

Proper Footwear While Wearing an Orthopedic Walker Boot

A thesis submitted to Miami University Honors Program  
in partial fulfillment of the requirements for  
University Honors with Distinction

By

Samantha Bowker

May 2012  
Oxford, OH

**Table Of Contents**

Abstract………………………………………………………………………………….4

Introduction……………………………………………………………………………5

Purpose………………………………………………………………………6

Hypotheses……….………………………………………………………..7

Limitations/Delimitations.………..………………………………..7

Review of Literature……………………………………………………………….8

Gait Analysis………………………….……..…………………………….8

Foot and Ankle Anatomy……………….…………………….…….12

Common Injuries…………………………….…………………………15

Walker Boot Literature……………………………………………..20

Flip-Flop Literature……………………………………………………26

Methodology…………………………………………………………………………31

Purpose……………………………………………………………………..31

Participants……………………………………………………………….31

Setting……………………………………………………………………….32

Instrumentation…………………………………………………………32

Conditions………………………………………………………………....32

Design and Procedure………………………………………………..33

Results/Discussion…………………………………………………………………34

Participant Demographics………………………………………….35

Self-Selected Speeds………………………………………………….36

Joint Angles at Toe-off and Heel Strike……………………...37

Joint Range of Motion………………………………………………..37

Joint Displacements…………………………………………………..38

Resources……………………………………………………………………………..39

Appendix A: Medical Questionnaire………………………………………42

Appendix B: Informed Consent From.……………………………………43

**Abstract**

As the use of Orthopedic Walker Boots increases it is important to study the effects of these boots. Walker boots have been shown to change kinetic and kinematic gait factors. However, the advantages of walker boots compared to casts often outweigh the possible negative effects of these changes. Specific advantages include the ease of application, easy adjustment to swelling and easy access for cleaning. Also, by maintaining some forces through the injured limb, proper healing can be encouraged. Besides the changes of gait, the decreased compliance and increased risk of falling are disadvantages that must be considered when using walker boots as treatment. The current study investigated the kinematic gait difference associated with walker boots and footwear worn on the opposite foot. The purpose of the study was the compare the changes in gait while wearing a walker boot and running shoe with the changes while wearing a walker boot and flip-flop. It was hypothesized that the flip-flops will lead to increased kinematic changes. To test this hypothesis, participants walked at self-selected speeds while motion capture systems were used to analyze the motion of the ankle, hip, knee and pelvic joints. Assessment of the self-selected speed indicates that there is a trend to support the hypothesis, but these differences are not significant to confirm the hypothesis. Full results were not able to be published in this work.

**Introduction**

Ankle injuries have plagued the athletic and general population for decades and there is no reason to suspect these injuries to decrease in prevalence. As the use of the orthopedic walker boots continues to gain popularity it is important to take an empirical look at the changes associated with walker boots. Although there are many different brands of walker boots, the overall general structure is consistent: a padded foot shell with semi rigid arms, and often a rocker-bottom sole (Wang & Hansen, 2010; Pollo Gowling, & Jackson, 1999). Walker boots have been cited to be used for a variety of injuries from lower leg stress fractures to plantar fasciitis to ligamentous and tendon injuries (Kadakia, Espinosa, Smerek, White, Myerson & Jeng, 2008; Pollo et al., 1999). Anecdotally these walker boots have been reported to be heavy, cumbersome, time consuming, embarrassing, and generally annoying. Many first time wearers report feeling uncomfortable, unsteady and awkward at first, but these feelings fade with increased use. For most people, the many advantages of walker boots outweigh the discomfort (Crenshaw, Pollo, & Brodsky, 2004, Crincoli & Trepman, 2001; Speck & Klaue, 1998). For practitioners using walker boots as treatment for patients, it is important that all the effects of the walker boot be considered. There are clear gait changes with respect to kinematics and kinetics, some of which are beneficial for healing and others that can create a chain of negative effects (Vanderpool, Collins, & Kuo, 2008; Zhang, Clowers, & Powell, 2006; Kadal, Segal, Orendurff, Shofer, & Sangeorzan, 2004). Most often the leg length discrepancy (LLD) noted when wearing the walker boot has been used to explain the discomfort and low back pain associated with walker boots. DonJoy© developed a device called the Evenup. This device is used to add height to the contralateral limb to decrease the LLD. While this device has been shown to slightly decrease gait differences and increase compliance, this product adds to the cost of treatment. The effectiveness of this product shows that the footwear of the contralateral foot is important (McDonald, Kihm, & Nimick, 2008). However, many patients still wear their usual work shoes, sandals, dress shoes, and boots. The following study will investigate the importance of proper footwear on the contralateral foot. This study specifically used a basic running shoe and a flip-flop as comparison.

Flip-flops, especially during the summer, are one of the most common types of footwear. Flip-flops are associated with both kinetic and kinematic gait changes when compared to running shoes and barefoot. The lack of arch support and need for increased muscle activation have been blamed for many of the injuries thought to be caused by flip-flop wearing (Shroyer & Weimar, 2010; Shroyer, 2009; Parker-Pope, 2008; Yara, 2006). Flip-flops were chosen for this study because of the popularity of the shoes. Also, because the thin sole of flip-flops the LLD will be greatest using flip-flops therefore if the contralateral footwear significantly alters gait it will be greatest with flip-flops. The gait changes that occur with flip-flops usage alone also added to the reasons for using flip-flops. Because both walker boots and flip-flops are associated with increased risk of back pain, it has been hypothesized that the factors leading to this back pain will be compounded and lead to increased risk for low back pain.

*Purpose of Study*

Therefore, this study will investigate the kinematic gait changes associated with walking in a walker boot. The purpose is to examine to kinematic differences between normal walking and walking in a walker boot and running shoe, and then to compare those differences to the differences between normal walking and walking in a walker boot and flip-flop.

*Hypotheses*

The overall hypothesis for the current study is that the differences will be greater between normal walking and walking with a walker boot and flip-flop. Specifically it has been hypothesized that pelvic girdle motion will increase resulting in greater pelvic tilt and pelvic drop while wearing a walker boot and flip-flop. It has also been hypothesized the hip extension will decrease in both limbs while wearing a walker boot and flip flop, but will only decrease on the walker boot limb for the walker boot and running shoe condition. In addition, the displacement of the ankle throughout the swing phase has been hypothesized to be higher while wearing a walker boot. Lastly, it was hypothesized that walking speed will be the slowest for walker boot and flip-flop condition.

*Limitations*

The limitations for the present study include the following:

1. Type of running shoe will not be standardized across all trials
2. Only one type of flip-flop style will be used for evaluation
3. The familiarity of participants with flip-flop walking will not be considered

*Delimitations*

The delimitations for the present study include the following:

1. Participants will be walking on a treadmill at a self-selected speed
2. Participants will be required to wear reflective markers on lower body
3. The flip-flops used in the study will be new and never worn before
4. Participants will only be wearing walker boots for the six minute trial

**Literature Review**

*Gait Analysis*

Study of human motion can be dated back as far as Aristotle. Aristotle noted that a person walking upright does not maintain a constant height during each cycle. Since Aristotle, many scientists have added new information and asked more questions about human locomotion including Galileo, Newton, Descartes, and Borelli (Johanson, 1994). While each of these scientists and many others hypothesized concepts of human motion, Muybridge and Marey are credited with developing methods for analysis of motion through photographic analysis (Johanson, 1994).

Defining the different aspects of gait is the first step to studying gait. General terms with agreed upon definitions include step length, stride length, and step width. Step length is the distance between the contact point of the right heel and the left heel parallel to the direction of motion within the same gait cycle. Stride length is the distance between the same location on the same foot measured from the same point in one gait cycle to the next cycle. Step width is the distance between the left and right heels perpendicular to the direction of motion. Average step width is two to four inches (Sutherland, Kaufman, & Moitoza, 1994). Step and stride length are dependent on height (Starkey, Brown, & Ryan, 2010; Houglum, 2005; Hoppenfeld, 1976). Walking speed can be measured in two different ways. First, the walking cadence can be measured as the number of steps per given period of time (Sutherland et al., 1994). Average walking cadence is 90-120 steps/min (Hoppenfeld, 1976). Second, walking speed can be measured as the average speed obtained after three steps (Sutherland et al., 1994).

There are many different ways to describe the gait cycle and its phases. Different researchers call the same phase by different names or researchers condense or expand phases (Starkey et al., 2010; Houlgum, 2005; Sutherland et al., 1994). For the purpose of this study, the two main phases will be referred to as stance and swing phase. The main points of interest will occur during stance phase, but range of motion affects all parts of the gait cycle, so a proper understanding of what occurs during each phase is essential. The swing phase can be divided based on the goals of actions. The three phases include the acceleration phase, swing through or foot clearance, and foot deceleration (Houlgum, 2005; Sutherland et al., 1994; Hoppenfeld, 1976). The stance phase can be divided into five different phases. This study will specifically investigate the motion at heel strike and at toe off. These two phases are the start and the end of the stance phase both occurring during double limb stance. Between these two phases loading response, midstance, and preswing occur. The goal of the stance phase is to shift the weight from behind the foot to in front of the foot (Starkey et al., 2010; Sutherland et al., 1994; Hoppenfeld, 1976).

No matter what the phases are referred to, the goals remain the same. Most importantly the goal of walking is to maximize forward motion while minimizing vertical and lateral motion of the center of gravity (Starkey et al., 2010; Houglum, 2005; Inman, Ralston, & Todd, 1994; Hoppenfeld, 1976). Center of gravity (CoG) is a point in the body where any plane passing through it would create equal mass moments on each side. In other words, if someone were to be suspended by their CoG they would be perfectly balanced (Starkey et al., 2010; Inman et al., 1994). The body accomplishes this goal through a variety of slight kinematic changes throughout the gait cycle. Pelvic motion is a subtle but important aspect of maintaining CoG. The most important pelvic motion occurs during single limb stance when the CoG must be shifted laterally over the support limb to avoid falling. The pelvic girdle has been seen to shift up to 5 cm toward the support limb while a slight dip is seen on the side of the swing leg (Starkey et al., 2010; Houglum, 2005; Inman et al., 1994; Hoppenfeld, 1976).

Each phase has an individual goal which needs to be accomplished to maintain this overall goal. During initial contact and loading response, the body is absorbing the shock of body weight. At the start of the stance phase the limb absorbs and transfers up to 60% of body weight in the form of kinetic energy from the ground (Starkey et al., 2010). During these phases the body is decelerating (Sutherland et al., 1994; Hoppenfeld, 1976). Near the end of the loading response the body weight begins to shift forward transitioning toward midstance (Hoppenfeld, 1976). During midstance, all the body weight is positioned over the support leg (Starkey et al., 2010; Sutherland et al., 1994). During the midstance the CoG is at its highest point before it begins to decrease again to the lowest point during preswing (Sutherland et al., 1994). Terminal stance is defined by when the body weight begins to shift in front of the support leg and ends when single limb support ends (Starkey et al., 2010; Sutherland et al., 1994). When double limb stance begins again the body begins to accelerate and the kinetic energy absorbed at the start of stance phase from the ground is transferred back to the ground during push-off in order to move forward (Starkey et al., 2010; Sutherland et al., 1994).The phases of the swing phase have fewer goals and require less muscular activity (Starkey et al., 2010). The main goals of the swing phases are foot clearance, limb progression, and limb repositioning. These goals are reached using some muscular activity, but momentum and gravity help significantly to allow for decreased muscle activity (Starkey et al., 2010; Sutherland et al., 1994; Hoppenfeld, 1976).

While gait analysis is often done on subjects for only a short time or short distance, it is important to remember that walking is a motion intended to last for an extended period of time. The walking motion is one of the few motions which can be sustained for hours with only mild fatigue. The main reason for its sustainability is the cyclic nature of walking. Within each step cycle, there is a cycle of acceleration-deceleration and muscle relaxation-muscle activation (Houglum, 2005; Sutherland et al., 1994). The acceleration-deceleration cycle is important for maintaining a constant speed throughout walking. Deceleration will occur as a person steps onto one foot, and acceleration will occur as a person pushes off the ground to lift one foot (Sutherland et al., 1994). More important for limiting energy expenditure, and therefore increasing sustainability of walking, is the muscle relaxation-muscle contraction cycle. During the swing phase of walking muscle activity is relatively low, but higher during the start and end of the stance phase. Altering contraction-relaxation can decrease muscle fatigue (Starkey et al., 2010; Houglum, 2005).

By the time a person is able to fully communicate, it is likely they already walk as if it were second nature (Inman et al., 1994). While, walking is not something that most people have to think about it can be altered by a number of things including pain, fused joints, muscle weaknesses and overall instability (Hoppenfeld, 1976). The relaxation-contraction cycle is important for walking because many muscles are involved in walking as decelerators, accelerators, stabilizers, or shock absorbers (Houglum, 2005). With all these different functions of muscles, it is easy to explain why many lower extremity injuries can be evaluated and noticed through gait analysis (Starkey et al., 2010; Sutherland et al., 1994; Hoppenfeld, 1976). Similarly using these muscles incorrectly through poor mechanics can put strain on the muscles, joint, ligaments, and tendons throughout the back and lower extremity (Starkey et al., 2010).

*Foot and Ankle Anatomy*

It is important to have an understanding of the injuries which are treated by walker boots and therefore important to explain the pertinent anatomy of the foot and ankle. The foot and lower leg are comprised of thirty bones, including 2 sesmoids. The tibia and fibula together make up the lower leg. The tibia is the primary weight bearing bone of the lower leg. The fibula’s primary functions include support for the ankle, muscular and ligamentous attachment, and to act as a pulley to increase efficiency (Starkey et al., 2010). Weight is transferred from the tibia through the talus and the calcaneus, which comprise the rearfoot. The midfoot is formed by the cuboid, three cuneiforms, and the navicular. The navicular is the crucial bone supporting the medial longitudinal arch of the foot. Continuing distally from the tarsal bones (the collective term for the rear and mid foot bones) are the metatarsals each corresponding to a toe. Metatarsals are numbered starting with the big toe, often referred to as hallux, from one through five. Articulating with these metatarsals are the phalanges forming each toe. Just as the thumb in the hand, the hallux only has two phalanges. In addition, directly inferior to the head of the first metatarsal are two sesmoid bones. These sesmoid bones are formed within the flexor hallucis longus tendon in response to the increased force on that area of the foot (Floyd, 2007).

With so many bones in the foot and ankle, there are many articulations. However, most of these articulations do not have significant movements available. The ankle joint is a combination of 3 different articulations. The distal tibiofibular syndesmosis defines the upper limits of what in layman’s term is the ankle joint. The tibiofibular syndemosis is formed by the distal articulation of the tibia and the fibula. The bones are connected by an interosseous membrane which runs the length of both bones, the anterior and posterior tibiofibular ligaments, and the crural interosseous ligament. The talocrural joint allows the most motion of the ankle joints. This joint is formed by the articulation of the tibia and fibula with the talus. Plantarflexion and dorsiflexion are motions produced by this joint. Because this joint produces the most motion, it is supported by the most ligaments. The lateral ligaments can be distinctly separated into the anterior talofibular (ATF) ligament, the calcaneofibular (CF) ligament, and the posterior talofibular (PTF) ligament. Medially, four ligaments support the talocrural joint and are collectively referred to as the deltoid ligament. Just distal to the talocrural joint is the subtalar joint formed by the inferior surface of the talus and the superior surface of the calcaneous. Inversion and eversion as well as supination and pronation are often said to occur at this joint. However, these motions are a combination of motions from many articulations in the foot, so defining them as singular plane motion at the subtalar joint ii misleading. Articulations occur between many of the tarsal bones, between the rear and midfoot, and within the midfoot. These joint have very little motion and are supported by various ligaments as well as the plantar fascia. The tarsometatarsal joints between the cuneiforms and the metatarsals play a significant role in arch support and can create a host of problems if their ligamentous supports are damaged. The metatarsophalangeal (MTP), the distal interphalangeal (DIP), and the proximal interphalangeal (PIP) joints allow for toe flexion and extension (Starkey et al., 2010).

Although there are many muscles which function to provide motion for the foot and ankle, there are ten muscles most commonly referred to in the study and research of foot and ankle injuries. The large calf muscle is the gastrocnemius. This muscle helps with ankle plantar flexion and knee flexion. The smaller calf muscle, the soleus, is only responsible for plantar flexion because its origin is below the knee. In addition to the two main calf muscles, the tibialis posterior helps with plantar flexing the ankle and inverting the ankle. Eversion of the ankle is performed by a group of muscles collectively known as the peroneals. The peroneus longus, peroneus brevis, and in some people the peroneus tertius comprise the peroneal group. The peroneous longus and peroneous brevis also help to plantar flex the foot. A third peroneus tertius, absent in some people helps dorsiflex the foot. The anterior musculature responsible for only ankle motion is the tibialis anterior. This muscle is primarily responsible for dorsiflexion, but similar to the tibialis posterior, also aids with inversion. There are many muscles with the primarily responsible of toe flexion and extension that also aid with ankle motions. Extensor digitorum longus helps with dorsiflexion and eversion of the ankle, but primary responsibility is extension of toes two through five. Similarly, the extensor hallucis longus aids with ankle dorsiflexion but primarily extends the big toe. Conversely, the flexor digitorum longus muscles will help evert and plantar flex the foot while causing flexion in toes two through four. The flexor hallucis longus will help invert and plantar flex the ankle as well, while flexing the big toe (Floyd, 2007).

*Common Injuries*

Orthopedic walker boots have become a favorable alternative to casting for many reasons, which will be discussed in a later section. While casting is still the appropriate and recommended treatment for some injuries, more and more injuries are being treating with walker boots (Kadakia, Espinosa, Smerek, White, & Jeng, 2008; Speck & Klaue, 1998). This section will address the common injuries which can be treated using an orthopedic walker boot. While there are many other injuries for which walker boots can be used, the injuries covered in this section are most common. It is important that decisions regarding the use of a walker boot be discussed and decided by a health care professional to prevent further injury due to unnecessary immobilization or to weight-bearing on a severe injury.

Inversion ankle sprains are the most common injury in the athletic population. The ankle is most stable when it is in the “closed-packed position” meaning the ankle is dorsiflexed. The “open-packed position” of the ankle used to describe the ankle being in an inverted and supinated position (Starkey, Brown, & Ryan, 2010). Inversion ankle sprains involve injury to the lateral ligaments of the ankle. When the ankle is inverted, plantarflexed and internally rotated excess tensile force is placed through the lateral ligaments of the ankle. The most commonly injured ligament is the anterior talofibular ligament. Due to its position it is already taught in the inverted, supinated position so little tensile force is required to sprain the ligament (Starkey et al., 2010). If sufficient forces are placed through the lateral ankle the calcaneofibular ligament, and, rarely, the posterior talofibular ligament can be sprained as well. Most common mechanisms of injury include jumping and landing with an inverted ankle or running/walking on uneven surfaces (Prentice, 2009). Unfortunately, there are many predisposing factors which can lead to increased risk for inversion ankle sprains including decreased proprioception, decreased muscular strength, and decreased coordination. Also, tightness within the triceps surea (the group of posterior calf muscles including the gastrocnemius, soleus, and posterior tibalis) can predispose a person to lateral ankle sprains due to the ankle’s resting position being in the “open-packed position”. The open-packed position meaning the ankle is plantarflexed. Current data shows that athletes with previous ankle injury have a greater than 70% recurrence rate, so proper treatment of lateral ankle sprains is vital. (Starkey et al., 2010).

Often the term “sprained ankle” is used to describe the common lateral ankle sprain. However, there are two other types of ankle sprains: eversion ankle sprain, and syndesmotic ankle sprain. Eversion ankle sprains are similar to inversion ankle sprains because it involves the ligaments supporting the subtalar joint. Eversion ankle sprains account for anywhere from 3% to 15% of ankle sprains (Starkey et al., 2010). A quick look at the anatomy of the ankle can explain the vast difference in occurrence between eversion and inversion sprains. First, the lateral malleolus extends much further distally than the medial malleolus which creates a bony barrier to eversion. Second, the deltoid ligament is much stronger than the lateral ligaments (Prentice, 2009). When eversion sprains do occur they often have associated injuries such as avulsion fractures or syndesmotic sprains (Starkey et al., 2010). Biomechanical factors such as excessive pronation, hypermobility in the ankle, and a depressed arch can increase the risk of eversion ankle sprains (Prentice, 2009).

Syndesmotic ankle sprains, another form of ankle sprains have been estimated to account for 10%-18% of all ankle sprains in the NFL (Starkey et al., 2010). Syndesmotic sprains are often referred to as “high-ankle sprains” because the ligaments involved are slightly superior to the ankle joint. Three separate structures can be injured in a syndesmotic sprain: the anterior tibiofibular ligament, the posterior tibiofibular ligament, and the interosseous ligament (Prentice, 2009). Syndesmotic sprains are the result of excessive external rotation of the ankle and forced dorsiflexion. This combination of motion causes the talus to be pushed upward and create excess space between the tibia and fibula resulting in stretching and spraining the ligaments supporting that junction (Starkey et al., 2010; Prentice, 2009).

In addition to ligamentous problems, walker boots can be very useful for the treatment of tendon pathologies. Most common tendon problems occur within the Achilles tendon and its tendon sheath. Although there are many stages of inflammation and irritation with the Achilles, the condition often manifests with pain as tendinosis or tendinopathy. The pain is often described as a burning sensation along the tendon (Starkey et al., 2010). However, very little swelling around the tendon is noted. The Achilles tendon will often have an abnormal, enlarged, appearance. The tissue within the tendon will become degenerative, and due to poor blood supply, the condition will gradually worsen if not treated properly (Starkey et al., 2010; Prentice, 2009). As with many ankle injuries, decreased flexibility within the triceps surae group is a predisposing factor. Sports which involve overloading the tendon such as running and jumping have higher occurrences of Achilles tendinopathy. In addition, teams or players which do early season conditioning without proper resting periods are prone to Achilles tendinopathy (Prentice, 2009).

Less common tendon pathology in the ankle involves the peroneal tendons. These tendons are located on the lateral portion of the ankles and are held in place by a superior and inferior retinaculum. Forceful and sudden dorsiflexion with eversion or sudden and forceful plantarflexion with inversion will cause stretching of the superior retinaculum resulting in subluxing peroneal tendons. Aside from the pain and snapping sensations reported by the athlete, the major problem with this injury is the peroneal muscles, which usually aid with dorsiflexion, will not aid plantarflexion (Starkey et al., 2010; Prentice. 2009). Sports in which subluxing peroneal tendons is common include, wrestling, football, hockey, figure skating, skiing, basketball and soccer. Functionally, peroneal subluxation is caused by turning and cutting sharply or a direct blow to the lateral ankle causing disruption of the retinaculum (Prentice, 2009).

Walker boots can be useful in the treatment of not only ankle injuries, but also foot and lower leg injuries. Plantar fasciitis is the most common foot injury treated with walker boots. Plantar fasciitis is a degenerative condition affecting the plantar fascia. The plantar fascia also known as the plantar aponeurosis, is a broad band of dense connective tissue extending from the heel to the head of the metatarsals which assists in maintaining stability of the foot (Prentice, 2009). In addition to plantar fasciitis as a degenerative condition, a single traumatic event creating enough tension along that fascia can cause the fascia to pull from the origin (Starkey et al., 2010). Biomechanically plantar fasciitis is caused by chronic tensile forces along the fascia due to toe extension, depression of the arch due to weight bearing, and increased forces at toe off. There are many other anatomical factors that can predispose a person to plantar fasciitis including leg length discrepancy, excessive pronation, inflexibility of the longitudinal arch, and tight triceps surea (Prentice, 2009). Most important to the study at hand study, the foot wear choice can impact the presence of plantar fasciitis. Running shoes are designed to have a built in splint to help with supporting the arch during weight-bearing. However, shoes with no arch support, flip-flops, for example, can predispose a person to plantar fasciitis (Prentice, 2009).

A very common lower leg injury which can be treated with walker boots is medial tibial stress syndrome. This condition, which is sometimes seen as a catchall term for any pain in the anterior portion of the leg, accounts for between 10%-15% of all running injuries. Most recently, medial tibial stress syndrome has been defined as periostitis at the posterior medial border of the tibia (Starkey et al., 2010). However, the term has also been used to describe stress fractures, muscles strains, and chronic anterior compartment syndrome (Prentice, 2009). Medial tibial stress syndrome is a chronic condition caused by repetitive microtrauma. As with most chronic orthopedic conditions there are many contributing factors to injury. Weak leg muscles, overtraining, hypermobile foot, excess pronation, and wearing shoes that provide little support all predispose a person to developing medial tibial stress syndrome (Prentice, 2009).

Lastly, stress fractures of the tibia and fibula can be treated with walking boots. Similar to medial tibial stress syndrome, stress fractures are the result of chronic microtrauma. Stress fractures have many factors which increase the risk of developing them including overtraining, training errors, amenorrhea, and nutritional deficiencies. Stress fractures are most common in the fibula for people who overpronate, and most common in the tibia in people with excessive supination (Prentice, 2009).

In addition to the common specific injuries which can be treated with the use of walker boots, walker boots are effective to promote the healing process for many soft tissue injuries. In general, any injury in which immobilization yet weight-bearing is still desired, the walker boot is an easy and convenient treatment plan (Kadakia et al., 2008; Crenshaw et at., 2004; Crincoli & Trepman, 2001).

*Walker Boot Literature*

The use of walker boots for the treatment of orthopedic foot and ankle injuries has become common place for many types of injuries. The common injuries treated with walker boots were addressed earlier. The most common injuries include sprains, foot and ankle fractures, and post-surgically (Pollo et al., 1999). Walker boots have an array of advantages compared to casts. Walker boots are less costly, allow patients and doctors to access wounds, are adjustable to swelling, are removable for hygiene, decrease anxiety associated with casts, and require less training of medical personnel (Crenshaw et al., 2004, Crincoli & Trepman, 2001). The decision between casts and boots for post-operative treatment can be challenging due to a lack of research for surgeons to refer to, but the adjustability of boots to swelling can be an important advantage if the patient has significant post-operative edema (Kadakia et al., 2008). Most importantly boots remove the negative effects of being non-weight bearing for weeks. Speck and Klaue (1998) showed that for treatment of Achilles tendon injuries, the walker boot improved power and strength of the injured leg when compared to traditional casting methods without increasing the risk of re-rupture. Maintaining strength and power can help retard atrophy and speed recovery to normal gait (Speck & Klaue, 1998). While there are many different types of walker boots, the general structure of the boots is the same: a padded foot shell with semi rigid arms, and often a rocker-bottom sole (Wang & Hansen, 2010, Pollo et al., 1999). This structure immobilizes the ankle in order to promote healing through tendon and muscle relaxation (Kadal et al, 2004). Walker boots decrease pain caused by the mechanical stresses associated with running and walking. Crincoli and Trepman(2001) found that 70% of patients had decreased pain and 80% of patients had decreased physical findings.

In contrast to the important advantages, walker boots do present some problems for patients. Crincoli and Trepman (2001) found that 18% of patients had trouble sleeping while in the boot, 10% of patients had increased pain, and 4% of patients developed low back pain. Walker boots are heavy and cumbersome which may lead to the difficulty sleeping or the decreased compliance. The weather can influence the comfort of the walker boot. Hot days may lead to excess sweating especially within the boot. Rainy days leading to the boot being wet can cause discomfort and increased need to clean the boot. Walker boots similar to other shoes decrease traction over time. With the foot immobilized and the muscles relaxed, slipping becomes a concern because the patient will not be able to correct for the slipping (Vanderpool, Collins, & Kuo, 2008; Crincoli & Trepman, 2001).

While the ease of removal can be an advantage to walker boots, it can also be a disadvantage. Patients appear to be less compliant with walker boots than casts (Gutekunst, Hastings, Bohnert, Strude, & Sinacore, 2011; Kadakia et al., 2008). Gutekunst et al. (2011) demonstrated this when noting that although walker boots had the same or better decreases in pressure within the foot, fewer patients had healed ulcers.

Understanding why the above advantages occur within a walking boot is important for improvement of walker boots and for clinicians deciding if a walker boot is proper treatment for an injury. One goal of immobilization treatment is decreased muscle activation. EMG studies have found that walker boots succeed in decreasing muscle activity. Specifically, walker boots decrease the need and the ability for plantar flexion (Vanderpool et al., 2008). The gastrocnemius, soleus, and peroneals were all found to have significantly less EMG activity when compared to barefoot walking (Kadal et al., 2004). Walker boots are designed to accommodate walking so that plantar flexion and dorsiflexion are not necessary to the same ranges as shoed walking. Kadakia et al. (2008) investigated if the boots decreased the range of motions (ROMs) for plantarflexion and dorsiflexion as well as casts do. They found that while there was a significant decrease in ankle ROM in a walking boot that it was inferior to the stability and limiting properties of the casts. However, due to changes in swelling, the researchers hypothesized that the ROM within a cast will increase over time, but the walker boot ROM will not change because the straps can be tightened to accommodate for atrophy (Kadakia et al., 2008). Inversion and eversion ROMs have been shown to decrease while in a walking boot (Vanderpool et al., 2008; Zhang, Clowers, & Powell, 2006.). While there is a decrease in muscle activation within the ankle musculature, there can often be increases elsewhere to accommodate for the lack of plantar flexion at push-off in the ankle. Most commonly increases in knee extensors and hip flexors have been noted (Pollo et al., 1999).

An important aspect to non-weight bearing in initial healing process is decreased forces through the ankle. However as the ankle begins to heal it is important clinicians use Wolff’s law to promote proper healing. Wolff’s law explains that tissue will heal in response to the forces placed on them (Starkey et al., 2010). Specifically, fibers will align in tendons and ligaments in order to resist forces being placed through it. Walker boots can be important for allowing some forces but not enough to cause reinjury (Speck & Klaue, 1998). Gutekunst et al., (2011) demonstrated that there was a 33-35% decrease in maximum force while in a walker boot, and that peak plantar pressures decreased 75-77% from baseline. Gutekunst did not specify where the maximum forces were occurring, often maximum forces occur at loading phase (Starkey et al., 2010). Keefer, King, Powell, Krusenklaus, and Zhang (2008) found that there was no difference in ground reaction forces (GRF) at loading phase or push-off. No changes in stride length were noticed between baseline shoe wearing and walker boot conditions (Gutekunst et al., 2011). Minimum GRF were larger in the boot than in the shoe. While this may appear to be a negative effect of walker boots, it can be important for healing. Minimum GRF is usually seen during the mid-stance phase of walking. By walker boots having a higher minimum GRF, yet smaller maximum GRF, the GRF stays more consistent across the gait cycle. Not having to accommodate for changes in forces, muscles are able to maintain their relaxed state (Keefer et al., 2008; Vanderpool et al., 2008; Zhang et al., 2006). One interesting finding in GRF studies with walker boots is the addition of a force peak before the load response (Keefer et al., 2008; Zhang et al., 2006). These effects appear to be lasting, at least beyond the single trial. Keefer et al. (2008) tested the baseline shoe condition last, and differences similar to the walker boot trials were noted between the right and left even within this trial.

Ambulation and movement are essential for daily living. For injured individuals, maintaining a quality of life is important in order to avoid many psychological side-effects that can be caused by injury. Walker boots can allow an injured person to walk around as needed, however limiting the weight-bearing period will help to promote healing (Crincoli & Trepman, 2001). It is important that when any sort of bracing device is used, that the desired ROM limitations and decreased muscle activation are accomplished with minimal effects on healthy joints. Conflicting results have been found with regards to walker boots’ effects of the hip and knee joints. Knee motion has been the most varied. Zhang et al. (2006) showed that there was an increase in knee flexion. The need to propel the body forward due to decreased ankle motion is viewed as the functional reason for this increase. While this explanation seems logical knee flexion has not been shown to be effected by walker boots by other researchers (Wang & Hansen, 2010; Vanderpool et al., 2008; Pollo et al., 1999). Hip flexion was found to be the same in a walker boot as in shoed walking (Wang & Hansen, 2010; Vanderpool et al., 2008; Zhang et al., 2006; Pollo et al., 1999). However, hip abduction has been shown to change while walking in a walker boot. Hip abduction appears to decrease while wearing a walker boot especially during early stance phase of walking. This alteration can lead to adverse effects for the hip and back (Zhang et al., 2006; Pollo et al., 1999). The foot progression and stride length were not shown to change in the walker boot conditions (Wang & Hansen, 2010; Pollo et al., 1999). Walking speed in a walker boot has been shown to stay the same as shoed walking (Pollo et al., 1999). On the other hand, McDonald, Kihm, and Nimick (2008) noted that walker boot conditions were slower than shoed walking for quick walking and comfortable paced walking over 50ft.

In addition to straight walking, stair climbing and descending was assessed. McDonald et al. (2008) found walker boots caused patients to move slower up and down stairs. One explanation for this change and many other kinematic changes is the altered weight of the walker boot (McDonald et al., 2008; Vanderpool et al., 2008; Zhang et al., 2006). While this claim has not been tested to this investigators knowledge, research has been done to investigate the increased energy requirements of walker boots. Vanderpool et al. (2008) found that while there was an increase in energy expenditure while wearing a walking boot, the increased energy expenditure appeared to be due to the addition of the walker boot weight rather than gait differences.

Although there has been lots of research looking at the effects on the injured ankle, little research has been done looking at the contralateral ankle. It was hypothesized by Zhang et al. (2006) that possible compensatory changes on the uninjured side if present may cause low back pain or SI pain. Recently McDonald et al. (2008) investigated the use of the Donjoy Evenup device. They found that the even up device was able to shift gait changes toward baseline norms, but were still significantly different. Although, objective data did not indicate that the Evenup was successful in returning gait to normal, the participants reported decreased impact, decreased hip and knee discomfort, and overall more comfort and preferred the Evenup device to no device. As discussed above, walker boots present an issue for compliance, so devices and interventions which can increase patient comfort, and therefore compliance, are important for practitioners to consider (McDonald et al., 2008).

*Flip-Flip Literature*

Often described as a thong-style sandal, the flip-flop has been the footwear of choice for thousands of years. Today’s flip-flop has been compared to the very first known footwear of mankind. (Kopp, 2009). The flip-flop is one of few items to span centuries, social classes, and continents being worn by Pharaohs, Assyrians, Romans, and Greeks (Kopp, 2009; Dash, 2006). Even in today’s cinematic renditions of ancient myths and legends, producers use period appropriate footwear which resemble today’s flip-flops. (Wilson, 2004).

Despite reports on the ill health effects of long-term flip-flop wearing, sales continue to rise. According to the most recent data from Surf Industry Manufactures Association, sandal sales increased to over $1.5 billion in 2010, an 8.2% increase from 2008. (Lausche, 2011). While the exact membership of SIMA is unclear, this data mainly represents independent surf shops and some chain stores such as PacSun and Zumiez, but does not include the billions of dollars spent at department stores, shoes stores, or other specialty clothing stores (Lausche, 2011, Kell, 2007). Although ancient times depict these shoes being worn by many men, the trend has only recently regained popularity with men. While many people associate flip-flips with a cheap form of footwear, there is a wide range of prices for these popular shoes. Prices can be as low as a couple dollars for simple rubber flip-flops from commons stores such as Wal-mart, Target, and Old Navy. Prices can get as high as $175 for a pair with Swarovsky crystals or $850 for a pair of Dolce and Gabbana flip-flops (Kopp, 2009). Prices even within stores range for example at a small boutique in Fells Point prices range from $15 to $115 (Dash, 2006). Flip flop styles vary greatly but, in general, can be categorized into three different functional groups: no arch support, arch support with no heel cup, and arch support and heel cup (Shroyer, 2009).

Reports about the health problems associated with flip-flops sporadically appear in the news media. Often reporters interview podiatrists as well as the general public for their experience with flip-flops. Flip-flops have been explained as a comfortable, cheap, easy, and quick form of footwear. However, not all reports from flip-flop wearers are positive. Some report chronic pain or even acute pain from slips, trips, and falls (Dr. Foot, 2012; abcNEWS, 2007). Podiatrists are often cited in news articles to support the anecdotal report. Heel pain, tendon overuse, altered gait, and poor shock absorption are the most commonly reported injuries associated with flip-flop wearers (Dr. Foot, 2012; Parker-Pope, 2008; abcNEWS, 2007; Yara, 2006). Positano, a podiatrist in New York was interviewed by abcNEWS and explained the problem best:

“The problem with this [trend of flip-flops] is absolutely no support…the foot is able to go in any direction it wants to go in and it directly impairs the ability of the foot to function as a shock absorbing part of the body.” (abcNEWS, 2007).

While the foot is said to be able to move in whatever direction it wants, the flip-flop presents a unique problem of requiring the foot to do work to keep the shoe on. This requirement alters the motion of the foot and presents with many gait changes which can create pain and injury throughout the entire kinetic chain (Shroyer, 2010, Parker-Pope, 2008). The current recommendation from experts, researchers and podiatrists, on flip-flop usage is to try to limit wearing them to beaches, pools, and following athletic events (Parker-Pope, 2008).

Surprisingly there is very little research done on flip-flops related to gait or injury. Most beliefs held about flip-flops and injuries are due to anecdotal evidence supplied by podiatrists. As far back as 2000, there were reports of Iliotibial band (ITB) friction syndrome being helped by limiting flip-flop usage. A group of university athletic trainers discovered that one of the causes of the patient’s ITB pain was abnormal neuromuscular control. They set rehab goals to re-educate the flexor hallux longus muscle in order to restore proper motion in the first ray. Improper movement of the first ray can cause overpronation during the stance phase of walking causing extra tensile force along the ITB and increasing compression forces between the ITB and the lateral epicondyle (Pettitt & Dotsk, 2000). It has been shown that athletic shoes can limit pronation (McPoil, 2000). It is possible that limiting flip-flops in favor of athletic shoes can help limit this overpronation. Citing this case study, Shroyer and Weimar (2010) hypothesized that one of the problems with flip-flops is the accessory contraction of the flexor digitorum longus and the flexor hallucis longus.

Low back pain is the most common orthopedic complaint in the US today, with estimates that eight out of ten people will experience low back pain at some point in his/her life ( National Institutes of Health, 2011). Flip-flops have been anecdotally linked to low back pain but not empirically shown to be a cause of low back pain (Parker-Pope, 2008). Through gait analysis studies, one hypothesis has emerged to explain the anecdotal connections. Similar to the cause of ITB syndrome, the decrease in proper first ray motion does not allow proper movements at the hip and back during walking. To ambulate, it is important that the center of balance shift as one leg remains on the ground and the other swings forward. The swing leg will first move into hip extension in order to increase the elastic properties of the hip flexors. This hip extension is initiated by extension at the metatarsophalangeal (MTP) joint. During walking, the accessory contraction of the flexor digitorum longus and flexor hallucis longus required to keep the flip-flop on the foot, does not allow this extension to occur correctly. Without this MTP and hip extension, the elastic properties of the hip flexors cannot be initiated leading to excess forces through those muscles and eventually overuse injuries. When the hip flexor muscles cannot function properly, low back pain can occur due to uneven pressures and pulling through the pelvic and lumbar spine (Shroyer & Weimar, 2010).

Another common complaint, especially among the athletic population, is shin splints. Shin splints are a general term encompassing nearly any anterior lower leg pain. In addition to the accessory contraction of the toe flexors to keep the flip-flop on the foot, there is an increase in the activity, compared to barefoot walking, of the tibialis anterior, a muscle which is responsible for dorsiflexing the foot (Shroyer, 2009). Any increase in repetitive muscular contraction is prone to pain and discomfort. Shin splints may be the manifestation of fatigue and discomfort caused by this increase in muscular activity.

In addition to altered gait patterns which have direct links to injuries, there are other gait differences which currently have no direct path to injuries and complaints caused by flip flops; however, the research on flip-flops and gait are continuing to become more comprehensive. Research was done to compare the gait patterns when wearing flip-flops to those when wearing sneakers. The most note worthy findings included that stride length and stance time decreased for flip-flop walking. Kinematic data showed that plantarflexion increased at the start of the double support phase (immediately following heel strike) and that throughout the entire swing phase dorsiflexion was decreased (Shroyer & Weimar, 2010). Second flip-flops were compared to barefoot walking. Shroyer (2009) used three separate sandals fitting into the three separate categories: no arch support, arch support with no heel cup, and arch support and heel cup. He found that the flip-flop with arch support and heel cup best represented barefoot walking. However, the flip-flop with no arch support and no heel cup had many differences. Unlike when compared to sneakers, flip-flops had a longer stride length than barefoot walking. Also, the dorsiflexion was decreased when wearing flip-flops compared to barefoot walking. This finding at first seems to contradict his other finding that tibialis anterior activity increased. However, due to the increase in flexor digitorum longus and flexor hallucis longus muscles which also play a role in plantarflexion, the tibalis anterior activity may be counteracted. Also, the need to keep the heel of the flip-flop close to the heel of the foot to assure stepping onto the shoe is another reason for decreased dorsiflexion (Shroyer, 2009).

Although there is a limited amount of research on flip-flops, there has long been research on the importance of proper footwear often looking at runners and their shoes. The advantages of proper footwear as explained by McPoil (2000) include protecting the foot, providing traction, motion control, and attenuation of impact forces. Two important features of athletic shoes are the midsole and the rearfoot area. The midsole is essential in attenuating and distributing forces over a large area of the foot and supporting the arch of the foot which acts much like the arch of a building to support the structure above it. Unlike the unsupportive, open flip-flops, the rearfoot stabilizer in combination with a snug midfoot region of athletic shoes help those with overpronation by limiting the motion of the foot (McPoil, 2000). Allowing for proper pronation and limiting excess motion of the foot will allow for proper movement up the kinetic chain and ideally limit lower extremity and lumbar injuries.

**Methodology**

*Purpose of Study*

Investigate gait changes while wearing an orthopedic walker boot in two different conditions: A) Running Shoe on “healthy” foot, B) Thong-style Flip-Flop on “healthy” foot.

*Participants*

Fifteen college aged students participated in this study. The overall purpose of this project was to investigate differences in gait mechanics between three different walking conditions. For the purpose of this study, people with previous walker boot experience, inexperience with walking on a treadmill, previous leg injuries requiring surgery or immobilization, diagnosed LBP, or true leg length discrepancy were excluded from participation. True leg length discrepancy was defined as a difference between right and left legs of greater than 15mm measured from the anterior superior iliac spine to the medial malleolus (Starkey et al., 2010). A medical screening questionnaire was administered prior to data collection to check for exclusion criteria (Appendix B). Participants signed an International Review Board approved consent document prior to participation in study indicating voluntary willingness (Appendix A).

*Setting*

All testing and data collection occurred in the Biomechanics Laboratory of Miami University. This lab is a large room with all the equipment necessary to carry out data collection.

*Instrumentation*

VICON 8-camera system (Vicon, Los Angeles, CA, USA) was used to collect kinematic data while participants walked on a treadmill situated in the center of the room. Prior to each trial, specific bony landmarks were marked using infrared markers. Marker locations were the same bilaterally and included the sacrum, the anterior superior iliac spine, mid thigh, joint line of the knee, mid lower leg, medial malleolus, head of the second metatarsal, and the heel. Markers were glued to the walker boot at the location of the medial malleolus. Heel, toe, and mid lower leg markers on the right leg were moved as needed using Velcro straps on the walker boots.

*Conditions*

Each participant performed three separate trials with three different footwear combinations. The control trial consisted of participants in his/her own running shoe. The following experimental trials used an orthopedic walker boot. The walker boots used in this study were ProStep Walkers (DonJoy Global, Vista, CA, USA). One of the experimental trials used the participant’s own running shoe. The other trial used a lab provided flip-flop. Lab provided flip-flops were Old Navy’s Men’s and Women’s Classic Flip-Flops (Gap.inc, Grove City, OH, USA). These flip-flops were chosen because of their simplicity and price.

*Design and Procedure*

After meeting the criteria for participation and giving consent, height, weight, leg length, and knee and ankle width measures were taken. Participants were then given the opportunity to select walking speeds at each condition. Participants walked for 1-2 minutes to determine a self-selected speed for each condition: A) Control: Running shoes on both feet, B) Experimental 1: Walking boot on right foot, running shoe on left foot, C) Experimental 2: Walking boot on right foot, flip-flop on left foot. Self-selected speeds were recorded for use during the data collection trials. Participants were then markered up at the bony landmarks mentioned above.

Static capture was performed before each condition with the participant standing at the origin of the capture volume standing with arms crossed to ensure proper visualization of all markers. Once the static capture was performed, the markers were identified and labeled with the VICON software. Following static capture participants walked for a 6 minute familiarization period at the self selected speeds for each trial (Matsas, Taylor, & McBurney, 2000). Gait was recorded for the last 30 seconds of each trial. For each participant the control trial was performed first. Up to three different control conditions were recorded based on self-selected speeds. Participants first walked at the self-selected speed in two running shoes. Following these 6 minutes, participants walked for another 2 minutes at each of the experimental self-selected speeds while still wearing both running shoes. Strides were recorded for the last 30 seconds at each speed. These other control conditions will allow for comparison between the experimental conditions and the control removing speed as a possible source for gait changes. The experimental trials were randomized following the control. Each experimental condition was performed at only the self-selected speed for that condition.

**Results/Discussion**

Walker boots are a popular, effective treatment for many lower extremity injuries, but have been shown to alter gait patterns (Wang & Hansen, 2010; Vanderpool et al., 2008; Pollo et al., 1999). This study was designed to investigate the importance of footwear on the contralateral leg while wearing a walker boot. The current research on walker boots concentrates on how these walker boots promote healing, but little research has been done to investigate their effects on the rest of the kinetic chain. Data was analyzed to determine kinematic differences between three different trials. First, a control trial performed at up to three different speeds (a self-selected control speed, the self- selected speed of the shoe and boot condition, and the self-selected speed of the flip-flop and boot condition). Second, experimental condition one with a walker boot on the right foot and a running shoe on the left foot. Third, a second experimental condition with a walker boot on the right foot and a flip-flop on the left foot. The following sections will describe the results found. Unfortunately due to time restraints only partial results were able to be obtained in time for the deadline of this paper. More detailed results will be presented at a later date.

*Participant Demographics*

Fifteen students volunteered for participation in the current study and met the inclusion criteria. All volunteers included in the study completed a medical questionnaire (Appendix A) to double check inclusion criteria and an Informed Consent Form approved by the University Institutional Review Board (Appendix B). The sample population for this study included eight female and seven male participants. All participants were college students between the ages of 18 and 24. The average of the participants’ demographics is summarized in Table 1. Unfortunately, only eleven participants’ data was able to be analyzed for kinematic variables. This smaller sample included five female and six male participants. Averages of this smaller population’s demographics are summarized in Table 2. There were no statistical differences between the analyzed population and the overall population.

|  |  |  |
| --- | --- | --- |
|  | Mean | Standard Deviation |
| Height | 71.71 kg | 14.60 |
| Weight | 172.12cm | 10.47 |

Table 1: Demographics for All Participants

|  |  |  |
| --- | --- | --- |
|  | Mean | Standard Deviation |
| Height | 72.67 kg | 15.36 |
| Weight | 173.47 cm | 10.58 |

Table 2: Demographics for Analyzed Participants

It is important to note that the population selected for this study does not represent the general population. Participants were all between the ages of 18-24 years old. Also, all students were students within the kinesiology department. Students within this department tend to be more active and healthier than the general population.

*Self-Selected Speeds*

The first hypothesis proposed suggested that walking speed would decrease as more novelty was added to the trial. In other words, the control trial speed would be the fastest and the walker boot matched with a flip-flop will be the slowest. As can be seen in Figure 1, the overall trends do support this hypothesis. However, the differences seen are not significantly different. It was also noted that some participants selected the speed for all three trials.

Figure 1: Averages of all fifteen participants for self-selected speeds for each condition

While these results indicate no significant change in speeds, some participants had large differences while other participants selected the same speed throughout all three trials. Also, participants walked on a treadmill to determine walking speed. It is possible that participants selected the same walking speed because they noted the number on the treadmill rather than it being the most comfortable speed. It is possible walking speeds may be seen to vary more while over ground walking when participants do not have a visible objective measure of their speed.

*Joint Angles at Toe-Off and Heel Strike*

The second hypothesis proposed suggested that hip extension would be decreased for both limbs while wearing a walker boot and flip-flop compared to the control trials, but that decreased hip extension will only be noted for the right leg during the walker boot and running shoe condition. No specific hypothesis was proposed about joint angles at heel strike. Unfortunately, this data was unable to be completely analyzed in time for submission. Joint angles to be analyzed include hip and knee angles in the sagittal and frontal planes which indicate changes in flexion/extension and abduction/adduction.

*Joint Range of Motion*

The third hypothesis proposed suggested that there would be an increase in pelvic girdle motion. This difference would be seen larger in the flip-flop and walker boot condition compared to control than the running shoe and walker boot condition compared to the control condition. Unfortunately, this data was unable to be completely analyzed in time for submission. In addition to pelvic motion, hip and knee ranges of motion will be reported.

*Joint Displacements*

The fourth and final hypothesis proposed suggested that the right ankle, while wearing a walker boot will be raised higher than the control trials due to the platform at the end of the walker boot. This additional length needs to be cleared over the ground. It has been suggested that this difference will be due to an increase in hip flexion due to the inability to properly push-off. Unfortunately, this data was unable to be completely analyzed in time for submission. In addition to ankle displacement, knee displacement will be analyzed to help determine if hip angle or knee angle is the cause of any differences found at the ankle.

**Resources**

# abcNews. (2007). Flip-flops be gone! Give your feet a break! Retrieved from http://abcnews.go. com/GMA/SummerSizzle/Story?id=3505928&page=1#.T5NcedV6uuJ.

Crenshaw, S. J., Pollo, F. E., & Brodsky, J. W. (2004). The effect of ankle position on plantar pressure in a short leg walking boot. *Foot & Ankle International*, *25*(2), 69-72.

Crincoli, M., & Trepman, E. (2001). Immobilization with removable walking brace for treatment of chronic foot and ankle pain. *Foot & Ankle International / American Orthopedic Foot And Ankle Society [And] Swiss Foot And Ankle Society*, *22*(9), 725-730.

Dash, J. (2006, July 3). The flap over flip-flops. *Baltimore Business Journal.*  Retrieved from <http://www.bizjournals.com/baltimore/stories/2006/07/03/story3.html>.

Dr. Foot. (2012). Flip-flop sandals linked to rising youth heel pain rate. Retrieved from <http://www.drfoot.co.uk/flip_flops.htm>.

Floyd, R.T. (2007). Manual of Structural Kinesiology. (16th ed.). Burr Ridge, IL: McGraw Hill.

Gutekunst, D. J., Hastings, M. K., Bohnert, K. L., Strube, M. J., & Sinacore, D. R. (2011). Removable cast walker boots yield greater forefoot off-loading than total contact casts. *Clinical Biomechanics*, *26*(6), 649-654.

Hoppenfeld, S. (1976). *Physical examination of the spine and extremities.* Upper Saddle River, NJ: Prentice Hall.

Houglum P.A. (2005). Therapeutic exercise for musculoskeletal injuries. (2nd ed.). Champaign, IL: Human Kinetics.

Inman, V.T., Ralston, H.J., & Todd, F. (1994). Human Locomotion. In Rose, J., & Gamble, J. G. (Eds.), *Human walking*. (2nd ed.). (pp. 1-22). Baltimore, Maryland: Williams & Wilkins.

Johanson, M.E. (1994) In Rose, J., & Gamble, J. G. (Eds.), *Human walking*. (2nd ed.). (pp. 201-224). Baltimore, MD: Williams & Wilkins.

Kadakia, A. R., Espinosa, N., Smerek, J., White, K., Myerson, M. S., & Jeng, C. L. (2008). Radiographic comparison of sagittal plane stability between cast and boots. *Foot & Ankle International*, *29*(4), 421-426.

Kadel, N. J., Segal, A. A., Orendurff, M. M., Shofer, J. J., & Sangeorzan, B. B. (2004). The efficacy of two methods of ankle immobilization in reducing gastrocnemius, soleus, and peroneal muscle activity during stance phase of gait. *Foot & Ankle International*, *25*(6), 406-409.

Keefer, M., King, J., Powell, D., Krusenklaus, J. H., & Zhang, S. (2008). Effects of modified short-leg walkers on ground reaction force characteristics. *Clinical Biomechanics*, *23*(9), 1172-1177.

Kelly, J. (2007). No slowing down for surf industry. Retrieved from http://www.sima.com/news-information/news-detail/id/25.aspx.

Kopp C. (2009, Feb. 11). Flip-flops, footwear of pharaohs. *CBSNEWS*. Retrieved from <http://www.cbsnews.com/2100-3445_162-1894297.html>.

Lausche, M. (2011). SIMA retail study confirms significant changes- Surf industry’s footwear, wetsuits, and board categories lead growth in 2010. Retrieved from http://www.sima.com/news-information/news-detail/id/108.aspx.

Matsas A., Taylor N., & McBurney H. (2000). Knee joint kinematics from familiarized treadmill walking can be generalized to overground walking in young unimpaired subjects*. Gait and Posture, 11*, 46-53.

McDonald P., Kihm, C., & Nimick C. (2008). Analysis of plantar pressure and gait characteristics in a post-surgical walking boot and without a contralateral limb length adjustment device. Poster at Temple University of Podiatric Medicine, Pittsburgh, PA.

McPoil, T. G. (2000). Athletic footwear: design, performance and selection issues. *Journal Of Science & Medicine In Sport*, *3*(3), 260-267.

National Institute of Health. (2011). Back Pain. *Medline Plus.* Retrieved from http://www.nlm.nih.gov/medlineplus/backpain.html.

Parker-Pope T. (2008, June 5). Summer flip-flops may lead to foot pain. *The New York Times.* Retrieved from <http://well.blogs.nytimes.com/2008/06/05/summer-flip-flops-may-lead-to-foot-pain/>.

Pettitt, R., & Dolski, A. (2000). Corrective neuromuscular approach to the treatment of iliotibial band friction syndrome: a case report. *Journal of Athletic Training*, *35*(1), 96-99.

Pollo, F.E., Gowling, T.L., & Jackson, R.W. (1999). Walking boot design: a gait analysis study. *Orthopedics, 22*, 503–507.

Prentice W.E. (2009).Arnheim’s principles of athletic training: A competency-based approach. (13th ed.). Burr Ridge, IL: McGraw-Hill Higher Education.

Shroyer J.F. (2009). *Influence of various thong style flip-flops on gait kinematics and lower leg electromyography. (Doctoral Dissertation).* Auburn University, Auburn, Alabama.

Shroyer, J., & Weimar, W. (2010). Comparative analysis of human gait while wearing thong-style flip-flops versus sneakers. *Journal of the American Podiatric Medical Association*, *100*(4), 251-257.

Speck, M. M., & Klaue, K. K. (1998). Early full weight bearing and functional treatment after surgical repair of acute Achilles tendon rupture. *American Journal of Sports Medicine*, *26*(6), 789-793.

Starkey, C., Brown, S.D., & Ryan, J.L. (2010). *Examination of orthopedic and athletic injuries*. (3rd ed.). Philadelphia, PA: EA. Davis Company.

Sutherland, D.H., Kaufman K.R., & and Moitoza J.R. (1994). In Rose, J., & Gamble, J. G. (Eds.), Human *walking*. (2nd ed.). (pp. 23-44). Baltimore, Maryland: Williams & Wilkins.

Vanderpool, M.T., Collins, S.H., & Kuo, K.D. (2008). Ankle fixation need not increase the energetic cost of human walking. *Gait and Posture, 28*, 427-433.

Wang, C.C. & Hansen, A.H. (2010). Response of able-bodied persons to changes in shoe rocker radius during walking: Changes in ankle kinematics to maintain a consistent roll-over shape. *Journal of Biomechanics, 43*, 2288-2293.

Wilson C. (2004, April 18). Men are toeing the sandal line. *USA Today.* Retrieved from <http://www.usatoday.com/life/lifestyle/2004-04-18-man-sandals_x.htm>.

Yara, S. (2006, May 4). Skip the flip-flops. *Forbes.* Retrieved from http://www.forbes.com/2006/05/03/flipflop-foot-problems\_cx\_sy\_0504htow.html.

Zhang, S., Clowers, K. G., & Powell, D. (2006). Ground reaction force and 3D biomechanical characteristics of walking in short-leg walkers. *Gait & Posture*, *24*(4), 487-492.

**Appendix A**

Subject\_\_\_\_

**Medical History/Exclusion Questionnaire**

Have you ever worn a walking boot before for any length of time? Y N

Have you ever walked on a treadmill? Y N

Have you had any previous injuries to the lower extremity requiring surgery or bracing? Y N

Have you ever been diagnosed with any back injury? Y N

**Selected Speeds:**

Shoe and Shoe: \_\_\_\_\_\_\_

Shoe and Boot: \_\_\_\_\_\_\_

Flip-Flop and Boot: \_\_\_\_\_\_

**Appendix B**

**RESEARCH PARTICIPANT INFORMATION AND INFORMED CONSENT**

You are invited to participate in a research study conducted by Samantha Bowker. I am currently an undergraduate student at Miami University conducting research for my Honor’s thesis. Because of my interest in becoming involved in the allied medical field to some capacity in my future career, I have chosen the topic of walker boot biomechanics for my project. I hope to learn about the effects of footwear on walking patterns.

If you decide to participate, you will be asked to perform three trials consisting of walking on a treadmill for a 6 minute familiarization and then 20 strides of recorded walking. These trials will take place during a single laboratory session of approximately 90 minutes. The first trial will be a control trial during which you will wear your own running shoes. The following two trials will consist of wearing a walker boot on one ankle. You will wear the same running shoe as for the control trial for one test trial and a laboratory provided flip-flop for one trial on the opposite foot. Trials will be performed in the movement studies lab in Phillips Hall on a treadmill. While this study will investigate possible problems associated with walker boots, such as low back pain, it is not likely that the short time walking the boot will cause any negative effects. You will be walking on a treadmill under conditions which will be new to you. Because the conditions will be new to you there is an increased risk of injury compared to daily activities. Participation in this experiment is voluntary and you will be shown how to stop the treadmill in the event you would like to withdraw from the study. If at any point in the study you feel any fatigue or discomfort please inform the researcher and the study will be suspended. Any information that is obtained in this study will be stored anonymously on a password protected laboratory computer.

Your participation is voluntary. Your decision whether or not to participate will not affect your relationship with Miami University or any members of the KNH department. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without penalty.

The benefit of this project, educationally, is that it will help me gain insight into experiences and perceptions involved with athletic injury rehabilitation, and biomechanics.

If you have further questions about this project, please contact me at (219-241-3377, bowkerse@muohio.edu) or contact my faculty advisor, Dr. Brett Massie (513-529-8105; [massiejb@muohio.edu](mailto:massiejb@muohio.edu)). If you have questions regarding your rights as a research subject, please contact the Office for the Advancement of Research and Scholarship (513-529-3600).

Thank you for your participation and assisting with my project. I am very grateful for your help and hope that it will be an interesting process for you. You will be given a copy of this form for your records.

I agree to participate in the project on athletic injury. I understand that in the event of physical injury resulting from the research procedures, financial compensation is not available and medical treatment is not provided free of charge.

Participant’s Signature Date\_\_\_\_\_\_\_\_\_\_\_