every day	1	2%

Which part of your foot/ankle feels the most discomfort when wearing heels?	People	Percent
Heel	2	5%
Toes	30	70%
Arch of foot	7	16%
Top (from straps)	1	2%
Ankles	3	7%

Would you pay more for high heels that can guarantee comfort?	People	Percent
Absolutely, comfort is most important	6	14%
Probably, as long as it's within reason	32	74%
Maybe	4	9%
No, I feel fine in all the heels I buy	1	2%

How important is comfort to you when wearing heels? (1 least important, 6 most)	People	Percent
1	1	2%
2	1	2%
3	4	9%
4	17	40%
5	18	42%
6	2	5%

How important are the aesthetics/looks of your heels? (1 least important, 6 most)	People	Percent
1	0	0%
2	0	0%
3	0	0%
4	4	9%
5	11	26%
6	28	65%

How important is stability to you when wearing heels? (1 least important, 6 most)	People	Percent
1	1	2%
2	0	0%
3	4	9%
4	8	19%
5	17	40%
6	13	30%

How aware are you with the possible long term physical health issues related to wearing high heels?	People	Percent
Very aware, I try to wear heels only when necessary	4	9%
Pretty aware	9	21%
I've maybe heard a thing or two about it	18	42%
I didn't know high heels could cause long term issues	12	28%

Bill of Materials

Level	Part No.	Description	Qty	UM
0	4	Converting High Heel	1	EA
1	5	Heel	1	EA
2	6	Plastic	AN	cubic meters
2	7	Hook Bracket (male)	1	EA
3	8	Screws	2	EA
3	9	Adhesive	AN	grams
1	10	Outsole	1	EA
2	11	Leather (thin cut)	1	EA
2	12	Eye Bracket (female)	1	EA
3	8	Screws	2	EA
3	9	Adhesive	AN	grams
1	13	Insole	1	EA
2	14	Gel Pad Strip	2	EA
2	15	Memory Foam Pad	2	square cm
2	16	Leather (thick cut)	1	square cm

Prototype Figures



Figure 7: Displays the sole and heelpiece connected and standing upright.



Figure 8: Displays the heelpiece in position to be connected to the outsole.

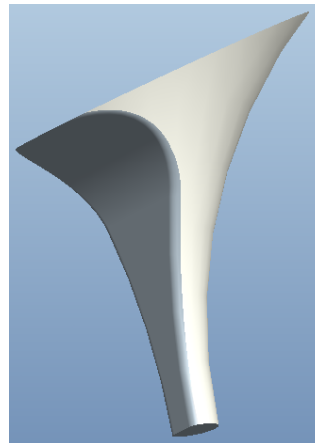


Figure 9: Displays the 3D CAD heelpiece

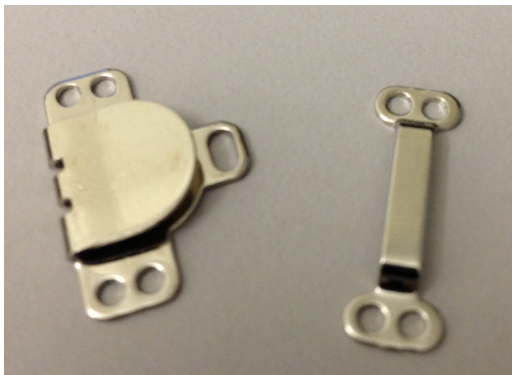


Figure 10: Displays the hook and bracket mechanism used on the prototype



Figure 11: Displays the full 3D CAD prototype