A Biomechanical Examination of the Lower Extremities in High Heeled Shoes

Ann Sylvia

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A Biomechanical Examination of the Lower Extremities in High Heeled Shoes

Ann Sylvia

Submitted in Partial Completion of the Requirements for Commonwealth Honors in Physical Education

Bridgewater State University

May 8, 2018

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A BIOMECHANICAL EXAMINATION OF THE LOWER EXTREMITIES IN HIGH HEELED SHOES

Ann Sylvia

Submitted to the Movement Arts, Health Promotion, & Leisure Studies Department at Bridgewater State University in partial fulfillment of Commonwealth Honors

May 2018
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Abstract

Women have been wearing shoes of various heel heights for hundreds of years. However, the effects of wearing high-heeled shoes upon a woman’s gait has not been significantly studied. Recently, high heeled shoes along with their purpose and place in society has come under fire with the current First Lady’s donning of 4.5” (0.11 m) Louboutin stilettoes. The vocal majority of criticisms seemed to center on the symbolization of high heels, denoting femininity and an elite position of wealth and power while a small minority focused on criticizing the potential negative health effects. Heel heights and styles fall in and out of popularity as trends change, currently high heels of 4” (0.10 m) and over are very much in fashion. Both men and women wear heels of various styles and heights daily; therefore, it would be beneficial to understand if biomechanical changes in various heel heights could affect health. The purpose of this study was to evaluate the biomechanical differences in common heel heights in the lower extremity during walking gait. Four female participants walked in three heel heights: barefoot, 2.5” (0.06 m) heel and 4.5” (0.11 m) heel. A two-dimensional kinematic analysis was conducted to examine walking gait with various heel heights. The findings of this study suggested that shoes with moderate and high heel heights to be limited in use and worn in moderation in order to minimize potential adverse health concerns to the body by altering the natural movements of the walking gait. Future studies are warranted to examine the long-term effect of wearing shoes in various heel heights and on different slopes.
Men and women have been wearing shoes of various heel heights for hundreds of years. However, the effects of wearing high-heeled shoes upon the human gait has not been significantly studied. Recently, high heeled shoes along with their purpose and place in society has come under fire with the current First Lady’s donning of 4.5” (0.11 m) Louboutin stilettoes. The objections to the First Lady’s choice of shoe were twofold. First, the stiletto style shoe and its history represents, to some, the oppression of women and symbolizes an elite wealthy class. Second, the biomechanical effects on the human body, specifically on the hip, knee, and ankle joints, are of great concern and have been called into question.

Heel heights and styles fall in and out of popularity as trends change, and currently high heels of 4” (0.10 m) and over are very much in fashion and worn by a variety of people every day (The Spine Institute, 2018). While, the stiletto is currently very poplar, a high heel is any type of shoe that positions the foot into plantar flexion (when the heel of the foot is higher than the toes). However, research suggests that “footwear of the stiletto type significantly increases the leg muscle activity” (Mika et al., 2012). While significant, long term research concerning the wearing of high heels is limited, it is clear shoe choice is responsible for causing muscle fatigue and imbalances, changes to the natural human gait, and pressure changes at the knee joint, among others (Simonsen et al., 2012). Research also suggests that the knee joint can become compromised over time. Patellofemoral pain syndrome, also known as “runner’s knee”, was found to be affected by heel height, specifically as “increasing heel height increases peak patellofemoral joint stress during walking” (Ho et al., 2012). Therefore, the purpose of this study was to evaluate the effects of common heel heights on lower extremity body joints. The results helped us better understand how the human gait could be affected by differing heel heights. This information is extremely important for both acute and long-term injury prevention because
understanding the effects of high heels on the human gait can better educate the general public and prescribe proper strength and conditioning program to minimize lower extremity injury.
Review of Literature

Walking Gait

An animal that walks or runs on two legs is known as a bipedal, such as humans. The ability to walk, or create locomotion, is of fundamental importance to human beings. Therefore, understanding the human gait cycle and biomechanical behavior of the lower limbs during locomotion is beneficial. One gait cycle is defined as starting “when one foot makes contact with the ground and ends when that same foot contacts the ground again” (Gait Cycle, 2018). Each gait cycle has eight phases: (1) Initial Contact (IC), also known as the heel strike; (2) Loading Response (LR), also known as the flat foot; (3) Mid-Stance (MST); (4) Terminal Stance (TST); (5) Pre-Swing (PSW), also known as the toe-off; (6) Initial Swing (ISW); (7) Mid-Swing (MSW); (8) Terminal Swing (TSW). These eight phases, specific, repetitive, and rhythmic in nature are used to create locomotion, propelling forward the center of gravity. Each gait phase has a normal range of flexion or extension for the hip, knee, and ankle joints as well as specific muscle activity and functions. The normal ranges are outlined in Table 1.

<table>
<thead>
<tr>
<th>Gait Phase</th>
<th>IC Initial Contact</th>
<th>LR Loading Response</th>
<th>MST Mid Stance</th>
<th>TST Terminal Stance</th>
<th>PSW Pre Swing</th>
<th>ISW Initial Swing</th>
<th>MSW Mid Swing</th>
<th>TSW Terminal Swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait Cycle</td>
<td>0%</td>
<td>0-12%</td>
<td>12-31%</td>
<td>31-50%</td>
<td>50-62%</td>
<td>62-75%</td>
<td>75-87%</td>
<td>87-100%</td>
</tr>
<tr>
<td>Hip Joint</td>
<td>20° flexion</td>
<td>20° flexion</td>
<td>0° flexion</td>
<td>-20° Hyper extension</td>
<td>-10° Hyper extension</td>
<td>15° flexion</td>
<td>25° flexion</td>
<td>20° flexion</td>
</tr>
<tr>
<td>Knee Joint</td>
<td>0-5° flexion</td>
<td>20° flexion</td>
<td>0-5° flexion</td>
<td>0-5° flexion</td>
<td>40° flexion</td>
<td>60-70° flexion</td>
<td>25° flexion</td>
<td>0-5° flexion</td>
</tr>
<tr>
<td>Ankle Joint</td>
<td>0°</td>
<td>5-10° Plantar flexion</td>
<td>5° Dorsal flexion</td>
<td>10° Dorsal flexion</td>
<td>15° Plantar flexion</td>
<td>5° Plantar flexion</td>
<td>0°</td>
<td>0°</td>
</tr>
</tbody>
</table>
The three phases of particular importance are the Initial Contact (IC) heel strike, Loading Response (LR) flat foot, and Pre-Swing (PSW) toe-off stages. While barefoot, the ankle joint will be in a neutral position during the heel strike allowing for the ankle and knee to act as shock absorbers during the loading response phase (Singh, 2017; Streifeneder Ortho Productions, 2018). During the flat foot stage, the ankle joint produces plantar flexion, and the knee joint moves into flexion, while the hip goes into hyperextension, allowing for the weight of the body to shift (Singh, 2017). The toe-off stage allows the toes to go into hyperextension and the ankle joint begins to plantar flex as the knee keeps moving into flexion” (Singh, 2017).

Today humans no longer walk barefoot and instead spend significant time wearing modern shoes that come in a variety of heel heights, from those that mimic barefoot walking with virtually no heel, all the way up to six inches (0.15 m) (and higher, although functionality becomes questionable with any heel over six inches (0.15 m) in height). The introduction of the shoe as a component of the human walking gait becomes especially important during the heel strike (IC), flat foot (LR), and toe-off stage (PSW), when the ankle, knee, and hip joints may be taken out of their natural gait positions due to the heel height of the shoe.

Fossils indicate that shoe use began as early as forty thousand years ago, during a time when both modern man and Neanderthals inhabited the earth (Trinkaus, 2005). It is widely accepted that early man wore shoes mainly for the function of protection from the elements; however, there is some evidence that expression through fashion did exist. “Beads found around the ankles and feet of human skeletons dated to 27,000 years ago suggest the presence of decorated footwear” (National Geographic News, 2008). What is unclear is exactly when footwear moved from being predominately used for functionality to become the aesthetic fashion statement of high heels today.
History of High Heeled Shoes

A high heel (HH) is any type of shoe that puts the foot into plantar flexion (when the heel of the foot is higher than the toes). Both men and women have worn high heeled shoes for centuries, but modern use began with elevated high heels. In other words, the sole of the shoe was elevated to create height, but the ankle of the foot was kept in a neutral position. These early platform shoes, known as ‘kothornos’ to the ancient Greeks and ‘cothurnus’ to the Romans (collectively known as “chopines”) were mainly used by classical actors to create a higher height to denote importance and social class (Tonchi, Weber, Small, & Zukerkorn, 2014). While the Greeks and Romans were just beginning to use high heels as a sign of status and importance, the function of the shoe was still the main purpose. Ancient Egyptian butchers wore elevated high heeled shoes (Figure 1.) in order to walk over bloodied carcasses and blood on the floor (Origin of High Heels, 2018) and the women of the Ottoman Empire wore them to walk over slippery bath house tiles (Tonchi, Weber, Small, & Zukerkorn, 2014).

Figure 1. Bath Clogs worn by women of the Ottoman Empire
(Photo Credit: Ann Sylvia)
These early elevated high heels, which continue throughout the fourteen and fifteenth centuries, would range anywhere from six to twenty inches in height (Tonchi, Weber, Small, & Zukerkorn, 2014).

**Figure 2.** Early elevated high heels
(Photo Credit Ann Sylvia)

Around the sixteenth century, the elevated high heel (Figure 2.) became a status symbol of the wealthy and began its long journey to becoming an equally loved and hated symbol of a woman’s femininity. All throughout Europe, the taller a woman was and the more impractical her footwear appeared to be was an indication of her wealthy socioeconomic standing (Tonchi, Weber, Small, & Zukerkorn, 2014). Elevated high heels also reached China where they were seen as a potential end the traditional custom of foot-binding. These new heels offered to “achieve much the same dainty, alluring femininity that the ancient custom of foot-binding practices produced but with none of the deformation and pain” (Tonchi, Weber, Small, & Zukerkorn, 2014).
At the end of the sixteenth century, advances in technology changed the construction of and revolutionized high heels. Instead of elevated heels that kept the ankle joint in a neutral position, the new design had a singular, high, leather stacked heel at the back of the shoe with arch support in the middle and a flat sole at the front, putting the ankle into plantar flexion during the gait phases of walking (Tonchi, Weber, Small, & Zukerkorn, 2014). This new shoe design, often referred to as the King Louis Heel (Figure 3.), became fashionable for both men and women as chopines fell out of style.

**Figure 3.** King Louis Style High Heeled Shoe  
(Photograph: Ann Sylvia)

Over the next two centuries, high heeled shoes ceased to exist being functional and became purely fashionable, becoming more and more ornate, but remaining around only two inches in height (Walford, 2007). They also shifted from being a shoe worn by both sexes to a shoe predominately worn by women. After having fallen out of fashion during the world wars, for a more productive and functional flat shoe, a shift came in the 1950's when the stiletto style high heel (Figure 4.) began its rise to dominance. Charles Jordan, in 1952, was the first to create thin stiletto type heels, using laminated wood (Walford, 2007). A technological development in
1954 allowed for heels to be “made by plastic instead of wood and had a metal rod running the length of them for added strength. The plastic heels were then covered to match the upper. The steel reinforcing rod resembled the short-bladed stiletto weapon” (Walford, 2007) and thus the modern-day stiletto was born.

Stilettos range from one inch in height up to ten inches and generally have a diameter at the ground of less than one centimeter. Throughout history, shoes have been used to separate classes, denote power (by both men and women), and symbolize both femininity and the oppression of women. Aside from the now outlawed Chinese practice of foot binding, the stiletto is the only type of shoe to evoke strong emotions, ranging from adoration to hate, and cement themselves in every aspect of life, from sexuality, femininity, politics, pop-culture, capitalism, and even the health industry.

**Figure 4.** Iconic 2008-2009 Christian Louboutin “Anemone” stilettos

(Photo Credit: Ann Sylvia)
Popularity of High Heeled Shoes

Stiletto high heels were once again thrust into the spotlight in August of 2017 when the First Lady of the United States, Melania Trump, was photographed boarding Air Force One wearing a classic pair of four and a half inch Manolo Blahnik stilettos en route to visit the Houston area which had just been devastated by Hurricane Harvey. Strong emotions to her footwear choice became evident as social media and news outlets erupted into fierce debate. One side condemned her choice as the “clichéd kind of femininity: decorative, impractical, expensive, elitist” that represented the oppression of women throughout history (Friedman, 2017). The other side defended Mrs. Trump’s right to choose her own footwear declaring that “when we judge one woman in power on superficial terms, we make it acceptable to judge any woman on those same terms” (Newsom, J. S. 2017).

While the debate concerning Mrs. Trump’s footwear choice centered on the symbolization of females wearing high heeled shoes, very little discussion was given to the health effects of wearing high heeled shoes for both the many men and women who consistently make footwear choices that take their foot from a neutral position into plantar flexion while walking. It is important to note that men also wear shoes with heels. For example, cowboy boots routinely have a two-inch (0.05 m) heel (in order to remain in stirrups). Another consideration is the evolving conversation concerning theories of gender and gender roles. Some biologically born men are transgender and therefore embrace traditionally female footwear. It is also becoming fashionable for men to wear varying heel heights and celebrities from Justin Bieber to EJ Johnson have consistently been spotted in heels that vary from a one-and-a-half-inch block heel all the way up to five-inch stilettos heels. So, while the conversation often centers around females and high heels, it is truly a subject that effects all human beings. Since adding even the
slightest heel to a shoe will have biomechanical effects on the body, it is first important to understand the generally accepted classification of heel heights, Table 2.

Table 2. Categorization of shoe heels heights (How to Measure High Heels, 2017)

<table>
<thead>
<tr>
<th>Heel Category</th>
<th>Heel Height (Inches)</th>
<th>Heel Height (Meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flats</td>
<td>Under 1 Inch</td>
<td>Under 0.025 m</td>
</tr>
<tr>
<td>Low Heels</td>
<td>1 inch – 2 inch</td>
<td>0.025 m – 0.05 m</td>
</tr>
<tr>
<td>Mid Heels</td>
<td>2 inch – 3 inch</td>
<td>0.05 m – 0.075 m</td>
</tr>
<tr>
<td>High Heels</td>
<td>3 inch – 4 inch</td>
<td>0.075 m – 0.1 m</td>
</tr>
<tr>
<td>Very High Heels</td>
<td>Over 4 inches</td>
<td>Over 0.1 m</td>
</tr>
</tbody>
</table>

It is difficult to ascertain the exact percentage of people wearing high heels on a consistent basis; however, the Spine Institute believes 72% of women wear high heels at some point in time and surveys on shoe use show that between 39% and 69% of women wear high-heeled shoes on a daily basis (Li et al., 2014). When these numbers are put into context with statistics gathered on shoe sales, they provide stronger rationale to investigate the effects of heel height to walking gait. The global shoe sales topple $52 Billion with nearly $30 billion in sales in the United States alone (Footwear Market Trends, 2017). The sales data is further broken down into the market share of shoe types, Table 3. Clearly, both women’s casual and dress shoes are popular categories that both contain a variety of heel heights. The question now becomes: Does raising the heel either significantly at four and a half inches or minimally at one half of an inch have an effect on the human walking gait and if it does what are the acute and long term consequences?
Table 3. Market share of shoe categories (Footwear Market Trends, 2017).

<table>
<thead>
<tr>
<th>Shoe Category</th>
<th>Percentage of Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women’s Casual Shoes</td>
<td>17%</td>
</tr>
<tr>
<td>Women’s Dress Shoes</td>
<td>13%</td>
</tr>
<tr>
<td>Women’s Athletic Shoes</td>
<td>10%</td>
</tr>
<tr>
<td>Men’s Athletic Shoes</td>
<td>20%</td>
</tr>
<tr>
<td>Men’s Casual Shoes</td>
<td>9%</td>
</tr>
<tr>
<td>Men’s Dress Shoes</td>
<td>6%</td>
</tr>
<tr>
<td>Other styles</td>
<td>25%</td>
</tr>
</tbody>
</table>

Foot Health and Injuries

The Foot Collective, a Canadian group of physical therapists, believes modern day footwear prevents our feet “from functioning as they were designed” (TFC barefoot education, 2017). The toes should spread nice and wide when in a standing position, the muscles of the foot should be strong and active in order to support a stable arch and the ankle muscles are capable of absorbing the impact forces of activities like walking and running (TFC barefoot education, 2017). They also believe poor footwear is a major contributor and in most cases the direct cause of problems with our feet as well as other health issues. Most shoes are too narrow (the main cause of bunions), have a lifted heel (which shortens one’s calf and limits ankle mobility), have supportive arches (which weakens the natural arch forming muscles) and steal away the ability of the feet to sense the ground below because of a thick layer of cushioning (which is not necessary and in fact is harmful to how humans walk and especially run) (TFC barefoot education, 2017). The scientific literature further supports this explanation.
Between 2002 and 2012, a little more than three thousand injuries, representing an estimated 123,355 high heel related injuries, were treated in emergency rooms around the United States (Moore et al., 2015). The vast majority of these incidents (72%) resulted in a strain or sprain to the knee, foot or ankle (Moore et al., 2015). Interestingly, this data coincides with the three joints that are most biomechanically affected by heel height. While these injuries are tangible and most likely due to a misstep during the walking gait, what is not tangible is the amount of injuries to the hip, knee or ankle joints that are attained over a period of time due to wearing high heels. Current research provides a glimpse into the type of health issues wearing heels can cause, but minimal longitudinal research exists to provide tangible results of wearing heeled shoes. It is only thought that high heeled shoes are the cause of the health problems. Some of the most popular health concerns are osteoporosis of the knee, hallux valgus, lower leg pain, plantar fasciitis and lower back pain or injuries.

**Osteoarthritis of the knee**

Osteoarthritis affects approximately thirty million American adults (Arthritis, 2018). It is a degenerative joint disease that affects mainly the hands, hips and knees. It is often referred to as a “wear and tear” disease because it breaks down the cartilage and bones within the joints (Arthritis, 2018). Besides pain, the biggest health concern is a significant decrease in range of motion. Knee Osteoarthritis is found predominantly in women and therefore it has long been thought that shoe choice, particularly high heels, might be the cause (Titchenal, Asay, Favre, Andriacchi, & Chu, 2014). Researchers found significant gait changes as heel height increased. This caused walking speed to significantly decline and knee flexion increased at both the heel strike (IC) and flat strike (LR) positions (Titchenal, Asay, Favre, Andriacchi, & Chu, 2014). This increased joint loading and knee flexion is thought to be a major cause of osteoarthritis.
Hallux Valgus

Hallux Valgus is the medical term for bunions, a painful and common forefoot deformity. It has an estimated prevalence of 23% to 35% and causes “symptoms on the medial edge of the foot, the sole, and the small toes” (Wülker & Mittag, 2012). Shoe choice is, once again, thought to be a major culprit in the development of bunions. “Women are much more commonly affected than men, because they frequently wear narrow, high-heeled shoes and often have more flexible soft tissues” (Wülker & Mittag, 2012). However, heel height seems to be only a partial cause in the development of bunions and works hand-in-hand with the size and shape of the toe box. It is important to note that high heeled shoes often have a very narrow and pointy toe-box, but all shoes narrow the natural spread of the toes. Menz et al. (2016) found that women most commonly wore shoes with high heels and a narrow toe box between the ages of 20 and 29 and that shoe choice declined to less than 10% by the age of 40. It is thought that although women choose shoes with a lower heel and broader toe box as they age, the constrictive footwear and high heels worn between the ages of 20 and 39 may be a critical component of developing hallux valgus in later years (Menz et al., 2016).

Lower Leg Pain

High heels have long been thought to be a source of chronic lower leg pain. It has been found that wearing “high heels induces chronic muscle shortening associated with discomfort, fatigue, reduced shock absorption, and increased injury risk” (Zollner, et. al., 2015). Shock absorption is an important concept during the flat-strike (LR) position of the human walking gait. Wearing five-inch-high heels shortens the gastrocnemius muscle by five percent and therefore alters not only walking gait, but also shock absorption (Zollner, et. al., 2015). This occurs as the
“muscle gradually adjusts to its new functional length by a chronic loss of sarcomeres in series. Sarcomere loss varies significantly across the muscle with an average loss of 9%, virtually no loss at the proximal and distal ends, and a maximum loss of 39% in the central region. These changes reposition the remaining sarcomeres back into their optimal operating regime.” (Zollner, et. al., 2015). The muscle adaptations that occur due to wearing high heeled shoes is an area that still needs to be studied to fully understand the health effects.

**Plantar Fasciitis**

The plantar fascia is a tight tissue that helps to maintain the arch of the foot and transmits weight across the foot as person propels forward, walking or running. Plantar fasciitis is a painful disorder affecting the heel and underside of the foot. It is relatively common resulting in a structural breakdown of the foot's plantar fascia. “High-heeled shoes can limit proprioception where the heel hits the ground first followed by the toe. It has been shown that high heeled stiff shoes restrict the inversion/eversion of the foot, which can lead to an increase in rearfoot pronation, therefore showing that the stiffer the shoe, the more the natural foot motion is restricted” (Khodair, Sameh, Younes, Qwuesna & Eg. 2015). While these are just a few of the common problems associated with wearing heeled shoes, many more exist. It is unknown exactly how many injuries or long-term health problems are associated with wearing heeled shoes. The first step in unraveling this mystery is to first understand how the body and more specifically the hip, knee, and ankle joints respond to wearing heeled shoes of various heights.
Summary

In summary, while high heeled shoes have evolved throughout the centuries in social, cultural, and political purpose, popularity, and functionality, they have maintained a place of mystique in society. High heeled shoes both fascinate and appall men and women today. As technology advanced, high heeled shoes moved from keeping the hip, knee, and ankle joints in a neutral position to putting all three joints in various states of flexion or extension. The human walking gait, comprised of eight phases, is specific and repetitive. The introduction of high heeled shoes as part of the human walking gait alters the natural state of the body and its joints while walking. This altered state has potential health consequences, such as osteoarthritis, that have not fully been studied or understood. While several thousand injuries (mostly to the ankle) are reported each year as the result of wearing high heeled shoes, there is limited knowledge on just how much high heeled shoes contribute to other health related issues. It is important to understand how the body’s natural movements are affected by heel heights of various sizes in order to fully understand the potential health risks.
Methods

Participants

Four female college participants between the ages of 18 to 25 (Age: 23 ± 1.2 years old) volunteered to participate in the study. Approval from the Institution Review Board (IRB) was obtained prior to the study. A written informed consent was obtained from each participant before the testing began. All participants were fully briefed on the study and were allowed to withdraw from the study at any time without any penalty.

Protocols and Experimental Set Up

The study was conducted at the Biomechanics laboratory in the Adrian Tinsley Center and each participant walked on a Milestone 4200 treadmill (Model: MS4200) at normal walking pace, one meters per second, in three different heel heights. The heel heights were barefoot, 2.5” (0.06 m) and 4.5” (0.11 m). Each participant was allowed to warm-up walking in each heel height until they felt comfortable prior to filming. Five joint reflective markers were placed on the left side of the participant at the shoulder (acromion), hip (greater trochanter), knee (lateral epicondyle of femur), ankle (lateral malleolus) and toe (base of fifth metatarsal). During the testing, each participant walked for approximately 15 seconds in each heel height. There was no slope on the treadmill. The order of heel heights was randomized to reduce any order effect.

Instrumentation and Statistical Analysis

An Android Galaxy 7.1.1 (Model: SM-J700T) video camera was mounted on a tripod and captured the walking motion in sagittal view at 30 Hz in conjunction with a 650W artificial light to assist with joint marker identification. A Dartfish Application was used for video recording and data analysis. A two-dimensional kinematic analysis was conducted for hip, knee and ankle joint angles from three successful trials at the heel strike (IC), flat (LR), and toe off (PSW) for each type of heel height using the Dartfish application. Images were captured to ascertain joint angles for
each foot position in each type of heel height footwear. Descriptive statistical analysis of mean and standard deviation were reported for comparisons.
Results

The results of this study indicate that wearing any footwear beyond barefoot or a zero drop “heel to toe” style shoe puts the hip, knee, and ankle into varying degrees of flexion or extension, Table 4.

**Table 4. Comparisons between three heel heights of the hip joint. Mean ± SD**

<table>
<thead>
<tr>
<th>Foot Position</th>
<th>Barefoot (°)</th>
<th>2.5” Heel (°)</th>
<th>4.5” Heel (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat (LR)</td>
<td>170.6 ± 4.7</td>
<td>168.7 ± 3.9</td>
<td>162.2 ± 2.7</td>
</tr>
<tr>
<td>Heel (IC)</td>
<td>161.2 ± 9.0</td>
<td>157.2 ± 8.4</td>
<td>154.8 ± 7.6</td>
</tr>
<tr>
<td>Toe (PSW)</td>
<td>172.9 ± 5.8</td>
<td>172.0 ± 7.6</td>
<td>170.8 ± 8.3</td>
</tr>
</tbody>
</table>

**Figure 5.** Comparisons of hip joint between three heel heights (A) barefoot, B) 2.5” (0.06 m) Heel, and C) 4.5” (0.11 m) Heel during flat loading response phase.

The hip joint, in the flat position (LR), decreases flexion from a mean of 170.6 ± 4.7° to 162.2 ± 2.7° as heel height increases. In the heel-strike (IC) the hip joint, decreases flexion on
average from 161.2 ± 9.0° to 154.8 ± 7.6° as the heel height increases and finally, the hip joint, in the toe-strike (PSW), decreases flexion slightly on average from 172.9 ± 5.8° to 170.8 ± 8.3° as the heel height increases, Figure 5.

**Table 5.** Comparisons between three heel heights of the knee joint. Mean ± SD

<table>
<thead>
<tr>
<th>Foot Position</th>
<th>Barefoot (°)</th>
<th>2.5” Heel (°)</th>
<th>4.5” Heel (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat (LR)</td>
<td>160.6 ± 4.0</td>
<td>158.7 ± 3.0</td>
<td>154.9 ± 4.6</td>
</tr>
<tr>
<td>Heel (IC)</td>
<td>169.1 ± 6.9</td>
<td>166.2 ± 8.9</td>
<td>161.9 ± 6.9</td>
</tr>
<tr>
<td>Toe (PSW)</td>
<td>147.2 ± 8.7</td>
<td>145.5 ± 9.0</td>
<td>143.3 ± 6.8</td>
</tr>
</tbody>
</table>

**Figure 6.** Comparisons of knee joint between three heel heights (A) barefoot, B) 2.5” (0.06 m) Heel, and C) 4.5” (0.11 m) Heel during flat loading response phase.

The knee joint, in the flat (LR) position decreases flexion from 160.6 ± 4.0° to 154.9 ± 4.6° as heel height increases. In the heel strike (IC) position, the knee joint decreases flexion from
169.1 ± 6.9° to 161.9 ± 6.9° as heel height increases and finally, the knee joint, in the toe-strike (PSW), decreases flexion on average from 147.2 ± 8.7° to 143.3 ± 6.8° as the heel height increases, Table 5 & Figure 6.

**Table 6.** Comparisons between three heel heights of the ankle joint. Mean ± SD

<table>
<thead>
<tr>
<th>Foot Position</th>
<th>Barefoot (°)</th>
<th>2.5” Heel (°)</th>
<th>4.5” Heel (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat (LR)</td>
<td>103.3 ± 7.4</td>
<td>118.5 ± 8</td>
<td>138.4 ± 10.1</td>
</tr>
<tr>
<td>Heel (IC)</td>
<td>111.1 ± 7.4</td>
<td>130.9 ± 8.3</td>
<td>149.4 ± 4.2</td>
</tr>
<tr>
<td>Toe (PSW)</td>
<td>106.3 ± 6.2</td>
<td>116.8 ± 4.4</td>
<td>137.5 ± 4.9</td>
</tr>
</tbody>
</table>

**Figure 7.** Comparisons of ankle joint between three heel heights (A) barefoot, B) 2.5” (0.06 m) Heel, and C) 4.5” (0.11 m) Heel during flat loading response phase.

The ankle joint, in the flat strike (LR) position increases plantarflexion from an average of 103.3 ± 7.4° to 138.4 ± 10.1° as heel height increases. In the heel strike (IC) position, the ankle
joint increases plantarflexion from an average of $111.1 \pm 7.4^\circ$ to $149.4 \pm 4.2^\circ$ as heel height increases and finally, the ankle joint, in the toe-strike (PSW), increases plantarflexion on average from $106.3 \pm 6.2^\circ$ to $137.5 \pm 4.9^\circ$ as the heel height increases, Table 6 & Figure 7.

Table 7 summarizes the actions of all three joints in response to an increase in heel height from barefoot up to 4.5” (0.11 m). Across all three walking gait positions (flat strike, heel strike and toe strike) both the hip and knee decrease in flexion while the ankle increases in plantarflexion. This is important to note because as flexion of the hip and knee joint decrease, extension increases. As the heel becomes higher, flexion of the hip and knee decreases placing both of these joints into unnatural degrees of extension, untimely altering the natural range of motion of these joints during the walking gait. This is a point further worth researching to see if it is the point of origin for many of the health-related concerns that arise from wearing high heel shoes.

**Table 7. Summary of lower body joints in three different gait positions**

<table>
<thead>
<tr>
<th>Foot Position</th>
<th>Hip</th>
<th>Knee</th>
<th>Ankle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat (LR)</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Increase Plantarflexion</td>
</tr>
<tr>
<td></td>
<td>Flexion</td>
<td>Flexion</td>
<td></td>
</tr>
<tr>
<td>Heel (IC)</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Increase Plantarflexion</td>
</tr>
<tr>
<td></td>
<td>Flexion</td>
<td>Flexion</td>
<td></td>
</tr>
<tr>
<td>Toe (PSW)</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Increase Plantarflexion</td>
</tr>
<tr>
<td></td>
<td>Flexion</td>
<td>Flexion</td>
<td></td>
</tr>
</tbody>
</table>
Discussion

While significant research has been completed on various types of athletic footwear and how that footwear may affect athletic performance, very little research has been done on the everyday footwear (of varying heel heights, styles and toe-box dimensions) that millions of people wear for long hours, either at work or socially, every single day. The results of this study indicate that the introduction of a heeled shoe may alter the biomechanics of the human walking gait across the hip, knee, and ankle joints, restricting movements of the lower extremities. Lee (2014) found similar results with a decrease in joint angles of the hip and knee and an increase in the ankle joint angle as heel height increased. Lee (2014) also noted that wearing high heels while walking changed the natural gait and the movements of the lower extremities were significantly reduced. Shoe choice deeply influences the human body and walking gait, but to what extent this causes health problems (acute or long term) is still virtually unknown.

“High-heeled gaits induce changes in the soft tissues around the foot by increasing the shock loadings during static and dynamic movements and are considered to cause potentially damaging conditions such as deformations in the foot and ankle, weakening of muscles, and damages to ligaments and joints” (Lee, 2014). It is especially important to understand the changes during the second stage of the human walking gait, the Loading Response phase (flat). This phase is particularly important because this is the point where the body absorbs the impact created by locomotion. This phase moves from force absorption at impact to force propulsion. (Shultz et al., 2016). While walking in high heeled shoes during this phase, this study noted a decrease in flexion of both the hip and knee joint and an increase in plantar flexion at the ankle joint. It is thought that altering the normal joint angles during this very important phase may cause pathologies over time.
There are some limitations in this study that should be considered. First, the personal experience of wearing high heels from participant to participant may alter the results. Second, muscular activity while wearing high heels was not evaluated with an EMG system, which will enable a better understanding of muscle activity on the effects of wearing high heels. Third, the material of the shoes was not evaluated. Perhaps a softer heel versus a harder heel may have yielded different results. Fourth, data analysis was limited to the Dartfish Application. Future studies would benefit from using a more scientific motion analysis software such as Ariel Performance Analysis System (APAS), which will minimize human errors in the data analysis process.

Thus, it is concluded that shoes with moderate and excessive heel heights should be limited in use and worn in moderation in order to avoid potential damage caused to the body by changing the natural movements of the walking gait. It is also noted that more longitudinal research is needed to isolate the exact effect wearing shoes with heels has on the body, especially since joint pathologies are also thought to be the result of injuries or due to obesity. When we fully understand the effect of shoe choice on the human walking gait, it will be possible to effectively prevent health issues or rehabilitate current health issues in a more effective manner. Further, it is necessary to study the effects of daily shoe choice on men. Nearly all research is focused on understanding the effects on a woman’s body, yet males wear heels as well and higher heels are becoming more prevalent in that segment of society.
Conclusion

Millions of human beings alter their natural walking gait by wearing shoes, especially high heels, every day. The health effects of wearing high heels, of various heights, has not been significantly studied in order to understand so that health issues can be prevented or more effectively rehabilitated. The purpose of this study was to evaluate the biomechanical differences in common heel heights in the lower extremity during walking gait. Four female participants walked in three heel heights: barefoot, 2.5” (0.06 m) heel and 4.5” (0.11 m) heel. A two-dimensional kinematic analysis was conducted to examine walking gait with various heel heights. The findings of this study concluded that shoes with moderate and high heel heights should be limited in use and worn in moderation in order to minimize potential adverse health concerns to the body by altering the natural movements of the walking gait. Future studies will examine the long-term effect of wearing shoes in various heel heights and on different slopes. It should also be noted that future studies should be conducted to include men as well.
References


Newsom, J. S. (2017, August 31). The Problem With Melania Isn’t Her Shoes. Retrieved February 12, 2018, from [https://www.huffingtonpost.com/entry/the-problem-with-melania-isnt-her-shoes_us_59a7599be4b00ed1aec9a593](https://www.huffingtonpost.com/entry/the-problem-with-melania-isnt-her-shoes_us_59a7599be4b00ed1aec9a593)


