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Biomechanical evaluation of modified track shoes

Marlon Alberetos Greensword

Louisiana State University and Agricultural and Mechanical College

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BIOMECHANICAL EVALUATION OF MODIFIED TRACK SHOES

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural Mechanical College
in partial fulfillment of the
requirements for the Degree of
Master of Science in Industrial Engineering

in

The Department of Construction Management and Industrial Engineering

By
Marlon Alberetos Greensword
B.S., L.S.U., 2007
B.A., L.S.U., 2005
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ABSTRACT

Track and field runners, especially sprinters and mid-distance runners, face many problems due to walking in spike shoes. Due to the fact that track and field spike shoes are designed specifically for running, the runner's feet remain in an uncomfortable, flexed position when walking between workouts and races. Problems caused by the dangerous foot-positioning include, but are not limited to, the following: back pain, shin splints, bone spurs, blisters, and overall decreased level of running performance. Over time, runners wearing improper footwear for walking may face chronic injuries such as plantar fasciitis, shin splints, Achilles tendinitis, chondromalacia, and iliotibial band syndrome. To address this problem, a modified spike shoe was tested. The modification consists of adding a removable heel to the shoe. The removable heels were attached to the sole after exercise or between races to shoe angle of flexion, so that the foot can be leveled. The modified shoes were tested in terms of health and comfort through the use of two experimental protocols. Nine healthy, resistance-trained participants volunteered to perform walking drills on a treadmill. They walked with regular spikes at 2 mph and 3 mph. Then, they repeated the drill with the redesigned spike shoes. EMG measurements were used to evaluate the participant's muscle activity, fatigue, and stress during the exercise. The analyzed muscles were the tibialis anterior and the medial gastrocnemius. The statistical tool used for the mathematical interpretation of the data was ANOVA, the hypotheses being tested with the softwares Statistix 9.0. and SAS 9.1 English version. Complementarily, participants were individually asked to rate their discomfort on a scale of 1 to 10, using a body map as a further evaluation of the effects of the removable heel. Results showed a 22 % average decrease in EMG muscle activity from walking without heels to walking with heels in the tibialis anterior and a 24.25% average decrease in the gastrocnemius. Results were consistent for all participants.

Similarly, when rating discomfort from walking without heels to walking with heels, the body map survey results indicate that participants noticed an average superior comfort of 2.7 points in the knees, 2.6 points in the calves, 3.9 points in the ankles, and 4.2 points in the feet on an ergonomic scale of 10 discomfort points. Thus, results showed that the removable heel helps reduce muscle fatigue and stress and therefore its related musculoskeletal problems.

1. INTRODUCTION AND BACKGROUND

Track-and-field athletes wear spike shoes, which are designed exclusively for running during training and competition (track meets). Based on observations of the LSU track team during regular track season, athletes wore their spike shoes for a daily average of one hour and 25 minutes, of which 45 minutes are spent walking. In addition, further observations indicated that, between workouts, athletes walk in their spikes on an average of 5 hours per week, which indicated an excessive time spent in footwear not meant for walking. Over a span of time, depending on the spike shoe design, some sprinters and mid-distance athletes (800 m runners) suffered several injuries, especially while walking in their spike shoes, which are made only for running. Such injuries include plantar fasciitis, shin splints, Achilles tendinitis, chondromalacia, and iliotibial band syndrome (McGrath and Finch, 1996).

Spike shoes' shapes differ depending on the athlete's area of competition (mid-distance, sprint/short distance (50 to 400 m), long distance (1 mile to marathon), jumps, etc.). These lightweight shoes are named after the small metal spikes that range in size, depending on the track surface on which an athlete competes. The metallic pieces are attached to the bottom of the shoes. Thus, they are removable, and the athlete may replace them with longer or shorter spikes according to his or her needs. Spikes also differ in aerodynamics, depending on the event. Runners use this specific type of shoe, because the shoe enables their feet to stick to the mondo or rubber surface, thereby minimizing shock and sliding.

This project is designed to test the feasibility of an innovative track-and-field spike shoe. In the first approach, a description of the ideal shoe that track-and-field athletes need provides data such as shape and materials needed.



Figure 1.1: Example of a typical track spike shoe used by runners

The second part exposes the main problems currently encountered with some of the classic spikes. This section is introduced with pictures showing different dimensions of the spike and is followed by an analysis of the shoe's potential harm to the athlete's feet. In effect, the shoes were created to fit runners, and therefore, wearing them for a different activity – in this instance, walking – may cause back pain, shin splits, bones pure, and blisters. It also tends to decrease running performance, since injured runners cannot perform to the best of their abilities.

Thirdly, the solution proposed and tested in this project is a shoe with a removable heel, that is, the opportunity for every track-and field athlete to get their own custom-built spikes specified to his or her activity – running and walking. The efficiency of this feature is tested on the classic Nike spikes, in terms of health protection and athletic performance, focusing on muscle fatigue.

Finally, this thesis concludes by elaborating on the implication of the study, including notes for further research.

Regarding the commerciality of the product, one must note that some of the features hereby proposed have already been presented but have never been applied to spike shoes. If Nike

were to adopt such a proposition, they would gain a wider clientele on the track-and-field market, more satisfied customers, as well as promotional benefits in terms of their interest in preserving the athlete's health.

2. LITERARY REVIEW

2.1. Common Running Injuries

McGrath and Finch's (1996) report features a cause-and-effect analysis of common injuries among track runners. The document provides detailed descriptions of what causes the problems faced when runners wear track spikes. This research showed the following related injuries that can occur when the spike shoes do not fit the athlete:

- **Plantar fasciitis:** an inflammation of the thick band of tissue from the heel to the base of the toes in the bottom of the foot. When placed under stress, the plantar fascia stretches and tears, leading to inflammation.
- **Shin splint, also called tibial stress syndrome:** the inflammation of the tendons on the inside of the front of the lower leg, i.e. the shins.
- **Achilles tendinitis:** occurs when the Achilles tendon, a large tendon connecting the two major calf muscles (gastrocnemius and soleus), is placed under too much stress causing inflammation. If the inflamed Achilles continues to be stressed, it can tear or rupture.
- **Chondromalacia:** a cracking or wearing away of the cartilage under the kneecap, resulting in pain and inflammation.
- **Iliotibial band syndrome:** inflammation and pain on the outside of the thigh, where the iliotibial band rubs against the femur.

Such findings are comparable to the previously mentioned observations of the Louisiana State University track-and-field team. They also coincide with statements from the track-and-field team staff.

In a personal interview (2007), Assistant Coach Mark Elliott, who coaches distance and mid-distance at Louisiana State University, stated that track athletes wear spikes on a minimum basis of four days per week and three hours per day. Elliott added that from two months to one

year, the amount of time spent wearing spikes accumulates, and athletes tend to develop problems in their legs, lower back, tibia, metatarsals, and patella, as illustrated in Figure 2.1.

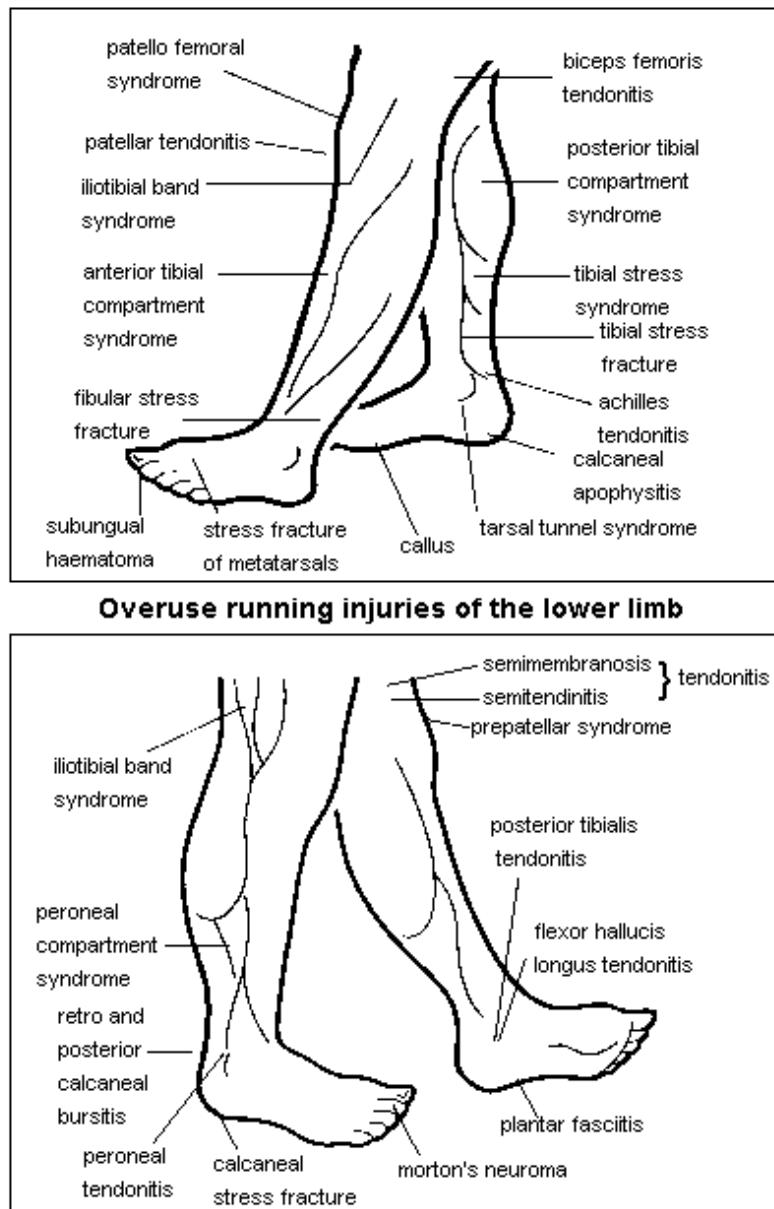


Figure 2.1: Common overuse running injuries of the lower limbs

Source: McGrath and Finch (1996, 37-38)

The research of Myburgh et al. (1988) indicated that 84% of injuries among runners occur on the tibia (shin) area, and 13% are linked to the Achilles tendon. This project thus focuses on these two areas and the related muscles.

2.2. Running and Walking Techniques and the Common Track Spike Shoe

2.2.1. Running and Walking Biomechanics

Au et al. (2006) provided a model for the ankle-foot walking process, in which the study described each phase and its corresponding foot angle. The walking process is divided into two major stages: stance and swing. Stance, which constitutes the majority of the walking process (about 60%), is made up of three phases or moments:

- Controlled plantarflexion: begins at heel-strike and ends at foot-flat. During this phase, the heel and forefoot make initial ground contact.
- Controlled dorsiflexion: begins at foot-flat and continues until the ankle reaches a state of maximum dorsiflexion. The main function of the human ankle during controlled dorsiflexion is to store the elastic energy needed to propel the body upwards and forwards during the next phase
- Powered plantarflexion: begins at maximum dorsiflexion and ends at toe-off. During this phase, additional energy is supplied, along with the spring energy stored during the previous phase to achieve the high plantarflexion power during late stance.

Swing is thus the phase that separates each stance, starting at toe-off and ending at heel-strike. During swing, the foot is lifted, proceeding to actual geographic locomotion. The following figure illustrates the biomechanics of walking and its distinct phases:

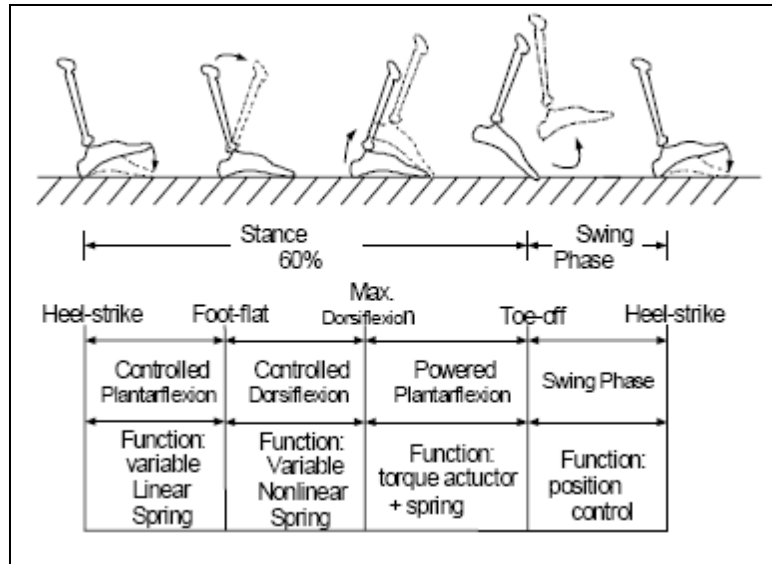


Figure 2.2: Biomechanics of a normal human ankle during level-ground walking

Source: Au et al. (2006)

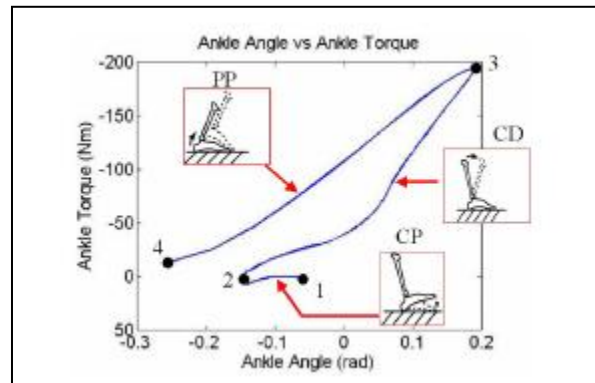


Figure 2.3: Ankle torque versus angle during level-ground walking

Source: Au et al. (2006)

Figure 2.3 graphs the ankle angle change in combination with the torque, that is, the rotary moment during walking. Segments 1-2, 2-3, and 3-4 represent the ankle torque-angle behaviors during Controlled Plantarflexion, Controlled Dorsiflexion, and Powered Plantarflexion phases of gait, respectively. One must note, however, that the foot does not touch the ground during the swing phase and therefore little pressure is exerted upon the heel, the Achilles tendon,

or the tibialis anterior. The research concerning this project is more centered on the stance phase. Furthermore, one may notice on Figures 2.2 and 2.3 that the swing phase of one leg corresponds to the stance phase of the other.

Given the fact that each athlete has a unique running technique (gait), a shoe should be adjustable to facilitate and support his/her motion. Raptopoulos et al. (2006) conducted a gait analysis of gait modes among men and women. Their results showed stronger hip movements among women. However, women's walking and running pattern indicate use of extrinsic foot muscles similar to that of men. When combined with observations from the Louisiana State University track team and testimonials from the team staff regarding female injuries, Raptopoulos et al.'s (2006) gait analysis indicate that female runners could benefit from the removable heel as much as men could.

In *Principles of Human Anatomy*, Tortora (2002) defines the movements that characterize different walking and running techniques:

- Inversion (to turn inward) is a movement of the soles medially at the intertarsal joints (between the tarsals).
- Eversion (to turn outward) is a movement of the soles laterally at the intertarsal joints.
- Dorsiflexion refers to bending of the foot at the ankle or talocrural joint (between the tibia, fibula, and talus) in the direction of the dorsum (superior surface). Dorsiflexion occurs when one stands on one's heels.
- Plantarflexion involves bending of the foot at the ankle joint in the direction of the plantar or inferior surface, as when standing on one's toes. Dorsiflexion is true flexion, whereas plantar flexion is true extension.

The classic spikes are designed for plantarflexion, that is, for short and mid-distance runners. Yet, these athletes walk in dorsiflexion mode (flat-footed), while common spikes are generally designed for athletes to run on the toes. Thus, those who walk on their heels after extreme physical activity have minimal stability and cushion and therefore, can easily hurt their Achilles' tendons, as much pressure is exerted onto their tibia and gastrocnemius.

In addition, Donley and Leyes (2001) wrote that extreme or repetitive dorsiflexion can lead to direct trauma, along with anterior bony ankle impingement, that is, the formation of osteophytes (bone spurs) on the anterior edge of the distal tibia. This is, according to the article, a common problem among runners. Injuries related to extreme dorsiflexion are limiting the athlete not only in terms of painful symptoms, but also because they eventually prevent the runners from performing to the best of their abilities: "patients will complain of painful limitation of dorsiflexion, catching, and swelling of the ankle. These symptoms can be debilitating and considerably limit their athletic performance." Such injuries would increase in intensity and gravity were dorsiflexion to be practiced in shoes designed for plantar flexion. For instance, the non-operative treatments Donley and Leyes (2001) proposed in a successfully experiment included rest, rubber-sole wedge shoes, and, interestingly, an internal or external heel lift.

Saunders et al. (1953) established a list of gait determinants that differentiate normal and pathological walking. According to their research, an inefficient, pathological gait pattern is characterized by numerous lateral and vertical excursions in the body's center of gravity. Thus, using the argument that "locomotion is the translation of the center of gravity through space along a pathway requiring the least expenditure of energy supplies" (Saunders et al., 1953), minimizing these excursions improves the quality of the gait. The article states that gait assessment is accomplished upon observation of these six major factors, also called major determinants:

- pelvic rotation,
- pelvic tilt,
- knee flexion,
- hip flexion,
- knee and ankle interaction, and
- lateral pelvic displacement

The determinant of interest in this thesis is the knee and ankle interaction. In effect, Thompson's (2002) study of Saunders et al. (1953) designated this determinant as one of the limitations to the troughs (or low points) in the sinusoidal pathway that occur during the gait cycle. An analysis of the biomechanics of walking (see Figure 2.3) finds that walking in spike shoes without a heel challenges the ankle in maintaining balance in the body, creating a vertical excursion in the center of gravity as pressure is exerted on the tibialis anterior and the Achilles tendon. Thus, when compared to the normal human gait pattern, walking in spike shoes with no heels qualifies as a pathological gait, and therefore requires correction. This project presents a removable heel as a potential correction to such a pathological gait.

Wakeling et al. (2001) conducted a study of the muscle activity as a response to ground reaction forces. Their project began from the starting point in which the human body reacts to the impact forces that occur at heel strike. Their study thus tests the level of muscle activity in the lower extremity muscles (among which are the gastrocnemius and the tibialis anterior) as they respond to the rate of impact forces, using a pendulum to deliver impacts to the heel repetitively, using various materials in the subjects' shoes, as seen in Figure 2.4. The pendulum apparatus, as set in the illustration, was pulled back to a reference stop. It swung for the subject to impact the wall with his right heel.

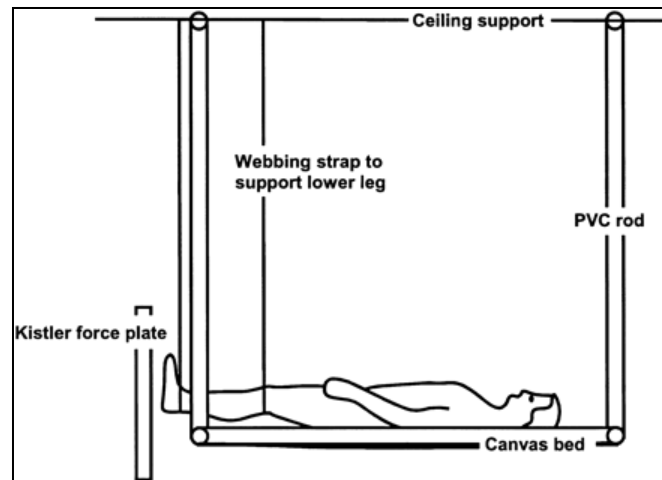


Figure 2.4: Pendulum apparatus used to test impact forces

Source: Wakeling et al. (2001)

The results of this study showed that there is a ratio of 96% in the tibialis anterior and 48% in the gastrocnemius between the pre-activation intensity and the muscle activity intensity. Therefore, conditions in which the impact to the ground is increased, such as when walking in heelless spike shoes, implicate a more intense muscle activity in the gastrocnemius and tibialis anterior, eventually or occasionally resulting in stress or fatigue. Inversely, a feature that would absorb some of the intensity of the impact, such as a removable heel, should reduce the intensity of muscle activity and thereby reduce risks of injuries related to stress and fatigue in the lower extremities.

2.2.2. Muscles Involved: The Extrinsic Foot Muscles

Extrinsic foot muscles can be defined as the “muscles that insert on the foot but originate proximal to the foot” (O’Connor et al., 2004). This group is constituted by the following muscles (Smith et al., 1996):

- Triceps surae
 - gastrocnemius
 - soleus

- tibialis posterior
- flexor digitorum longus
- flexor hallucis longus
- peroneus longus and brevis
- tibialis anterior
- extensor hallucis longus
- extensor digitorum longus

Because of their impact on foot motion, this specific group of muscles is related to numerous running injuries among track-and-field athletes. O'Connor et al. (2004, 2006) studied the role of extrinsic foot muscles during running using mfMRI technology and, more extensively, electromyography. According to the authors, these muscles act as “invertor muscles of the foot and are attributed the primary role in resisting foot pronation during the first stance” (O'Connor et al., 2006). Pronation being the act of turning one's feet downward – as opposed to supination – extrinsic foot muscles are responsible for maintaining balance and channeling energy toward the purpose of geographic motion (walking or running). Figure 2.5 provides a labeled visual representation of the extrinsic foot muscles.

Due to the importance of their role during the walking and running stance and to the preponderance of tibial stress syndrome and Achilles tendinitis injuries among track-and-field runners, two extrinsic foot muscles, the tibialis anterior and the gastrocnemius, were selected to provide insight into the quality of walking after running, thus evaluating biomechanically modified track-and-field spike shoes. These two muscles were targeted in the study as their muscular reaction to the removable heel provides valuable information as to any reduction in the risk of exercise-induced injury.

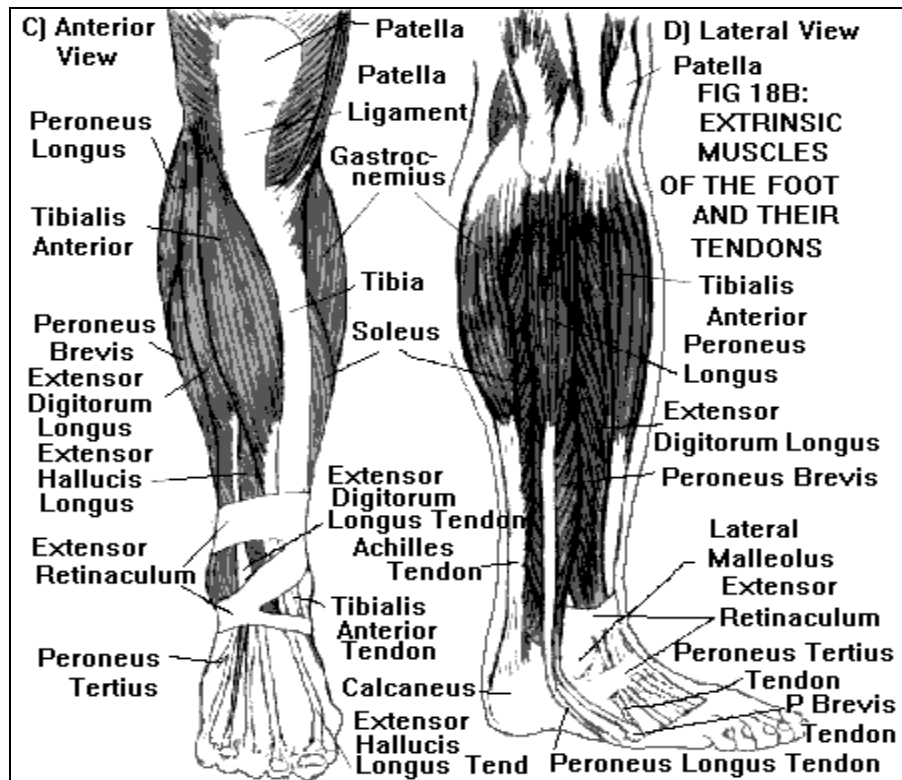


Figure 2.5: Anterior and lateral views of extrinsic foot muscles

Source: www.chionline.com/anatomy

2.2.2.1. The Tibialis Anterior Muscle

This muscle is an invertor of the foot. Reber et al. (1993) and Hunt et al.'s (2001) measurements of extrinsic foot muscles' impact indicate some degree of tibialis "overuse" among track-and-field athletes during running, but a failure to relieve and rest this muscle after exercise, as walking demands effort from this muscle as well if the foot does not have the support needed such as that provided by a heel. In effect, "tibialis anterior fires above the fatigue threshold for 85% of the time. This may account for the high number of fatigue-related injuries to the tibialis anterior muscle seen in runners" (Reber et al., 1993). This statement is particularly relevant in light of the tibialis anterior's controlling role on heel stress. Indeed, during walking, this muscle "restrains rearfoot plantarflexion from heel contact to 10% stance (see Figure 2.3)

and eversion between 10% stance and footflat” (Hunt et al., 2001). Thus, literature suggests that if extreme stress is inflicted to the tibialis anterior during running, an athlete must have extra heel support to make up for a fatigued foot-invertor muscle.

2.2.2.2. The Gastrocnemius Muscle

This muscle is responsible for controlling foot motion, exerting much force during walking and running for plantar flexion and foot pronation resistance (O’Connor et al., 2004, 2006). Thompson (2002) provides a visual of the role of this muscle during a normal walking gait, as depicted in Figure 2.6 that illustrates the gastrocnemius activity during stance, illustrating the intensity of the pressure exerted on the ankle and the gastrocnemius during walking.

Regarding Achilles tendinitis, the second most common injury among track athletes, it is important to understand the impact of the gastrocnemius muscle activity. Effectively, this injury is an inflammation of the Achilles tendon, which is constituted of tendons of the gastrocnemius and soleus muscles (see Figure 2.5). Roy (1988), who studied and experienced running injuries, explains that running shoes are supposed to possess a heel wedge to reduce Achilles tendon stretch. Similarly, Reilly’s (2009) historic of the ergonomics of running shoes explains that shock absorption properties such as outer and midsole with a wedge in between at the shoe’s back, air bubbles, or heel counters aids in stabilizing the rearfoot and decreasing the risk of Achilles tendinitis. Nevertheless, such features apply to shoes designed for long distance runners, since their stance is longer than that of sprinters and mid-distance runners; this stance increases the need for heel support during running. Yet, heelless sprint and mid-distance spike shoes are elevated at the toes to aid in speeding up the stance during running. In addition, they provide no heel wedge during the longer walking stance, which means that the Achilles tendon of a walking athlete is stretched more intensely – due to the shape of the shoe – and for a longer amount of time –walking taking longer than running – if the athlete does so in his / her spike shoes.

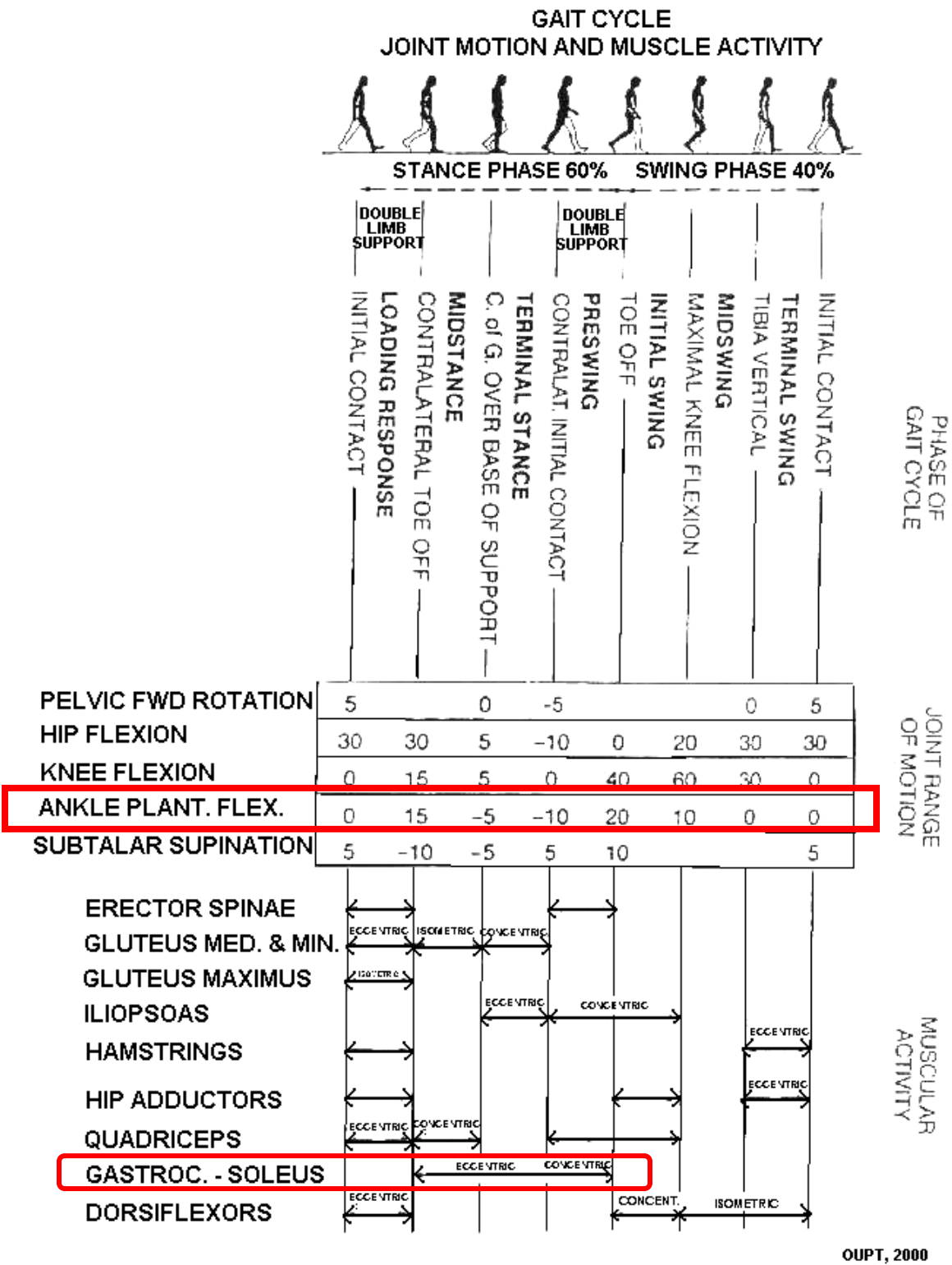


Figure 2.6: and muscle activity during normal walking gait cycle
Source: Thompson (2002)

In regard to another common injury among track-and-field runners that involves the gastrocnemius, namely plantar fasciitis, the main cause is an inflammation of the plantar fascia due to abnormal pronation (Roy, 1988), that is, a failure of the gastrocnemius to properly resist pronation.

2.3. Transition between Running and Walking

The biomechanical modification hereby tested enables runners to rest their heels as well as reduce gastrocnemius and tibialis fatigue after or before exercise or competition. Indeed, the study of O'Connor et al. (2006), examining the role of extrinsic muscles through mfMRI and EMG measurements, indicates that these muscles control rearfoot motion to alter the activation in order to maintain a preferred movement pattern. Thus, transition from one gait to another (from running to walking), is a naturally challenging phenomenon for the runner's extrinsic foot muscles. This suggests that a runner's extrinsic foot muscles could benefit from assistance or intervention in altering foot motion, especially after an intensive race.

Measurements of muscle fatigue during transition from running to walking and vice-versa have been performed and reported in a published study from the Department of Movement and Sport Sciences at Ghent University (Segers et al., 2006). The study mostly consisted of EMG measurements on a group of subjects' tibialis anterior. According to Segers et al. (2006), tibialis anterior fatigue is attributable to more than just the metabolic change or cost, which is to say, the "change to another type of locomotion reduces oxygen consumption." In effect, differences of foot angle when switching from plantarflexion (running) to walking tends to affect the intensity of tibialis anterior activity. EMG of the tibialis anterior during walking and running has a typical pattern with a burst during the eccentric foot plantar flexion movement following heel contact. Such eccentric activity tends to increase exertion, which might serve as protective mechanism to prevent further damage. Walking and running, when performed at speeds in proximity of the

transition-speed, differed in the fact that the touch-down angle of the foot is smaller during running. Another possible explanation could be the greater instability of the foot after TA fatigue. During the heel strike stage of walking stance (see Figure 2.3), the eversion load is maximized. If the TA fails to sufficiently counteract foot eversion, with secondary function preventing eversion, this would cause a medial shift of the center of pressure and a lateral shift of the center of mass.

This report thus indicates not only that the foot tends to be more instable when walking after running, but also that a reduction in heel pressure would certainly reduce fatigue of the tibialis anterior as well.

Similarly, Nigg et al. (2003) examined the influence of shoe soles on muscle activation and energy through EMG measurements. Their research indicated a change in oxygen consumption and a change in lower extremities muscle activation (including tibialis anterior and medial gastrocnemius), as the subjects ran in shoes with different heel materials. During running, track athletes experience forces of impact that range between 1.0 and 2.5 times their body weight. Running thus constitutes a great effort on muscles in the lower extremities, which could benefit from after-running support to absorb and provide relief from some of the shock due to heel impact when walking away from the track after competition or exercise. In addition, the authors use the expression “muscle tuning” to refer to the muscles’ tendency to adopt an activation pattern. This complements the conclusions of O’Connor et al. (2006). Nigg et al. explained that muscles become conditioned to acting a certain way during a specific activity, thereby making a transition to another activity increase muscle effort and sometimes trigger fatigue. In the case of the transition from running to walking, Nigg et al. suggested that “a reduction of muscle activity before heel strike is associated with fatigue.” Since walking implies a reduction of muscle activity from running, it can be deduced that a decrease in locomotion

speed (transitioning from running to walking) can also trigger fatigue due to the effort of pulling away from the previous “muscle tuning” experienced during running.

Thus, in light of Segers et al. (2006), it may be concluded that the heel material directly influences muscle activation and the subsequent oxygen consumption. One can therefore expect a significant change in muscle activity during the experiment performed in this thesis. However, one major difference from the studies of Nigg et al. (2003) and Segers et al. (2006) is that the task assigned to the subjects was to *run* in various heel and sole conditions, whereas in this thesis, participants were asked to *walk* at different speeds and in different heel conditions. Nevertheless, Nigg et al. stated that the phenomena studied and reported should provide insight into understanding “many aspects of human locomotion, including work, performance, fatigue, and possible injuries,” thus making their research and the corresponding results relevant for studying the locomotion mode of walking in various heel conditions.

2.4. Consequences of Inappropriate Equipment

Research regarding the ergonomics of sports shoes is a relatively new phenomenon. Reilly (2009) wrote a historical analysis of the running shoes market, whereupon sports shoes companies became attentive to safety issues in the 1970s-1980s explosion in the popularity of track-and-field events. Before that, runners carried lightweight spike shoes for the track, as well as heavier shoes to exercise outside the track. Manufacturers then introduced new materials based on “ergonomics criteria that prioritized comfort, safety, and performance” (Reilly, 2009), designed by Dr. Peter Cavanagh.

A personal interview with Kaitlin Smith (2007), an athletic trainer at Louisiana State University, was conducted on relative subject matters. Smith stated that among LSU track and field athletes, the most common injuries that resulted from wearing cleats, under normal circumstances (properly worn and fitted, and used only during the event), were turf toe, a sprain

of the ligaments in the big toe, and plantar fasciitis, the inflammation of the interface between the fascia and the first layer of intrinsic muscles. After returning from a period that excluded training in their spikes, Smith notes that the athletes complained a lot about overall soreness. Some examples were blisters, metatarsal bruising, and a tight Achilles or calf muscle. She further commented that the worst danger in over-use of cleats would be chronic Achilles tightness, shortening of the calf muscles, tight hamstring muscles, low back pain, associated foot soreness, and an altered running stride.

A level spike shoe to reduce some, if not all, of these risks was suggested. Smith replied: “A leveling of the heel increases heel striking, therefore making the runners slower. However, during times where the athletes do not need to be in spikes, the level cleat would benefit them. In conjunction with the level cleat, communication with the coaching staff of any problems is key, especially with the dangers of over-use of spikes.” According to Smith, the athletes would be interested in the use of a level cleat with a removable heel. This would not only cause an easy switch from walking footwear to competition footwear, but this would also reduce the number of various types of footwear that the athletes carry.

2.5. Electromyography (EMG)

2.5.1. Definition and Explanation

EMG is the use of various electronic devices that use volts to measure muscle activity in the body. It aims at measuring a specific muscle’s activity by interpreting electrophysiological signals. EMG is used in various industries, such as a) medicine, b) sports medicine and kinesiology, c) work physiology, and d) biomechanics, to provide “objective evaluation of the musculoskeletal stress” (Lee et al., 1986). Further, EMG monitors physiological parameters for the generation of ergonomic or medical solutions to problems related to muscle pain, fatigue, and abnormal / inappropriate activity (Solomonow et al., 2003).

There are several types of EMG systems, depending on the user's needs in regard to area / discipline. One of the most commonly used in biomechanics is surface EMG. Surface EMG is characterized by the use of adhesive electrodes (called non-invasive) that are placed on the skin that covers the muscle of interest. Other types of equipment include wire and needle electrodes that are inserted through the skin to the muscle of interest (Nimbarte, 2009).

For this study, surface EMG was employed (see Figure 5.7). A wireless, battery-operated device was used to provide the flexibility and freedom of movement needed for the participants to complete the walking drills (lightweight and transmission up to 250 m). Participants were tested with a Myomonitor IV Wireless Transmission and Datalogging system by Delsys.

Results of EMG testing are displayed in a graph called an electromyogram, sometimes called an EMG graph. Figure 2.7 provide examples of typical electromyograms:

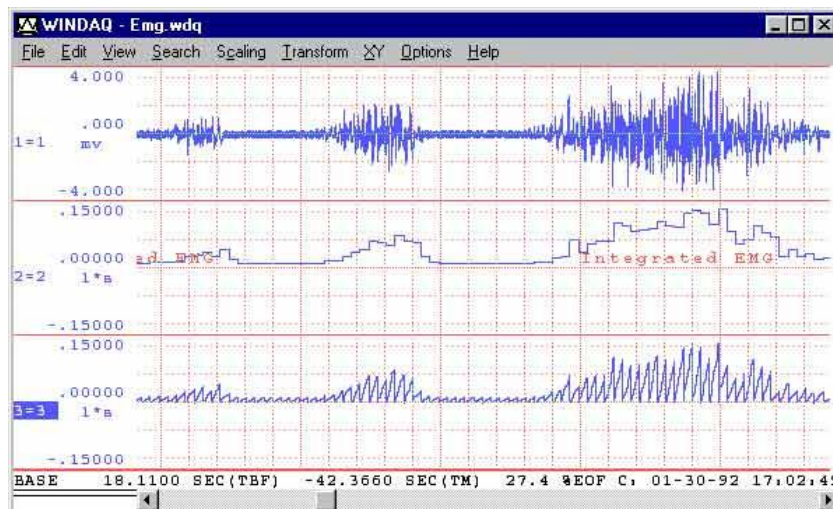


Figure 2.7: Electromyogram - Example 1

Source: Weimer, 2009

Using a software such as Excel, an electromyogram's appearance can be modified by adding comments, legends, or titles. To compile the data, to average it, or to compare different

subjects' information, EMG data must be normalized. Sommerich et al. (2000) provide an analytical review of the use of surface EMG. They present normalization as the process used “to address variation introduced in the measurement process by differences in electrode spacing, anatomical factors, and variation in electrode placement in order to facilitate comparisons between different muscles and individual subjects.” Failure to proceed to normalization can affect the reliability of the results because the amplitude's percentage will include exertion movement that are irrelevant to the study.

Weimer (2009) explained EMG waveform interpretation, stating that a solitary graph does not mean much. However, when compared to another one, a standard case or a different condition undergone by the same subject / patient / participant, an electromyogram reveals “which case represents the greatest amount of work done by the muscle”.

2.5.2. EMG Applications in Biomechanics, Work Physiology, and Kinesiology

Nigg et al. (2003) provided an example of EMG application for ergonomic purposes. The study used electromyography to identify muscle activity for selected muscles, including medial gastrocnemius and tibialis anterior, with 20 participants performing drills in two differently-heeled running shoes. Similar to the experiment conducted in this thesis, the data collected “were compared for the different conditions using an ANOVA ($\alpha = 0.05$).” The same testing procedure was used in this study, within a similar controlled environment, with the exception of the following major elements:

- Rather than changing shoes, the participants kept the same shoes, yet exchanged the removable heel for one of the drills.
- Body maps were also used to complement the objective scientific EMG data with the subjective ratings, to indicate how the subject experienced the heel/without heel change in terms of human pain and discomfort.

2.6. Previous Use of Removable Heels

The concept of a shoe with a removable heel is not a new invention per se. Several inventors have examined this option and even submitted patents in the past, as early as the 1880s. The earliest patents promoted removable heels, because heels historically represent the fastest worn part of a shoe. Replacing a heel is thus less expensive than buying a whole new pair of shoes. Later on, the literature indicates a certain diversity in the design and use of removable heels, and the concept has been adapted and adopted in various areas, including the arena of sports.

2.6.1. Orthopedics

Orthopedic heel elevations are common practice. They usually consist in adding a prosthesis inside the shoe. People with pathologically asymmetrical leg length use the prosthesis to even leg length and restore balance in their hips and back. The device is usually small enough to fit inside the shoe in a virtually invisible manner.

Orchard et al. (1996) used a similar device with long-distance track athletes who suffer from iliotibial band friction syndrome (ITBFS) (see Figure 2.1). This type of injury is common among distance runners (McGrath and Finch, 1996), because of their recurrent knee flexion to the angular zone in which friction occurs, that is, 30° (whereas not only do sprinters flex their knees beyond the impingement zone, but the flexion moment spent in the friction zone is much shorter, since they run faster than distance runners do). The study consisted in a cadaveric anatomical examination of 11 normal knees and a video analysis of 9 distance runners suffering from ITBFS who ran on a treadmill for 2 minutes twice. For this dynamic section of the study, the subjects ran once with normal running shoes, and then ran for a second time with a 50 mm heel raise.

Despite the methodological resemblance between the biomechanical model proposed in Orchard et al.'s (1996) study and the removable heel proposed in this thesis, the purposes differ in that the 50 mm heel elevation device was designed for etiological evaluation and assessment of ITBFS. Indeed, the model aimed at identifying angular patterns in the gait of distance runners with ITBFS, not at correcting these patterns, whereas the removable heel evaluated in this thesis is proposed as a solution to prevent running injuries among sprint runners.

2.6.2. Bowling

Famolare (1994) designed a bowling shoe, in which the removable heel functions to “vary the friction of the bowling shoe sole on the bowling surface.” This shoe is characterized by a hook and pile fastener that makes a sliding pad.

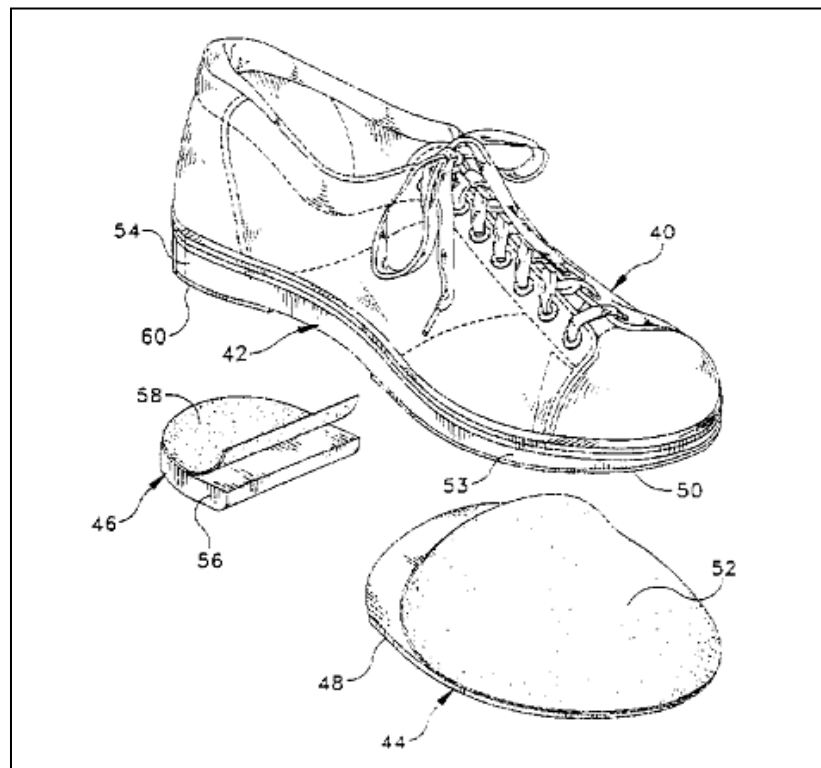


Figure 2.8: Bowling Shoe with Famolare's Separate Heel and Sole Pad
Source: Famolare (1994)

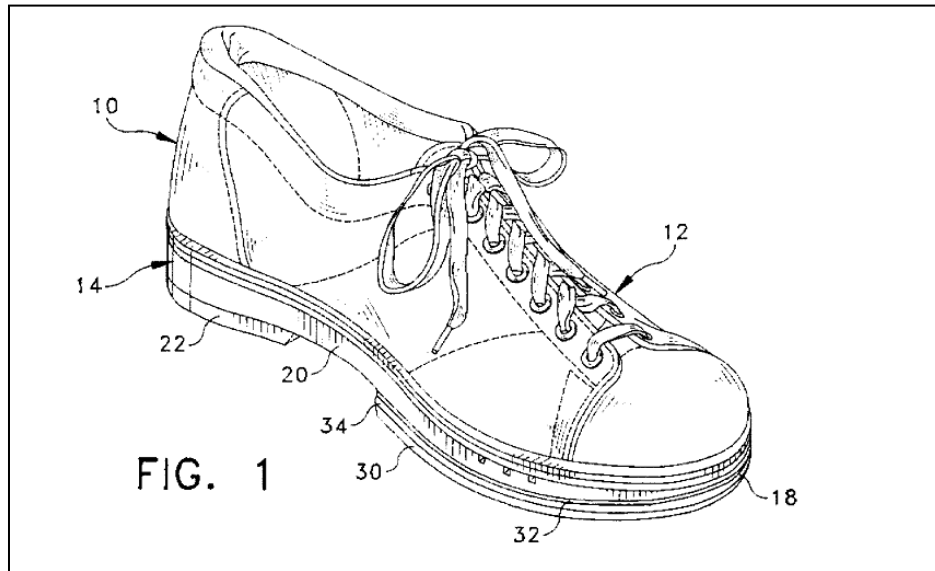


Figure 2.9: Bowling Shoe with Attached Sole Pad and Heel
Source: Famolare (1994)

As illustrated in Figures 2.8 and 2.9, the attachment proposed by Famolare is different from the removable heel evaluated in this study, in that it has a sliding mechanism, rather than being screwed to the sole. Moreover, the bowling shoe is modified by increasing the height of the sole together with that of the heel. In contrast, the track-and-field spike shoes considered in this thesis were modified exclusively at the heel area, since the purpose is to establish a balance of the foot, which is lost in the use of the original curved, spiked, track shoe.

The sliding mechanism is commendable in that it requires less effort – and less time – to install than the time required to screw a removable heel underneath a track spike shoe. However, this action requires a perfect match in dimensions, whereas the screw-on removable heel evaluated here can adapt to different models of spike shoes.

2.6.3. Basketball

In 1996, Lombardino proposed a removable heel for athletic shoes. Even though this invention represents the closest model to the modified spike shoes evaluated in this thesis, one major difference is that Lombardino designed a shoe with two heel options. In other words, the athlete can choose between two shapes of heels to fit the activity, whether it is plyometric training or general use. Another difference is that these shoes are better suited for basketball practice, as shown in Figures 2.10 through 2.12, whereas this thesis evaluates a shoe specifically designed for track.

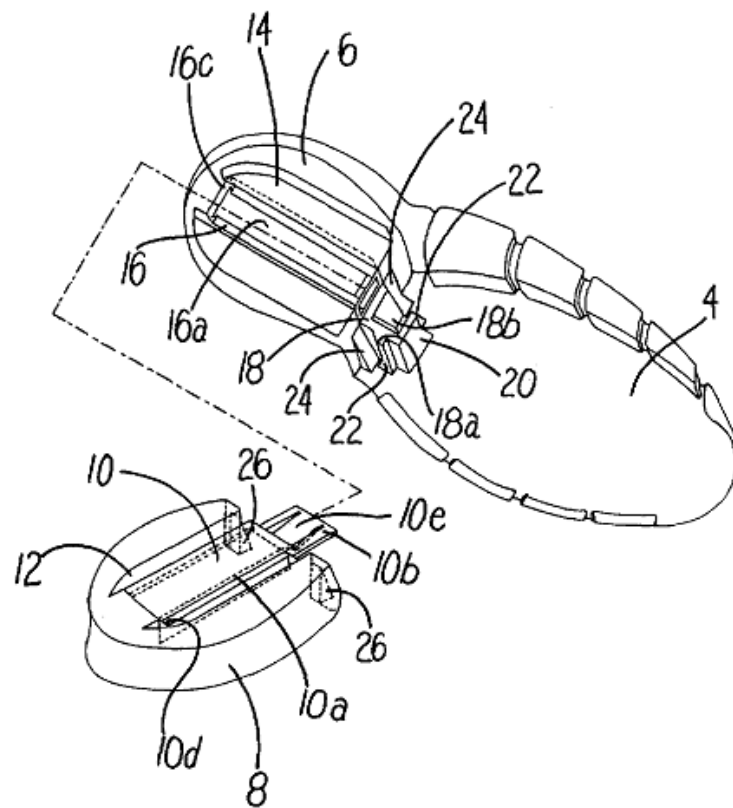


Figure 2.10: View of Lombardino's Shoe Sole with Original Heel Removed

Source: Lombardino (1996)

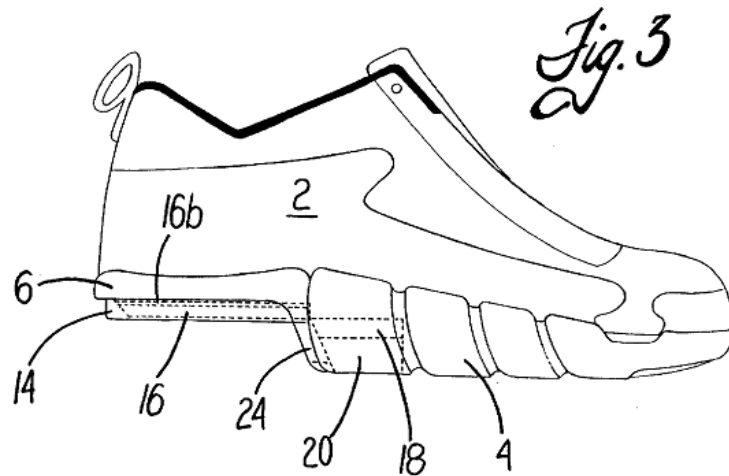


Figure 2.11: Profile View of Lombardino's Shoe with No Heel Attachment
Source: Lombardino (1996)

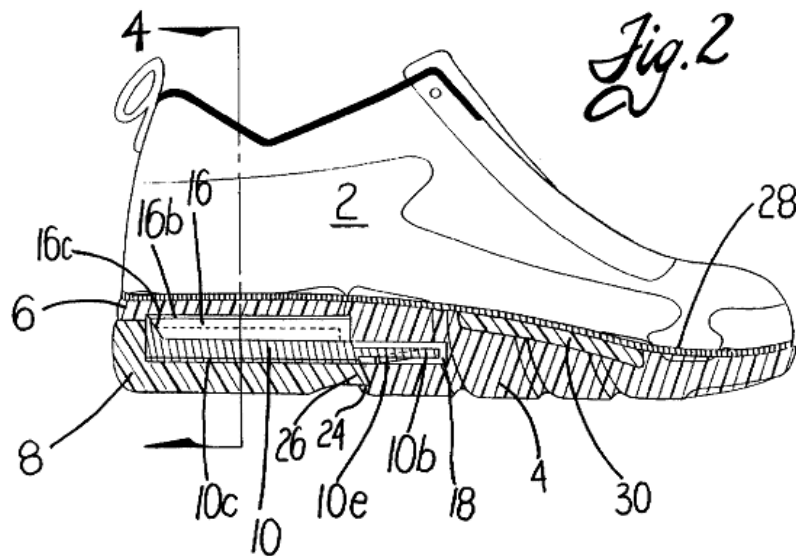


Figure 2.12: View of Lombardino's Shoe with New Heel Attachment
Source: Lombardino (1996)

The above figures display an attachment that slides in and locks at the sole. Again, this marks another difference with the removable heel of the track spike shoe.

2.6.4. Ladies' High Heel Shoes with Removable Heels

Numerous patents have been filed for such shoes. This feature is popular as it enables ladies to wear shoes that combine the aesthetics and professionalism of high heels, while relieving them from the resulting discomfort when not needed. Koehl et al. (1989), Schneider-Levy (2001), and Rodriguez Colon (1994) provide typical examples of studies of removable high heel characteristics.

Koehl et al. (1989) designed a heel that could be removed in case the original heel is damaged, or if the owner wants to change the shape and color of the heel, as illustrated by the drawing they included in the patent:

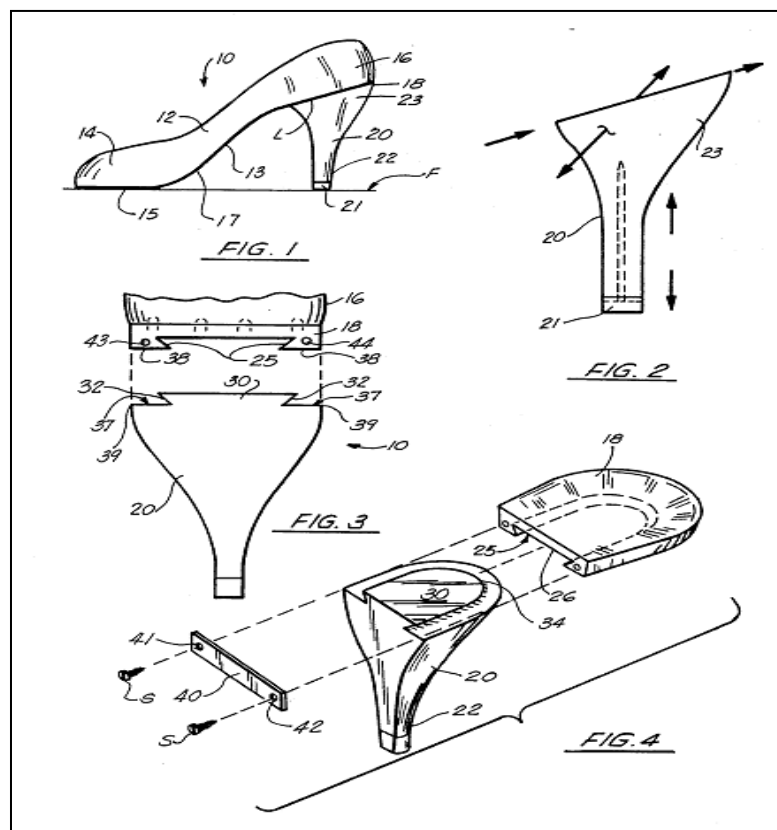


Figure 2.13: Shoe construction with self-seating removable heel

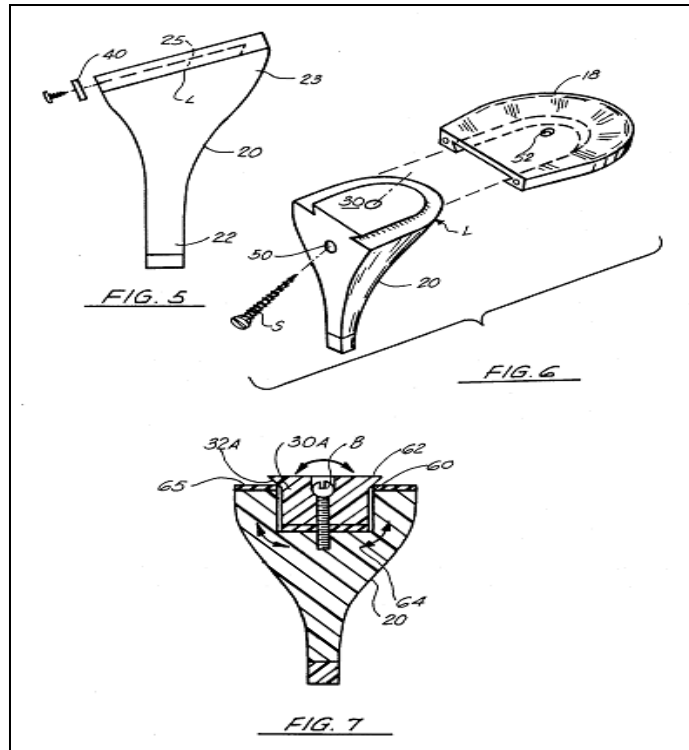


Figure 2.14: Shoe construction with self-seating removable heel_2

Source: Koehl et al. (1989)

As one can see on sections 5 and 6 of Figure 2.14, the heel attaches to an adapter (number 18) that connect the heel to various types of removable heels. One of the shortcomings of such a system is that the shoe is not designed to adapt to different heights of heel. Nevertheless, this is extremely useful for aesthetic, versatility purposes, and could help those who cannot wear thin high heels, such as people with diabetes, as it creates minimal pressure points, where all the body weight is forced (Ahroni and Scheffler, 2006).

High heels have been found responsible for serious foot and leg conditions, including pain, instability / imbalance, deformity, and hampered mobility (Dawson et al., 2002; Menz and Morris, 2005). Problems with high heel shoes are not always presently visible among younger ladies, but problems do tend to manifest later on, as seen in research among older women who wore high heels in the past. Dawson et al. (2002) studied the origin of problems of osteoarthritis

of the knee among older women (age 50-70). The results of their survey showed that all women with the condition had worn heels over many years. Although the exact height of the high heel hasn't been conclusively found to be a determining factor in this etiological analysis, additional studies such as Menz and Morris (2005) show the effects of wearing high heels in older people.

Menz and Morris state that repetitively wearing shoes with heels higher than 25 mm causes bunion and big toe inward deviation (hallux valgus) and other callosities (note that such data helps set design limitations on the height of the removable heel assessed in this thesis). Nyska et al. (1996) experimented by treadmill with women walking in high heels versus women walking in low heels. The experiment indicated that such a phenomenon is due to the high total weight-load on the forefoot, having shifted from the hindfoot while wearing the high heel shoe.

To help remedy this problem, Rodriguez Colon (1994) submitted a patent for a low-heel shoe that transforms into a high-heel one. This design provides more flexibility than that of Koehl et al., in the sense that his invention enables the owner of the shoe to alternate the height of her heels.

Since high heel soles are curved, it seems that removing the heel should trigger an imbalance and unevenness of the foot during stance, which would impose stress on the Achilles tendon similar to that of walking in sprint spike shoes without a removable heel. With this rationale, inventors / designers such as Rodriguez Colon apply the removable heel to shoes manufactured in flexible material, or adapt a shank to change the shape of the shoe, thus enabling the toes to lay flat during stance, as the heel is removed. Such a technique allows the foot to change to an appropriate, more comfortable position. The following figures provide an illustration of the shank mechanism as it is used to safely modify the angle of the sole.

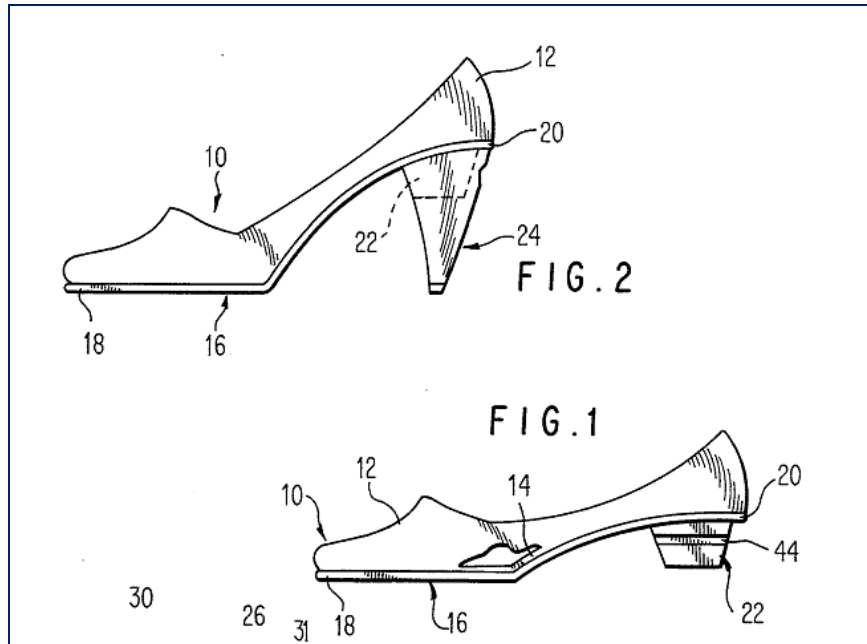


Figure 2.15: Side view of shoe with high heel and low heel
Source: Rodriguez Colon (1994)

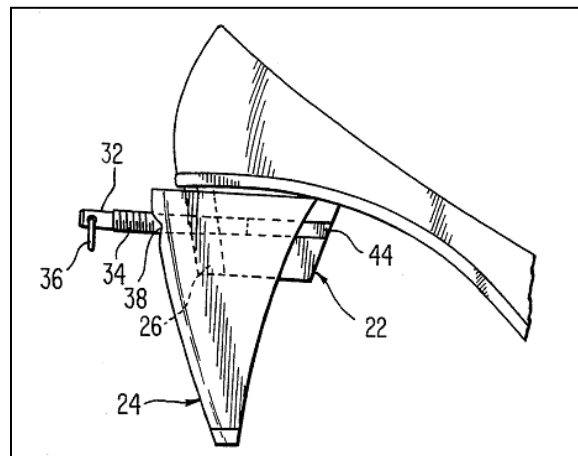


Figure 2.16: The high heel removal process
Source: Rodriguez Colon (1994)

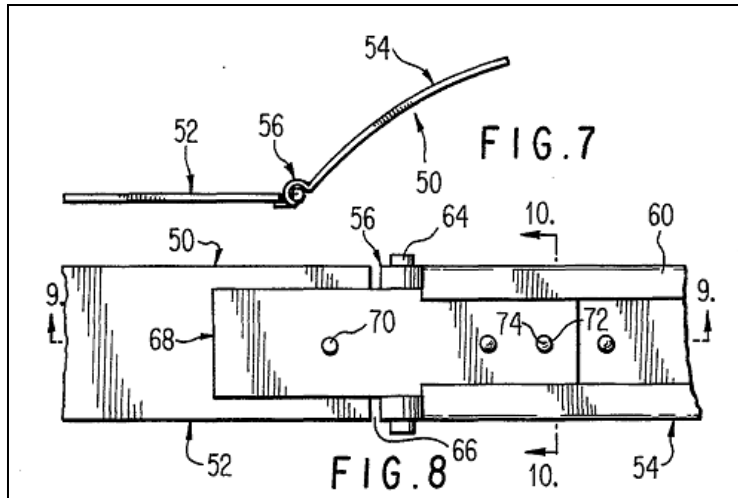


Figure 2.17: Side and top views of the adjustable shank
Source: Rodriguez Colon (1994)

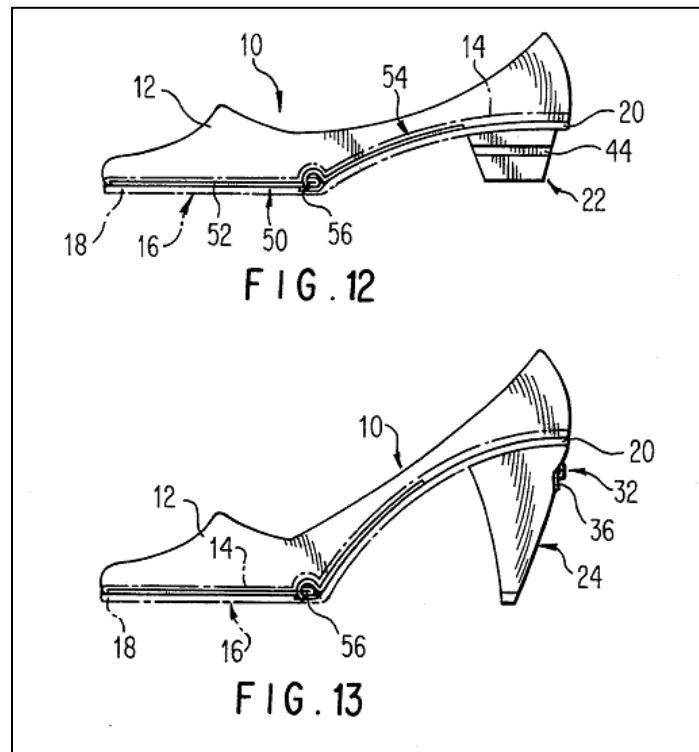


Figure 2.18: View of shoe with low and high heel when adjusted with the adjustable shank
Source: Rodriguez Colon (1994)

Figures 2.15 through 2.18 display the different features of the convertible shoe. By principle and design, it is quite comparable to the track spike shoe evaluated in this study, though the goal, in essence, becomes the inverse of the convertible high heel shoe design. In effect, this thesis assesses a shoe with a biomechanical modification aimed to remedy problems caused by a low-positioned heel, whereas Rodriguez Colon's invention was intended to remedy problems caused by a high-positioned heel.

2.7 Summary

Thus, one can summarize the literature on track-and-field and footwear and the relatable scientific research in the following terms:

- Excessive stress related to inappropriate wear of track spike shoes, such as wearing them during walking despite the fact that they are designed for running, causes inflammation of heels, toes, shins, Achilles tendons, cartilage under the kneecaps, and thighs (McGrath and Finch, 1996). Almost all athletes develop problems in these areas, from minor pain to more serious injuries, as they wear their shoes over 12 hours a week, inclusive of walks between workouts and competition (Elliott, 2007; Runners' Lane, 2005; Smith, 2007).
- Definitions and explanations of walking and running techniques show a contrast between the position of the feet when wearing spike shoes and the position of the feet needed for healthy walking, which, in turn, reveals the need for a heel lift to relieve running injuries.
- For instance, tibialis anterior fatigue among track-and-field runners was demonstrated to frequently be due to switching from plantar flexion (running) to

walking. That is, the shock resulting from the heel contact shows a need to reduce heel pressure (Tortora, 2002; Donley and Leyes, 2001; Segers et al., 2006).

- Electromyography is an appropriate device for identifying ergonomic problems and generating solutions, along with statistical evaluation of EMG data to prove hypotheses (Lee et al., 1986; Solomonow et al., 2003; Delsys Inc., 2009; Nigg et al., 2003).
- Removable heels have been shown to provide relief in various sports and for everyday use (Famolare, 1994; Lombardino, 1996; Koehl et al., 1989; Schneider-Levy, 2001; Rodriguez Colon, 1994).

Literature research reveals the effects and origins of common running injuries that affect track and field athletes. These problems are both internal (runner's gait, frequency of exercise, and category, i.e., long/mid distance) and external (shoes). In regard to the factors mentioned in causing runners' injuries, the literature tends to coincide with the notion of a spike shoe with a removable as an a priori efficient solution to the extreme and repetitive dorsiflexion that characterizes mid and long distance running techniques.

3. RATIONALE

The rationale behind this project is that by allowing the runner's feet to remain at an even level, a removable heel helps avoid the foot's excessive abduction upward when walking before and after practice or competition.

Based on Alangari (2006) and measurements from the Nike spike shoes with and without the removable heel, the regular spike shoe elevates the toes and the front half of the foot (see Figure 1.1). Such elevation alters phases 2 and 3 of the walking stance, as it increases the angle of the toes to about 25 degrees. Thus, phases 2 and 3 exert an enormous stretch on the Achilles tendon, as well as stress on extrinsic foot muscles. On the other hand, when wearing the spike shoes with a removable heel, the toes are still slightly elevated, but as the heel restores some of the balance lost to this elevation, the elevation is about 10 degrees less than when the heel is not present (see Figure 5.1). Therefore, Achilles tendon stretch and stress on extrinsic foot muscles is reduced in phases 2 and 3. Actually, when wearing the heel, only phase 2 differs from normal walking (see Figure 2.2) after balance is restored with the removable heel.

The removable heel is meant to offer the flexibility required to eliminate extensive stress. Effectively, this feature will reduce pressure from the *exterior digitorum longus* (the in-step part of the foot), as well as from the backward part of the *abductor digitii*, thereby avoiding injuries and inflammations such as *Achilles tendonitis*, *calcaneal apophysitis*, and *stress fractures of the metatarsals*. Furthermore, the removable heel would relieve the stress and pressure from the *patella* (at the lower section of what is commonly called the "knee-cap"), as well as from the *anterior tibial* area (commonly called the shin), and the *posterial tibial* area (the calf). By doing so, a heel that may be removed, according to the track-and-field activity, would help prevent *tibial compartment syndromes* and *patello-femoral syndromes*, discomforts so common among runners that have prevented many of them from performing to the fullest capability.

4. OBJECTIVES

The purpose of this study is to evaluate a shoe that mid-distance and short-distance runners may use when moving to and from the track before and/or after practice or competition. The focus and baseline is that though athletes do not always have the time to change shoes immediately after practice or competition, they need shoes that are appropriate for the activity being performed, whether it is running or walking. Consequently, the keywords to the biomechanically modified spike shoes are *flexibility* and *adaptability*.

The objectives can therefore be listed as such:

- Decrease the risk of injury among track athletes, which implies protecting their health and optimizing their performance potential
- Increase foot, ankle, and leg comfort
- Help runners save time by eliminating the need to change shoes after performance
- Help them save energy and comfort by reducing the quantity of shoes they carry

This means that the kind of spike shoe runners may wear is one flexible enough to be adjusted in order to adapt to and enhance each runner's performance. In other words, the shoe should adapt to the runner, not the other way around.

5. METHODOLOGY AND PROCEDURES

5.1. Participants

Nine healthy participants from a variety of backgrounds were selected:

- 3 long and mid-distance runners (all males)
- 3 sprinters (all males)
- 3 non-athlete subjects who exercise regularly (two males and one female)

All participants are between the ages of 19 and 29 years old, with a mean age of 25.2 years and a standard deviation of 3.07, a mean stature of 175.0 cm and a standard deviation of 7.11, and a mean whole body mass of 80.5 kg and a standard deviation of 6.50. They were selected based on different physiological factors and physical abilities to observe the effects of using regular spike shoes, as well as to ensure that the modified shoe accommodates the majority of its users, regardless of gender. The following table provides details for each participant:

Table 5.1: Participant running profile

Participant	Athlete	Specialty	Age (in years)	Height (in cm)	Weight (in kg)	Right or left-handed
1	✓	Sprint	27	180.3	86.8	R
2	✓	Distance	29	165.1	76.4	R
3		None	27	172.7	72.7	R
4		None	24	185.4	82.7	L
5		None	24	170.2	80.9	L
6	✓	Sprint	23	177.8	89.1	R
7	✓	Sprint	19	165.1	69.5	R
8	✓	Distance	26	177.8	81.4	R
9	✓	Distance	28	180.3	85.0	R

The diversity of backgrounds, including gender, is intended to demonstrate the difference of impact of the removable heel according to athletic history, as well as to provide comparative ground to sprinter participants, the group targeted by the biomechanical modification of the track shoe. While the electromyographic study of Zeller et al. (2003) indicate that muscle activity generates a heavier strain in women than it does in men, this experiment shows that women, despite their distinct gait, suffer discomfort when walking in regular spike shoes, and that they can benefit from a removable heel. Further series of experiment as a continuation of this thesis could assess the benefits of the heel according to gender.

On the other hand, Lynch et al. (1998) show that it is important to select participants of the same age group for data consistency, as their weight training program reported that age brings about loss of muscle mass and muscle function. Therefore, delimiting the participants' age is essential to ensure that muscle activity data remains untainted by such type of non-pathological muscle condition.

5.2. Equipment / Apparatus

- Spike shoes with removable heel
- Screwdriver
- Treadmill (Nautilus T914 Commercial Treadmill)
- EMG equipment: Myomonitor IV Wireless and connected computer
- Statistics 9 software
- Stop watch

5.3. Task Design

The participants were asked to walk on a treadmill, wearing the original shoes for a first session and biomechanically modified shoes for a second, comparative, session. No preliminary trimming or warm-up was implemented except the fact that participants walked on the treadmill

for one to two minutes to get accustomed to the equipment. The treadmill was set to two different speeds, 2 mph and 3 mph, which the literature (Gross and Shi, 2001) and LSU track athletes' testimonials report as speeds at which athletes are comfortable walking before or after running in general, while the EMG apparatus was set to measure specific muscle activity in all sessions. Each session lasted one minute, with a lapse of 2 minutes in between. Participants were then asked to rate their pain or discomfort on their body map areas 20 to 27 on a scale from 0 to 10 (see Figure 5.11, page 58).

5.3.1. Installation of the Heel

A heel compatible with a men's size 10 Nike pair of spikes was designed and built. The plastic heel is of a texture flexible enough to adjust to most walking techniques. With the help of a professional shoemaker, Velcro fabric was sewn on to the sole of the spike and the top of the removable heel, while holes were drilled to fit with the spikes' screws. The following figures display pictures of the modified track spike with a removable heel. There are pictures of the track spike with and without the heel. There is also a comparison with one track spike with the heel on and one without, so as to provide a visual notion of the appearance of the shoe once altered with a removable heel.



Figure 5.1: Spike shoe with removable heel - side view

The following picture provides a comparative view of the alteration.



Figure 5.2: Spike shoes: heel v. no heel - rear view

5.3.2. EMG Experiment

Electromyography measures a specific muscle's activity by interpreting electrophysiological signals. Its applications include, but are not limited to: biomechanics, work physiology, and kinesiology. EMG calculations evaluate muscle activity, fatigue, and stress during the entire duration of the exercise. Delsys Inc. (2009) explains the functioning process and equipment components.

- Software CD: once installed, it allows the computer to interpret data received from the main EMG unit.
- Main unit: it powers the body-worn EMG Sensors and digitizes each sensor's signal. The data are sent over the wireless local area network (WLAN) to the host

computer for real-time display and storage. The touch screen panel allows the user to control and maneuver the experiment, along with On/Off and Reset buttons and LCD Backlight. An amber LED helps obtain feedback regarding battery recharging. The top of the Main Unit has connectors for the Docking Module and the Input Module Cables, but both connections may not be established simultaneously due to safety reasons.



Figure 5.3: Myomonitor Main Unit
Source: Delsys.Inc (2009)

- DE-2.3 EMG Sensor: housed in polycarbonate, it subtracts EMG potentials detected at two distinct locations on the surface of the skin directly above an active muscle. EMG potentials from the electrode reflect the electric potential of a neutral site located away from the EMG muscle source, with a 20-450 Hz bandwidth:



Figure 5.4: DE-2.3 Single Differential Surface EMG Sensor
Source: Delsys, Inc. (2009)

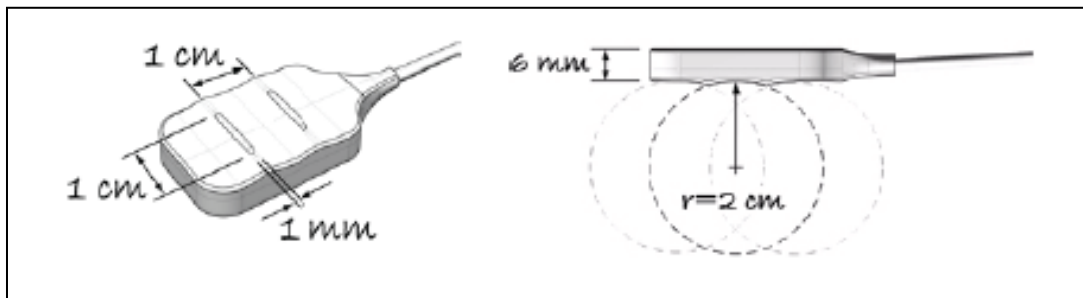


Figure 5.5: DE Sensor Geometry
Source: Delsys, Inc. (2009)

Delsys Inc. (2009) further explains: “The surface EMG signal is the result of the potential difference between V1 and V2 on the skin surface [...] The curved enclosure geometry is designed to maximize skin contact and adhesion while minimizing the negative effects of sweat during vigorous activities,” thereby ensuring accuracy in data collection during exercise.

- Docking Module
- 2 Input Module (1/2) 6 1GB SD Memory Card: connects with up to 8 sensors and with the electrodes’ cables. The memory card stores the EMG data for future use and reference. Users may clip it on a belt or lumbar pack.



Figure 5.6: Input Module

Source: Delsys, Inc. (2009)

- 3 Sensors (8/16) 7 Stylus
- 4 Power Supply 8 Input Module Cable (1/2): connects the Input Module with the Main Unit, supplying power to the active EMG Sensors and transmitting EMG data back to the Main Unit (Delsys, Inc, 2009).
- D-Link WUA-1340 Wireless G USB Adapter: connects the EMG apparatus with the computer without the need of a cable, providing the participant with freedom of movement during exercise.

EMG pads (electrodes) are placed on the participant's left tibialis anterior and the left medial gastrocnemius, assuming walking is a relatively symmetric task. The input module is clipped on the participant's belt, as illustrated by the following photographs:

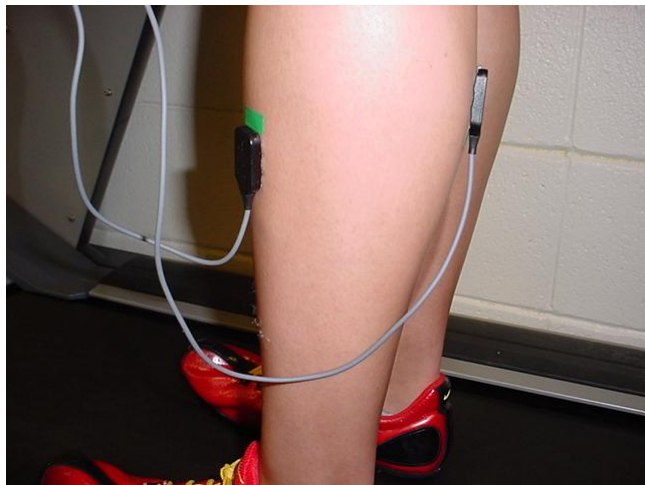


Figure 5.7: EMG alignment

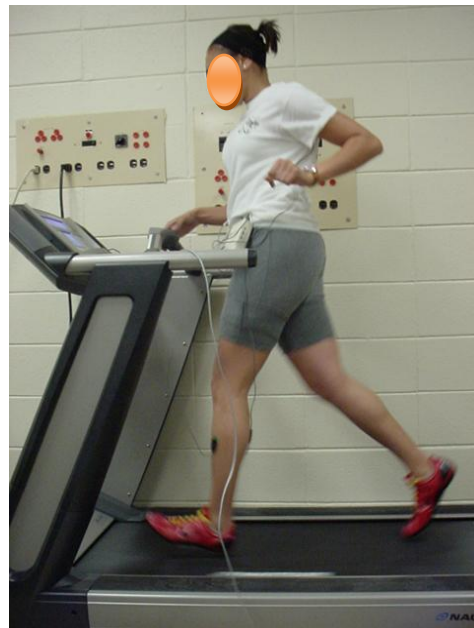


Figure 5.8: Subject performing during treadmill experiment

Figure 5.9 shows that the electrodes must be parallel to the muscle fibers for accurate reception of the signals from muscle activity during exercise (Figure 5.8). The next diagram depicts the alignment with the muscle under the skin:

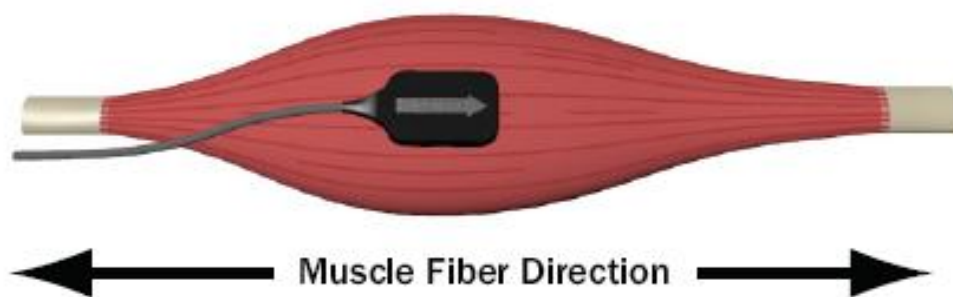


Figure 5.9: EMG Sensor orientation with respect to the muscle fibers
Source: Delsys, Inc. (2009)

A key defining characteristic of the digital signal is its sampling rate, or sample rate. This refers to the frequency of signal measurement during the experiment. The more frequently the signal is sampled, the more accurate is its interpretation. However, the higher the sampling rate, the more storage memory is needed. EMG results are displayed in the form of an electromyogram, a graph that enables the user to interpret data from the electric signals. For this thesis, a sampling rate of 500 Hz was used, for a recording duration of one minute for each walking drill.

The next step to interpreting EMG data is to normalize it by demeaning the EMG signal, rectifying the full-wave, normalizing according the highest reading, and averaging it to the mean average value (MAV). The MAV therefore constitutes the type of data outcome. EMG data can be particularly helpful when translating the electromyogram into an Excel graph.

5.3.3. Body Maps

In addition, the discomfort the subjects experience is specified by using body map parts (see Figure 5.10). After each test, each participant was asked to verbally number the level of pain they felt on areas 20 to 27 (knees, calves, ankles, and feet), which correspond to the extrinsic foot muscles tested and to areas where athletes commonly complain of pain or discomfort. Discomfort is described as the exertion level on Borg's ergonomic scale, that is, a scale from 0 to 10, 0 being no discomfort at all, at 10 being almost absolutely unbearable. Figure 5.11 provides a legend for the quantification of the discomfort felt.

The Borg CR-10 scale, named after the tool developed by Gunnar Borg (1998) to measure intensity of experience in the field of perceived exertion, measures the intensity of the sensation perceived. It is category-ratio scaling that combines Steven's ratio scaling, that is, the "interval scale in which distances are stated with respect to a rational zero rather than with

respect to, for example, the mean" (Nunnally, 1967), and psychophysical category scaling (Galanter and Jacobs, 1972).

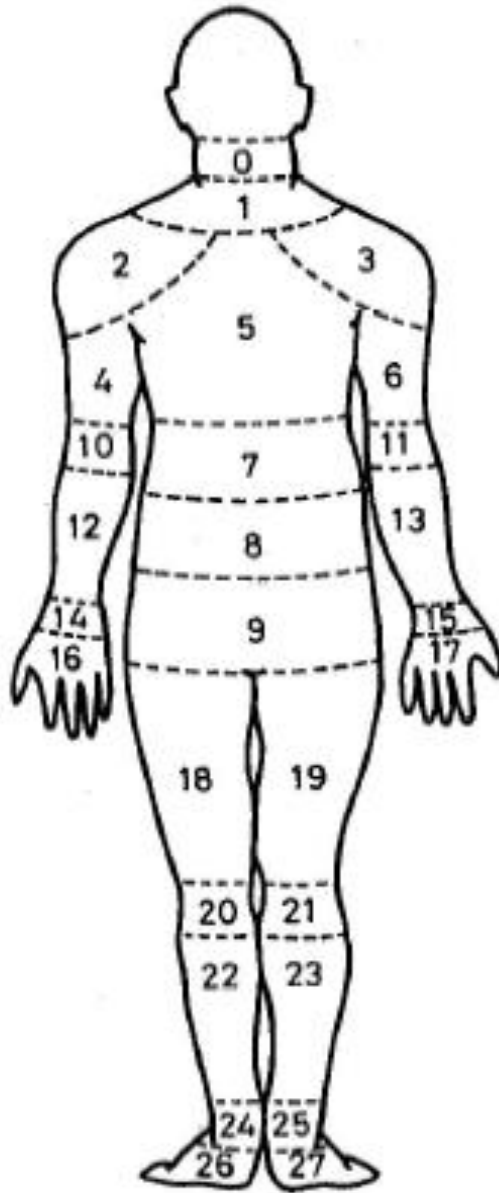


Figure 5.10: Body map sections
Source: Wilson and Corlett (1995)

<i>Borg CR-10 Scale</i>	
0	Nothing at all
0.5	Extremely weak (hardly noticeable)
1	Very weak
2	Weak (light)
3	Moderate
4	
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong (almost maximal)
• Maximal	

Figure 5.11: Borg's scale for fatigue measurement

Source: Dederling et. al. (1999)

5.4. Nature of the Data

The data obtained from the EMG experiment shows the difference in voltage resulting from muscle activity. The data obtained from the body maps, though subjective, is an assessment of the comfort the removable heel offers the athlete. The comfort rates disclosed by the subjects are as essential as the more technology-based EMG, in the sense that by assessing pain and discomfort, they provide a sense of the athlete's ability to perform at maximum capacity, once freed from the discomfort hinderance.

5.5. Hypothesis: Statement and Parameters

5.5.1. Hypothesis Testing

Experimental design:

- Dependent variables: normalized EMG data readings for gastrocnemius and tibialis anterior
- Independent variables: presence or absence of heel and 2 levels of walking speed, that is, either walking at 2 mph or 3 mph for each of the muscles tested.

For each case, the null statistical hypothesis, denoted H_0 , refers to the absence of significant change. The tested alternative hypothesis, denoted H_1 , is tested as the significant change desired to be demonstrated.

Hypothesis 1:

H_0 : There is no significant change in EMG reading data from walking without heels to walking with heels.

H_1 : There is a significant muscle activity change as revealed by the EMG reading, from walking without heels to walking with heels.

Hypothesis 2:

H_0 : There is no significant change in EMG activity when speed changes from 2mph to 3mph.

H_1 : There is significant change in EMG activity when speed changes from 2mph to 3mph.

Hypothesis 3:

H_0 : The mean average of discomfort is the same for all participants before and after adding the heel.

H_1 : The mean average of discomfort after adding the heel is not equal to the mean average of discomfort before adding the heel.

5.5.2. Statistical Analysis

Regarding the first and second hypotheses, ANOVA calculations reveal the variance – the difference in muscle activity as shown by the EMG when the subject uses the heel vs. when the subject does not – and thus statistically analyzes the effect of walking speed and presence or absence of heel on the dependent variables. The p value is calculated statistically, using ANOVA with the EMG data collected. Based on the p value obtained from the EMG data collected regarding the activity of each subject's gastrocnemius and tibialis anterior muscles, the null hypothesis is rejected. The rejection region is the range of p values greater than 0.05. Subsequently, a significant change is considered to correspond to a p value lesser than or equal to 0.05, and the alternative hypothesis will be correct, if the p value is lesser than or equal to 0.05.

The third hypothesis was tested through SAS 9.1 English version. A one-way ANOVA test was used to identify any significant difference in the level of discomfort before and after adding the heel during the experiment, with a p value establishing the rejection criteria at 0.05. The following equation determined the test results:

$$Y_{ijk} = \hat{\mu} + S_i + A_i + T_k + A_{tjk} + E_{ijk}$$

For which

- Y_{ijk} represents the mean for each area
- $\hat{\mu}$ represents the overall mean
- A represents the body map area
- T represents the time (before and after)
- S represents the individual participant
- E represents the error

- $i=1,2,\dots,9$ represents the number of participants
- $j=1,2,3,4$ represents the different body areas
- $k=1,2$ where 1=before adding the heel and 2=after adding the heel

5.5.3. Steps for Data Processing

1. EMG data was normalized, that is, made to fit into a bell curve, through the following steps:
 1. Demeaning the EMG signal
 2. Proceeding to full-wave rectification
 3. Normalizing with respect to the maximum (highest EMG reading)
 4. Averaging to determine the mean absolute value (MAV)
2. The root mean square was calculated in an Excel spreadsheet format
3. The root mean square for each subject and each activity was synthesized and analyzed.
4. Statistical analysis: Statistix 9.0 and SAS 9.1 softwares were used to analyze the variance of muscle activity in the gastrocnemius and tibialis anterior with heels and without heels, as well as the discomfort difference in all areas of the body map before and after installation of heel.

6. RESULTS

6.1. EMG

Differences in EMG values from values reveal a noticeable change in muscle activity from walking without the removable heel to walking with it, as shown in the following table:

Table 6.1: Average EMG values			
<u>EMG VALUES ACCORDING TO SPEED</u>			
	Locomotion	<u>AVERAGE EMG VALUE</u>	
		Tibialis	Gastrocnemius
Without Heel	2mph	<u>4.33E-04v</u>	<u>2.10E-04v</u>
With Heel	2mph	<u>3.40E-04v</u>	<u>1.61E-04v</u>
	Locomotion	<u>AVERAGE EMG VALUE</u>	
		Tibialis	Gastrocnemius
Without Heel	3mph	<u>6.58E-04v</u>	<u>4.44E-04v</u>
With Heel	3mph	<u>5.09E-04v</u>	<u>3.32E-04v</u>
<u>AVERAGED EMG VALUES FOR BOTH SPEEDS</u>			
		<u>AVERAGE EMG VALUE</u>	
		Tibialis	Gastrocnemius
Without Heel		<u>1.49E-04v</u>	<u>1.12E-04v</u>
With Heel		<u>9.29E-05v</u>	<u>4.92E-05v</u>
<u>AVERAGED % DIFFERENCE IN EMG VALUES FROM HEEL TO WITHOUT HEEL</u>			
	Locomotion	<u>% AVERAGE EMG VALUE</u>	
		Tibialis	Gastrocnemius
	2mph	<u>21%</u>	<u>23%</u>
	3mph	<u>23%</u>	<u>25%</u>

The same results of the EMG tests were graphed in the following diagrams.

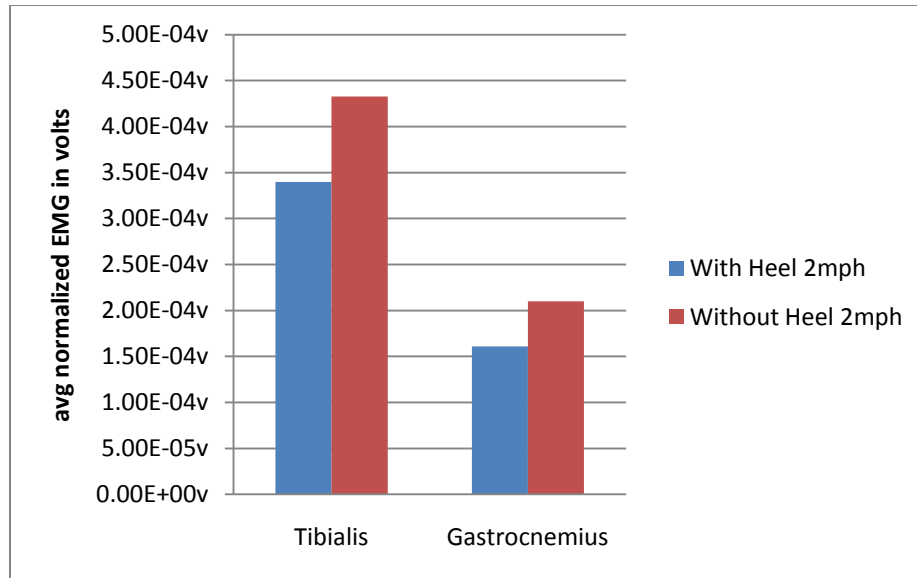


Figure 6.1: EMG results at 2 mph

Figure 6.1 shows that when walking with heels at 2 mph, the EMG reveals that the participants' level of activity in the tibialis and subsequent muscle fatigue decreases 21.5% from walking at 2 mph without heels on average. Fatigue in the gastrocnemius decreases 23.5% when the heel is installed while walking at 2 mph (see Figure 6.4).

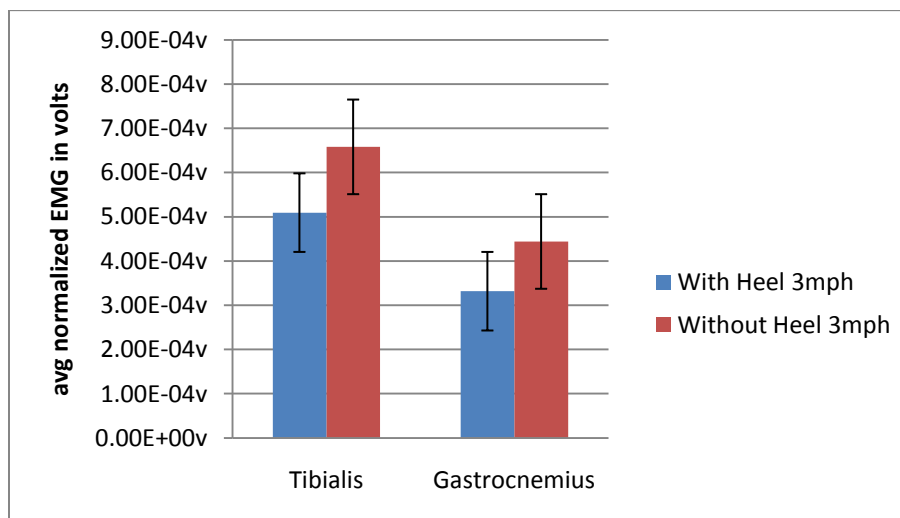


Figure 6.2: EMG results at 3 mph

Figure 6.2 shows that during the 3 mph experiment, adding the heel generated a muscle activity decrease of 22.5% on average in the tibialis and 25% in the gastrocnemius on average. Thus, all participants experienced an activity decrease in the tibialis during both walking experiments when the heel is added (see Figure 6.4).

Figures 6.3 and 6.4 are comparative graphs of the difference of results according to speed. They indicate greater difference in muscle activity with use of the heel as the speed increases. In all categories, the tibialis muscle seems to be used to a greater extent than the gastrocnemius is in terms of volts. The tibialis muscle is also the muscle that manifests a greater difference in intensity of use, according to the voltage, when the removable heel is installed to the bottom of the spike shoes.

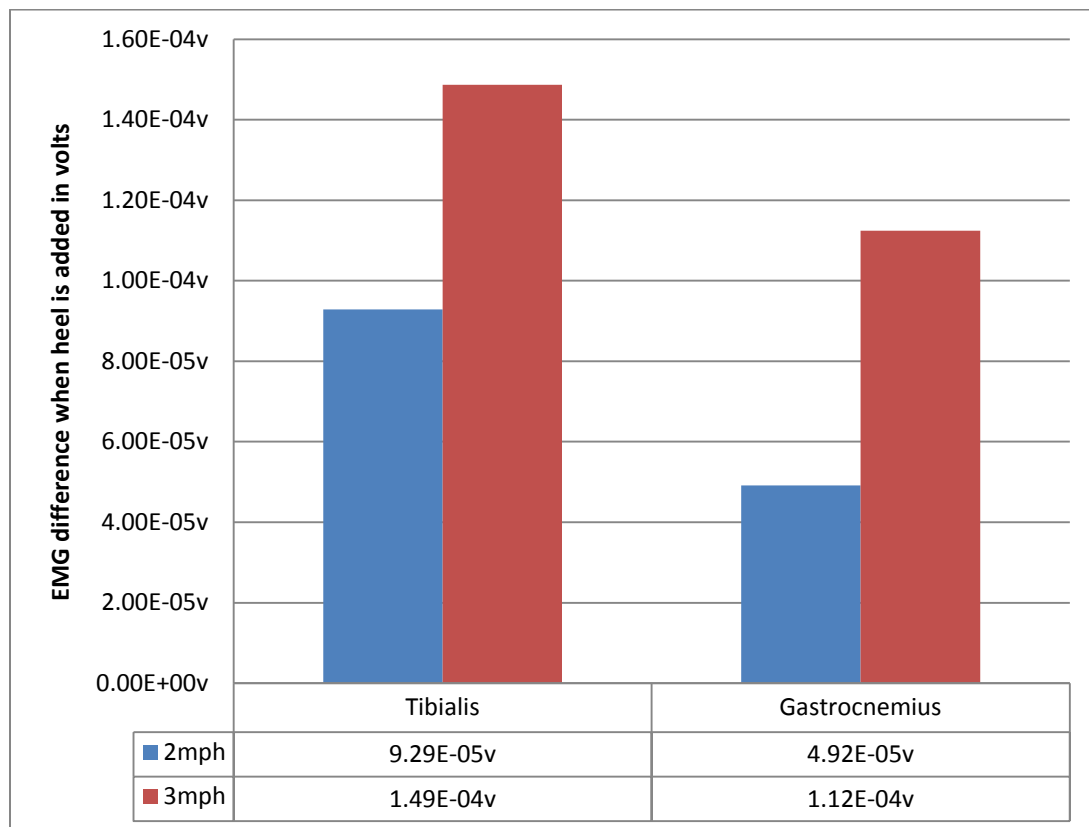


Figure 6.3: Effect of heels on EMG for different speeds

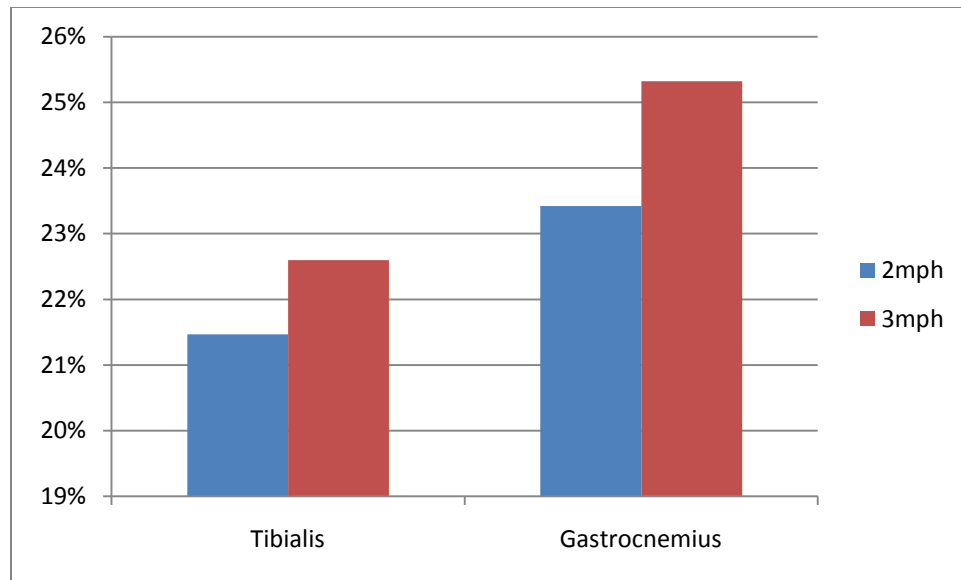


Figure 6.4: Percent decrease in EMG when the heel is added

6.1.1. Muscles Evaluated

The EMG graphs indicate greater muscle activity in the tibialis anterior than in the gastrocnemius, but there seems to be no proportionality in speed or presence or absence of heel.

6.1.2. Impact of Speed on Muscle Activity

EMG indicates a greater muscle activity in the tibialis anterior and the gastrocnemius, as the participants walk faster. Additionally, Figures 6.3 and 6.4 show that the removable heel provides more fatigue relief as the participants walk faster. This is due to the fact that the shock absorption at the heel increases with speed. Additional research could determine the proportionality equation to identify the effect of speed on muscle activity difference according to the presence or absence of heel.

6.1.3. Impact of the Participant's Running Background

In a general manner, the EMG calculations reveal that not wearing the heel brings about significantly greater muscle fatigue for both muscles. One must note, however, that trained

sprinters are used to practicing in spikes without heels. On the other hand, practicing on the toes is harder for distance runners, since during regular practice, they need to use their heels more than sprinters. As the difference between activity with and without heel is averaged for all participants, and then categorized in accordance with their athletic backgrounds, the following averaged results are obtained:

Table 6.2: Percent average of muscle activity decrease from walking without heels to walking with heels

Area and speed	Sprint runners	Distance runners	Non-athletes	Average
Tibialis – 2 mph	21%	23%	25%	23%
Tibialis – 3 mph	20%	22%	24%	22%
Average	20%	23%	24%	22%
Gastrocnemius – 2 mph	19%	24%	32%	25%
Gastrocnemius – 3 mph	21%	25%	34%	27%
Average	20%	25%	33%	26%

Among athletes, the heel benefits distance runners the most. Such an observation is not surprising. Effectively, tibialis and gastrocnemius fatigue is a problem occurring mostly among this group of athletes, based on the techniques with which they run and the duration of their performances. This group of runners performs in dorsiflexion and therefore needs extra support in their heels. The Nike spikes, used alone, cannot provide such support without the removable heel. Brukner et al., in providing definitions for different running gaits, present an insight into understanding the discrepancy of result values between participants of different running backgrounds. Long and mid-distance runners tend to have both heels and forefeet striking the ground together at the beginning of the contact stage of stance. On the other hand, sprint runners'

forefeet, most of the time, present the only contact with the ground throughout the stance phase (thus the curved shape of the spike shoe) (Brukner et al.).

The following diagrams illustrate this fact more remarkably in that they emphasize the contrast between each category of participants. Figures 6.5 through 6.8 display the averaged percent decrease in each muscle and each walking speed – 2 mph and 3 mph.

Nevertheless, the experiment is conducted for only one minute. In the future, one should consider making additional, longer experiments, in order to ensure that the results are not only consistent, but also consistently conclusive.

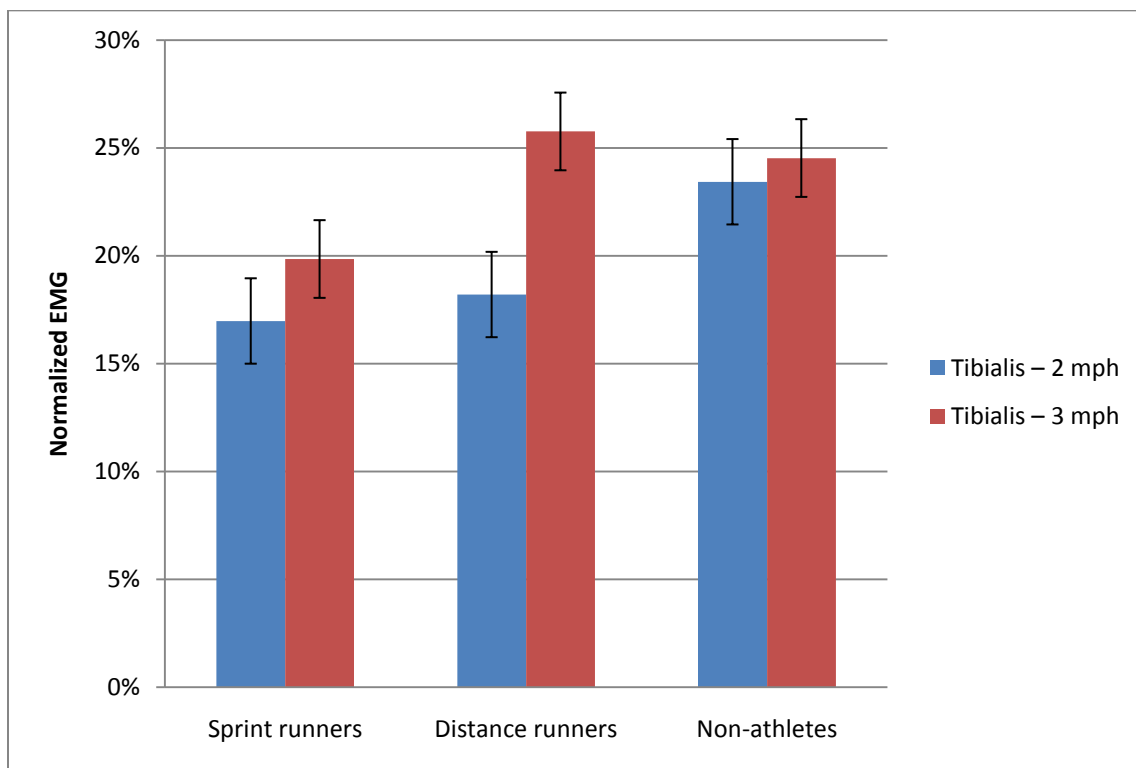


Figure 6.5: Percent decrease in tibialis activity for each participant group

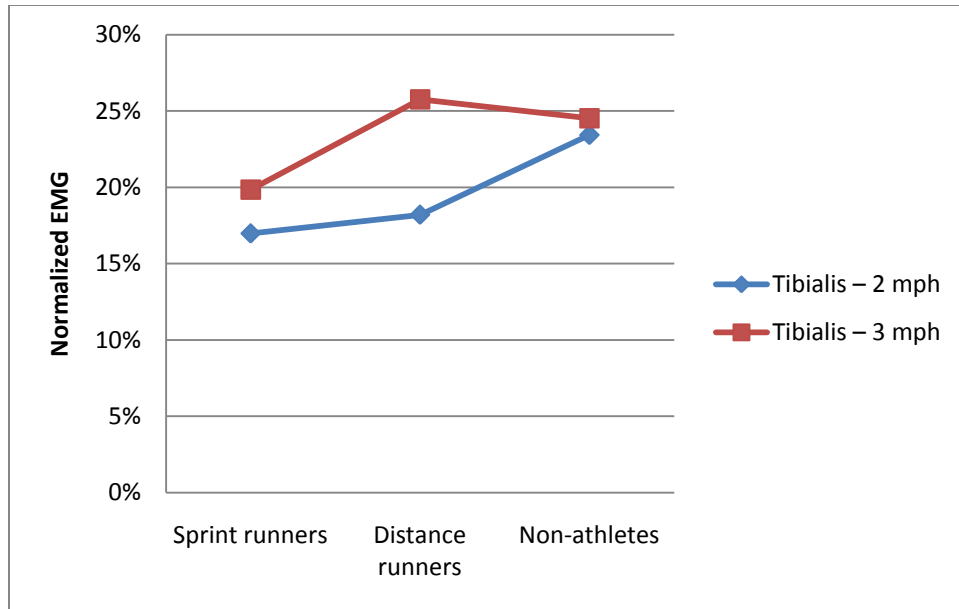


Figure 6.6: Plot diagram comparing decrease in tibialis activity for each group according to speed

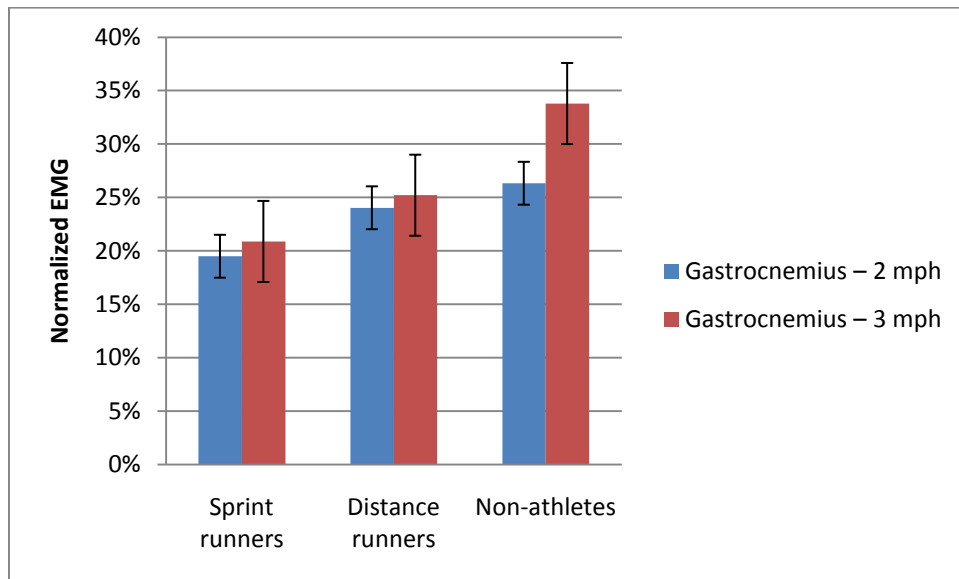


Figure 6.7: Percent decrease in gastrocnemius activity for each participant group

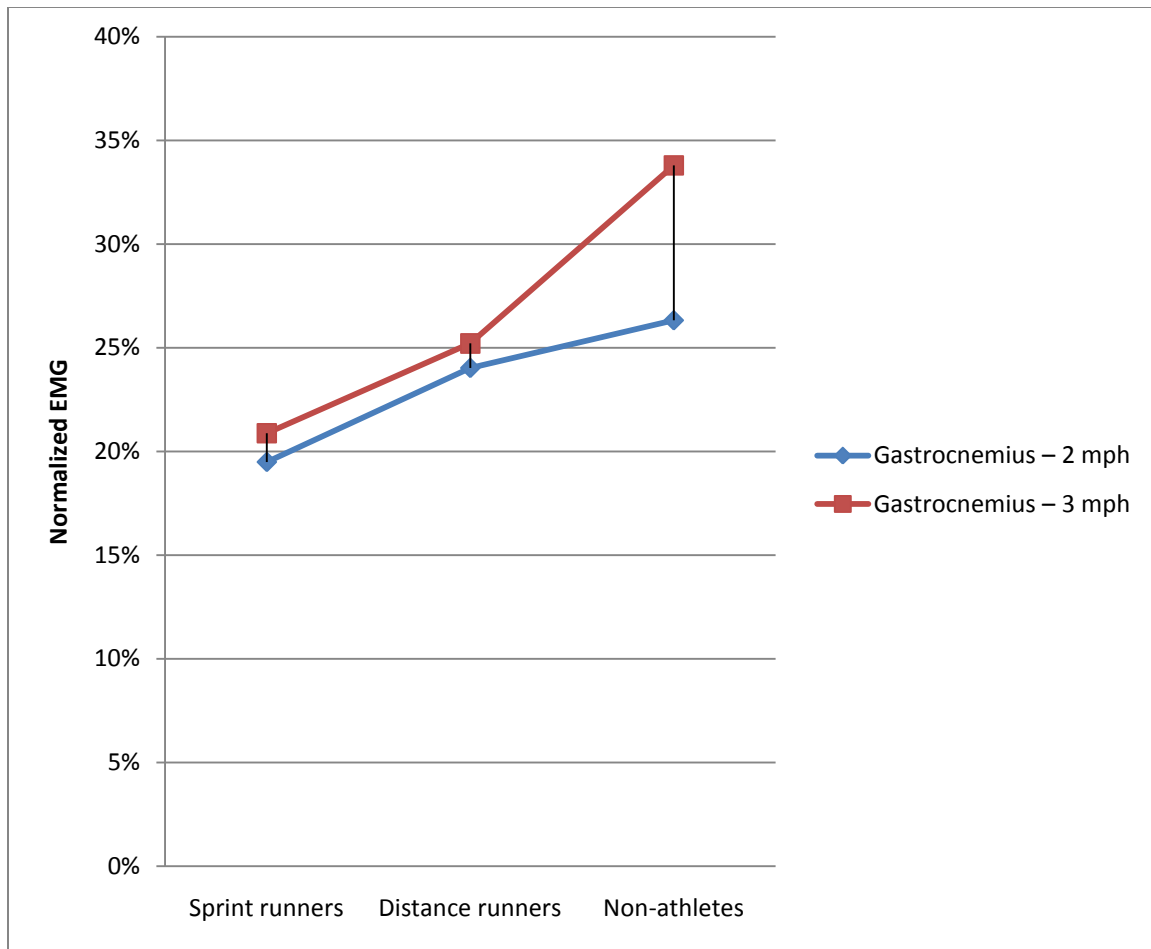


Figure 6.8: Diagram comparing decrease in gastrocnemius activity for each group according to speed

6.1.4. Statistical Results

Table 6.3 contains the results of ANOVA of the electromyographic data obtained from statistical calculations. It displays change across both speeds (2 and 3 mph). The term “locomotion” refers to the speeds at which the participants walk (2 or 3 mph). “Subject” refers to the participants. The p value that determines whether the hypothesis is true or not is noted under the last column, that is, the column labeled “P.”

Table 6.3: Analysis of variance for gastrocnemius and tibialis anterior activity

Analysis of Variance Table for Gastrocnemius					
Source	DF	SS	MS	F	P
Subject	8	1.654E-07	2.067E-08		
Heel	1	1.267E-07	1.267E-07	24.25	0.0012
Error Subject*Heel	8	4.179E-08	5.224E-09		
Locomotion	1	5.455E-07	5.455E-07	29.82	0.0006
Error Subject*Locomotion	8	1.463E-07	1.829E-08		
Heel*Locomotion	1	2.767E-09	2.767E-09	4.87	0.0583
Error Subject*Heel*Locomotion	8	4.543E-09	5.679E-10		
Total	35	1.033E-06			
Grand Mean 3.01E-04					
CV(Subject*Heel) 23.98					
CV(Subject*Locomotion) 44.88					
CV(Subject*Heel*Locomotion) 7.91					
Analysis of Variance Table for Tibialis					
Source	DF	SS	MS	F	P
Subject	8	2.777E-07	3.472E-08		
Heel	1	2.408E-07	2.408E-07	31.55	0.0005
Error Subject*Heel	8	6.105E-08	7.631E-09		
Locomotion	1	1.092E-06	1.092E-06	25.70	0.0010
Error Subject*Locomotion	8	3.400E-07	4.250E-08		
Heel*Locomotion	1	2.492E-09	2.492E-09	0.57	0.4730
Error Subject*Heel*Locomotion	8	3.515E-08	4.394E-09		
Total	35	2.050E-06			
Grand Mean 4.76E-04					
CV(Subject*Heel) 18.37					
CV(Subject*Locomotion) 43.35					
CV(Subject*Heel*Locomotion) 13.94					

6.1.4.1.Hypothesis 1

The ANOVA measurements reveal a significant difference in the normalized EMG results (MAV) between the muscle activities without heel and with heel at 2 and 3 mph on the treadmill. The gastrocnemius results show a ($p < 0.05$) result when using the heel at 3 mph with a p value of 0.0012. The tibialis anterior results show a ($p < 0.05$) result when using the heel at 3 mph with a p value of 0.0005.

This proves that wearing the heel reduces muscle activity, and thus rejects the null hypothesis and proves the alternative hypothesis true.

6.1.4.2.Hypothesis 2

As Table 6.3 indicates, the “locomotion” factor impacts the activity level for both muscles in accordance with the EMG measurements as ($p < 0.05$) results indicate p values of 0.0006 and 0.0010 in the gastrocnemius and the tibialis anterior, respectively. Again, both p values being lesser than 0.05, it can be deduced that a change of speed from 2 mph to 3 mph is associated with significant change in muscle activity, as the participants switch from walking with heels to walking without heels.

However, although Figures 6.3 and 6.4 show speed has some impact on the amount of muscle activity decrease from wearing the heel according the EMG, Table 6.3 reveals no statistically significant interaction between speed and presence / absence of heel, based on the heel*locomotion p values of 0.0583 in the gastrocnemius and 0.4730 in the tibialis. This means that speed influences the amount of relief provided by the heel, but not at a *statistically* significant level for these selected speeds.

6.2. Body Maps

The subjects were asked to assess and compare the discomfort / pain they endure during the tests, with and without heels. The target areas are 20-27 on the body map displayed in Figure 5.11.

. Wilson and Corlett (1995) explained that “because ‘pain’ is sometimes seen as a specific and localized experience, the term ‘discomfort’ is used.” Discomfort / pain is expressed on the standard ergonomics scale established by Borg’s category-ratio scale (CR-10), from 0 to 10, as detailed in the chart displayed in Figure 5.12. Results were averaged for all participants; individual results are provided in Appendix B.

Table 6.4: Averaged discomfort values before and after heel installation

	Before Heel Installation	After Heel Installation	Discomfort Decrease
Area 20-21	5.2778	2.6111	2.6667
Area 22-23	5.2222	2.6111	2.6111
Area 24-25	6.7778	2.8889	3.8889
Area 26-27	6.7778	2.2778	4.5

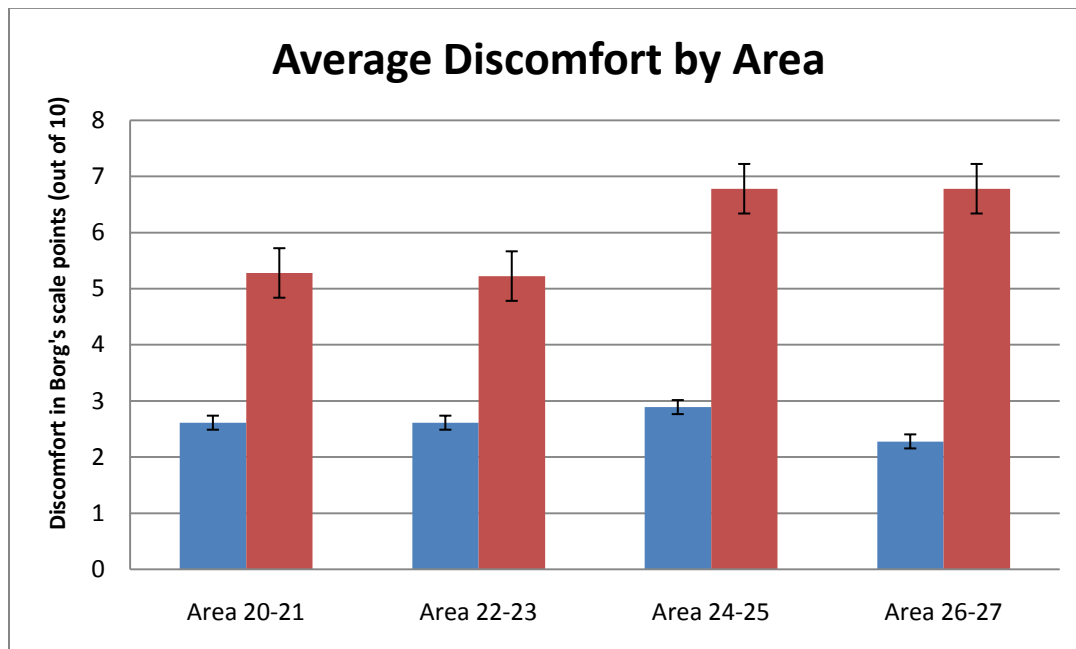


Figure 6.9: Average discomfort when walking without heels and walking with heels

All subjects experienced a greater discomfort without the heel than they did with the heel. The discomfort difference was thus calculated by subtracting the discomfort value without the heel from the value with the heel, which indicates the subjective change in comfort level triggered by the biomechanical modification. The results obtained indicate that the removable

heel provides an average discomfort relief of 2.67 points on Borg's CR-10 scale in the knees, 2.61 points in the calves, 3.89 points in the ankles, and 4.22 points in the feet. Thus, an observation of the results indicates a greater relief at the ankles and the feet.

6.2.1. Statistical Results: Hypothesis 3

As the statistical equation is applied to each area and each hypothesis, the following categorized series of formulas is obtained:

Table 6.5: ANOVA formulas by area

	Null hypothesis	Alternative hypothesis
Area 20-21	$H_0 = \hat{Y}_{11} = \hat{Y}_{12}$	$H_1 = \hat{Y}_{11} \neq \hat{Y}_{12}$
Area 22-23	$H_0 = \hat{Y}_{21} = \hat{Y}_{22}$	$H_1 = \hat{Y}_{21} \neq \hat{Y}_{22}$
Area 24-25	$H_0 = \hat{Y}_{31} = \hat{Y}_{32}$	$H_1 = \hat{Y}_{31} \neq \hat{Y}_{32}$
Area 26-27	$H_0 = \hat{Y}_{41} = \hat{Y}_{42}$	$H_1 = \hat{Y}_{41} \neq \hat{Y}_{42}$

Once calculated, the one-way ANOVA test results are displayed in the following table:

Table 6.6: ANOVA of body map results

Effect	Area	Num DF	Den DF	F Value	Pr > F
Area*Time	2021	1	56	58.43	<.0001
Area*Time	2223	1	56	56.03	<.0001
Area*Time	2425	1	56	124.28	<.0001
Area*Time	2627	1	56	166.40	<.0001

This above SAS table displays the ANOVA results from the hypotheses' equations in table 6.4. The p values for each area help conclude that there is a significant difference in discomfort between walking without heels and walking with heels, as they are lesser than 0.05. The following figure displays the graphed results of Table 6.4 before and after heel installation (Detailed results of the ANOVA are displayed in Table B.0.3 in the Appendix).

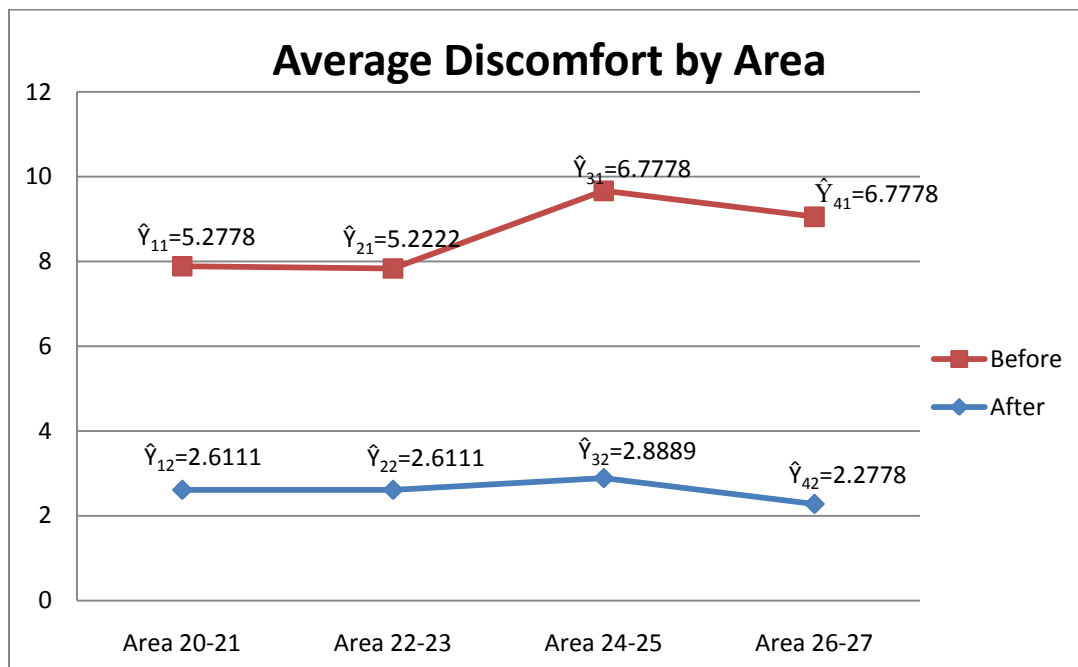


Figure 6.10: Graphed ANOVA results by area

Each spot represents the mean for the 9 participants. The chart shows the lines are not parallel, which shows the presence of an interaction. The divergence of lines toward the end shows that there is more interaction in the last 2 areas, which indicates that participants experienced more discomfort in areas 24-27 when performing without the removable heel.-

6.2.2. Relevance of the Participants' Athletic Background

As the body map survey results are grouped and averaged by participant category, the following results are obtained:

Table 6.7: Average discomfort difference by participant category

Body map area	Participant group		
	NON-ATHLETES	DISTANCE RUNNERS	SPRINT RUNNERS
20 & 21	3	3	2
22 & 23	2.7	3.8	1.3
24 & 25	4.5	4.2	3
26 & 27	5	4.2	3.5

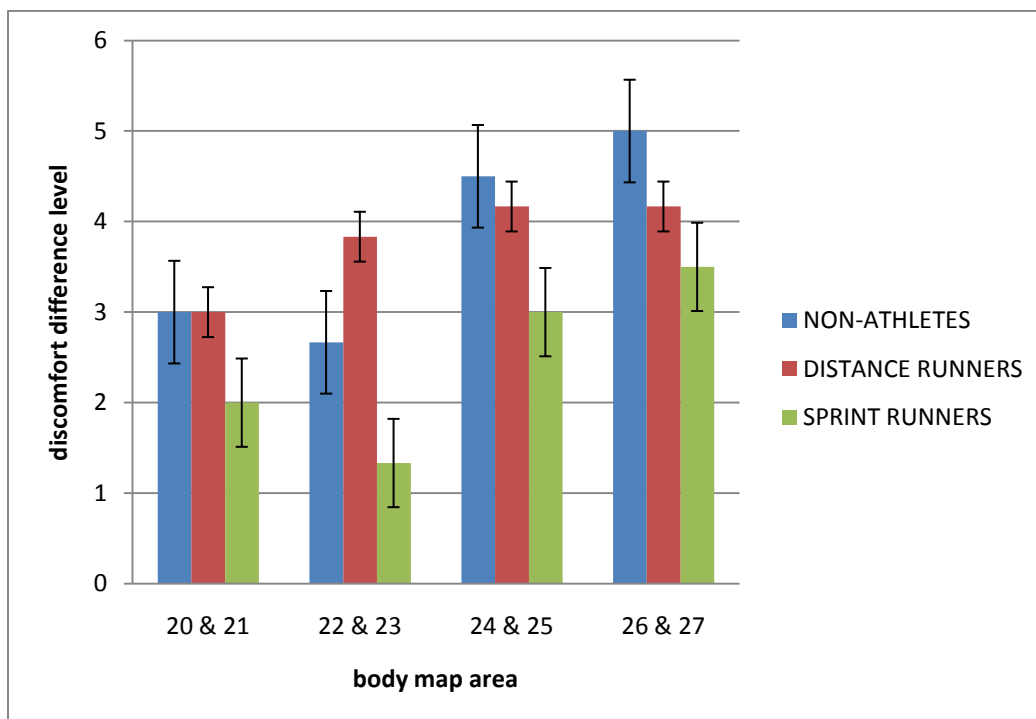


Figure 6.11: Average discomfort difference by participant athletic category

Table 6.7 and Figure 6.10 reflect the fact that non-athletes seem to experience the greatest relief from the removable heel as a whole. Effectively, they reported the greatest difference in discomfort values upon completion of the exercise, with heels in all areas except for the calves, an area for which distance runners experienced the greatest relief. This is due to the fact that having the least athletic experience in track, they constitute the group that needs the most leg

support as they are not used to walking in spike shoes. Unsurprisingly, sprinters experienced the least relief from the removable heel, even though the biomechanical modification was designed especially for this target group. This is due to the fact that sprinters are most accustomed to walking in spike shoes. Nevertheless, the amount of relief they felt was still very significant for all areas, which confirms their need for leg support while walking in spike shoes and the efficiency of the heel in addressing such a need.

Unlike the EMG data, the body map offers relatively subjective results. Thus, the absence of a statistical analysis or inclusion of the body map results in ANOVA is due to the fact that even though it provides insight as to the level of relief the modified spike shoes bring about, the data is not as rigorously reliable as the EMG data is on a scientific level.

6.2.3. Remaining Discomfort

Even though these results are much more subjective than the EMG calculations, they perfectly illustrate and confirm the efficacy of the removable heel. Effectively, Table 6-7 reveals that the subjects felt a significant decrease of pain and discomfort when performing with the heeled spikes.

The results, however, reveal that some discomfort remains, even after installation of the heel. The main complaints the subject mentioned were the relative hardness of the heel material, and the fact that the heel's square shape provided no curving for walking particularly fast.

7. IMPLICATIONS

This project began with the problems that track athlete experience all the time, but have never really been addressed with a concrete solution that enables them to continue running and to do so healthily. Many athletes experience pain in the foot and knee areas while practicing and competing. The track spikes in which runners are competing are designed to keep them on their toes. This is a good design for certain events, but only during those events. When the athlete is not competing, the same design presents bad posture to the foot, which causes pain in multiple places.

The proposed solution to this problem is a removable heel that gives the runner more support. The heel allows the runner to quickly attach or detach the extra support whenever needed. The experiment reveals that the heel does, in fact, lessen the pain in the major affected areas and provides the runner with more comfort overall.

7.1.Shortcomings

7.1.1. Limited Number of Participants

The shoe is only tested on a limited number of participants. Due to that fact and the limited amount of time to prepare, it is impossible to fully and/or accurately identify the portion of pain felt by the subject due to their own, individual gait, bone structure, age, experience in running, or gender, and the portion of pain due to the shoe.

7.1.2. Limited Prototype Quantity

The second downfall is that because there is only one prototype, there is only one size – size 10 – available. This limits the number of subjects fit for the experiment, especially in terms of trained athletes. Furthermore, because of the prototype's quantitative limitation, any technical malfunction delays the experiment considerably, reducing the already limited size of the population tested.

7.2. Further Developments

7.2.1. Running and Monitoring Conditions

In the future, it is agreed to make the experiment more accurate by allowing the athlete participants to run at their speed of choice, that is, to have them run at the same speed they would on the track before wearing the removable heel. In the same purpose to make the conditions more faithful to real track performance, the participants will run, and then walk, for the same amount of time they would in a race, rather than limiting the experiment to one minute.

Additionally, electrodes should be placed on both legs to ensure better accuracy of muscle activity.

7.2.2. Participants Selection and Shoe Characteristics

In the future, the experiment will be conducted on more trained subjects, both males and females. The participants' remarks, concerning the material and shape of the heel, will also be taken into account: a softer material (probably rubber; though it is not long-lasting material, due to the friction on the mondo surface) with a more curved shape. The heel being removable, it could be replaced when needed. In addition, considering the works from other inventors of removable heels together with time considerations, a faster attaching mechanism should be considered, such as sliding instead of screwing the heel to the sole.

7.2.3. Further Assessment

Considering research such as Wakeling et al. (2001) who measured the reaction force that triggers muscle activity during normal walking, a future study to this thesis might measure the amount of intensity absorbed when the removable heel is applied, which would serve to quantify the ergonomic worth and value of the heel.

Also, angular measurements could help identify the gait modification brought about by the removable heel. To do so, technology and methodology similar to those used by Orchard et

al. (1996) who utilized a 3D Motion Analysis System to perform a biomechanical evaluation of heel elevation devices of 50 mm and 150 mm.

7.3. Final Remarks

Although the experiment is not a success in all categories, it can be concluded that the removable heel would be ideal for a mid-distance or long distance runner. As a whole, the project was a success since a more ergonomic product was designed for the track athlete. This project presented a valued learning experience. Investigating those problems that had not been previously addressed was enlightening. Hopefully, the concept presented here will aid track athletes in the future.

In addition, ergonomics must to be further implemented in sports. Indeed, there are too many long-term injuries in sports that can be prevented by devices as simple as a removable heel. The removable heel could constitute one step forward in protecting the health of many athletes.

Nevertheless, considering research such as Wakeling et al. (2001) who measured the reaction force that triggers muscle activity during normal walking, a future study to this thesis might measure the amount of intensity absorbed when the removable heel is applied, which would serve to quantify the ergonomic worth and value of the heel.

REFERENCES

- Ahroni, Jessie H.; Scheffler, Neil M. *101 Tips on Foot Care for People with Diabetes*. 2nd Edition. American Diabetes Association. 2006.
- Alangari, Abdulrahman S. "Biomechanics of Sport's Shoes". 9th Congress of Asian Federation of Sports Medicine. Riyadh, Saudi Arabia. 18-22 November 2006.
- "Ask The Coaches." *Running Times Magazine*, 22 March 2006. <http://runningtimes.com>.
- Au, Samuel K.; Dilworth, Peter; Herr, Hugh. "An Ankle-Foot Emulation System for the Study of Human Biomechanics". Proceedings of the 2006 IEEE International Conference on Robotics and Automation. Orlando, FL. May 2006.
- Borg, Gunnar. "The Borg CR10 Scale® Folder: A Method for Measuring Intensity of Experience". Borg Perception. Sweden. 2004
- Brukner, Peter; Khan, Karim; Kron, John. *The Encyclopedia of Exercise, Sport, and Health*.
- "Canadian Track and Field Sponsorship Deal Highlights Ergonomics in Sport." *Ergoweb*. 4 July 2005. <http://www.ergoweb.com/>.
- Dataq Instruments, Inc. "User's Manual". Akron, Ohio. 1997.
- Dawson, Jill; Thorogood, Margaret; Marks, Sally-Anne; Juszczak, Ed; Dodd, Chris; Lavis, Grahame; Fitzpatrick, Ray. "The Prevalence of Foot Problems in Older Women: A Cause for Concern". *Journal of Public Health Medicine*. Vol. 24. Royal Colleges of the United Kingdom. UK. 2002. 77-84.
- Dederling, Asa.; Németh Gunnar, Harms-Ringdahl Karin. "Correlation between Electromyographic Spectral Changes and Subjective Assessment of Lumbar Muscle Fatigue in Subjects without Pain from the Lower Back". *Clinical Biomechanics*. Vol. 14. 1999. 105.
- Delsys, Inc. "Myomonitor IV EMG System User's Guide". Boston, MA. 2009.
- Donley, Brian G. and Manuel Leyes. "Anterior Bony Ankle Impingement". *Operative Techniques in Sports Medicine*. Vol. 9, No 1. January 2001. 2-7.
- Elliott, Mark. Personal Interview. Louisiana State University. March 2007, March 2008.
- Ergonomics Maps. <http://www.ergmaps.com>.
- Famolare, Leo H. "Bowling Shoe Construction with Removable Slide Pad and Heel". Dexter Shoe Company. Kennebunkport, ME. Patent filed Dec. 21, 1994.
- Galanter, Eugene ; Jacobs, Diana E. "A Comparison of Category Scaling Methods". Colombia University New York Psychophysics Laboratory. NY. 1973.

- Gross, Ralph and Shi, Jianbo. "The CMU Motion of Body (mobo) Database". Carnegie Mellon University Robotics Institute. Pittsburgh, Pennsylvania 15213. June 2001.
- Hunt, Adrienne E.; Smith, Richard M.; Torode, Margaret. "Extrinsic Muscle Activity, Foot Motion and Ankle-Joint Moments during the Stance Phase of Walking". *Foot Ankle International*. Lidcombe, Australia. July 2001. 543.
- "Knee Problems?" Yahoo Answers. <http://answers.yahoo.com/question/index>.
- Koehl, Timothy and Mackentroth, Joseph. "Shoe Construction with Self-Seating Removable Heel". Patent # 5058290. Louisiana. Patent filed Aug. 28, 1989.
- Lee, K. S.; Waikar, Avinash M.; Aghazadeh, Fereydoun; Tandon, S. "An Electromyographic Investigation of Neck Angles For Microscopists". Human Factors and Ergonomics Society Annual Meeting Proceedings, Volume 30, Number 6. Human Factors and Ergonomics Society. 1986. 548-551.
- Lombardino, Thomas D. "Combination Athletic Shoes and Plyometric Training Device". Patent # 5692322. Howard Beach, NY. Patent filed Oct. 3, 1996.
- Lynch, N.A.; Metter, E.J.; Lindle, R.S.; Fozard, J.L.; Tobin, J.D.; Roy, T.A.; Fleg, J.L.; Hurley, B.F. "Muscle Quality. I. Age-Associated Differences between Arm and Leg Muscle Groups". *Journal of Applied Physiology*. 1998. www.jap.org.
- Mann, Roger A.; Hagy, John L. "Biomechanics and Walking, Running and Sprinting". *American Journal of Sports Medicine*. 1980. 345-350.
- McGrath, Alicia C. and Caroline F. Finch. "Running the Race against Injuries: A Review of the Literature". Monash University Accident Research Centre. October 1996. Report No. 104. Victoria, Australia.
- Menz, Hylton B; Morris, Meg E. "Footwear Characteristics and Foot Problems in Older People". *Gerontology*. Vol. 51. S. Karger AG. Basel. Australia. 2005. 346-351.
- Nigg, Benno M.; Stefanyshyn, Darren, Cole, Gerald; Stergiou, Pro.; Miller, Janice. "The Effect of Material Characteristics of Shoe Soles on Muscle Activation and Energy Aspects During Running." *Journal of Biomechanics*. Vol. 36, No. 4. Elsevier Science. Oxford, UK. 2003. 569-575.
- Nimbarte, Ashish. "Modeling the Risk Factors Associated with the Neck Disorders During Manual Material Handling Tasks". Dissertation. Louisiana State University. 2009.
- Nyska, Mir; McCabe, Chris.; Linge, Keith; Klenerman, Leslie. "Plantar Foot Pressures During Treadmill Walking with High-Heel and Low-Heel Shoes". *Foot Ankle International*. Vol. 17. 1996. 662-6.
- Pribut, Stephen M. DPM. "Athletic Shoes: A Quick Look." *Dr. Stephen M. Pribut's Sports Pages*. 13 March 2004. <http://drpribut.com/sports/spshoe.html>.

- Raptopoulos, Luciano Santos Constantin; Dutrab, Max S; de Noronha Castro Pintob, Fernando A.; de Pina Filhob, Armando Carlos. "Alternative Approach to Modal Gait Analysis through the Karhunen–Loeve Decomposition: An Application in the Sagittal Plane". *Journal of Biomechanics*. Vol. 39. Rio de Janeiro, Brazil. 2006. 2898–2906
- Ratamess, Nicolas A., Williams J. Kraemer, Jeff S. Volee, Duncan N. French, Martyn R. Rubin, ana L. Gómez, Robert U. Newton, and Carl M. Maresh. "The Effects of Ten Weeks of Resistance and Combined Plyometric/Sprint Training with the Meridian Elyte Athletic Shoe on Muscular Performace in Women". *Journal of Strength and Conditioning Research*, August 2007, 21,3. 882.
- Reber, Lyle; Perry, Jacqueline; Pink, Marilyn. "Muscular Control of the Ankle in Running". *American Journal of Sports Medicine*. Vol. 21. December 1993. 805-810.
- Reilly, Tom. "Finding Your Feet: The Ergonomics of Running Shoes". *The Ergonomist*. No. 466. Leicestershire, UK. April 2009.
- Rodriguez Colon, Jorge A. "Low Heel Shoe Convertible to High Heel Shoe and Vice-Versa with an Adjustable Shank". Patent #5347730. Puerto Rico. 1994.
- Saunders, John B.; Inman, Verne T.; Eberhart, Howard D. "The Major Determinants in Normal and Pathological Gait". *Journal of Bone and Joint Surgery*, 35A. 1953. 543-558.
- Schepsis, Anthony A.; Hugh Jones; Andrew L. Haas. "Achilles Tendon Disorders in Athletes". *The American Journal of Sports Medicine* 30:287-305. 2002. <http://ajsm.highwire.org/cgi/content/abstract/30/2/287>.
- Schneider-Levy, Barbara. "Heel Side: Mike Goldsmith Invents Shoe with Removable Heels in Different Colors and Materials". *Footwear News*. July 2001.
- Segers, Lenoir, Aerts, and De Clercq. "EMG Measurements". Department of Movement and Sport Sciences. Ghent University. Ghent, Belgium. 2006.
- "Shoe/Spike Types." *Venue Sports*. <http://vsathletics.com>.
- Smith, Kaitlin. Personal Interview. Louisiana State University. 22 April 2007.
- Smith, Laura; Weiss, Elizabeth Lawrence; Lehmkuhl, Don. *Brunnstrom's Clinical Kinesiology*. 5th edition. F.A. Davis Company. 1996.
- Solomonow, Moshe; Hatipkarasulu, Selen; Zhou, Bing He; Baratta, Richard V.; Aghazadeh, Fereydoun. "Biomechanics and Electromyography of a Common Idiopathic Low Back Disorder". *Spine*, 2003. Volume 28 - Issue 12. Lippincott Williams & Wilkins, Inc. 15 June 2003. 1235-1248.
- Sommerich, Carolyn; Jones, Sharon; Hermans, Veerle; Moon, Samuel. "Use of Surface Electromyography to Estimate Neck Muscle Activity". *Journal of Electromyography and Kinesiology*. Vol. 10. August 2000. 377-398.

- Starkey, Chad. *Evaluation of Orthopedic and Athletic Injuries*. 2ed. 132,124.
- Thompson, Dave. "Kinematic Analyses of Gait". University of Oklahoma Health Sciences Center. 2002. <http://moon.ouhsc.edu/dthomps/gait/knematics/gait.htm>.
- Tortora, Gerard J. *Principles of Human Anatomy*, 9th ed. John Wiley and Sons, Inc. NY. 2002.
- Wakeling, James M.; Pascual, Silvia A.; Nigg, Benno M.. "Altering Muscle Activity in the Lower Extremities by Running with Different Shoes". *Medicine and Science in Sports and Exercise*, Vol. 34, No. 9. 2002. 1529-1532.
- Wakeling, James M.; von Tscharn, Vinzenz; Nigg, Benno M; Sergiou, Pro. "Muscle activity in the leg is tuned in response to ground reaction forces". *J Appl Physiol*. Vol. 91, Issue 3. Alberta, Canada. September 2001. 1307-1317.
- Weimer, Melissa. "Electromyogram Waveform Analysis Using Advanced CODAS: An Application of the Integral Function for Waveform Area-Under-the-Curve Determinations". Dataq Instruments, Inc. 2009. www.dataq.com.
- Wilson, John R. and E. Nigel Corlett. *Evaluation of Human Work: A Practical Ergonomics Methodology*. 2nd edition. Taylor and Francis. Philadelphia, PA. 1995. 686-687.
- Zeller, Brian L.; McCrory, Jean L.; Kibler, Ben; Uhl, Timothy L. "Differences in Kinematics and Electromyographic Activity between Men and Women during the Single-Legged Squat". *The American Journal of Sports Medicine*. Vol. 31, No. 3. 2003. 449-456.

APPENDIX A: CHANGES IN MUSCLE ACTIVITY

Table A.0.1: Detailed fatigue change for each subject from EMG results

Participant	Heel	Tibialis	Gastrocnemius
1	With Heel 2mph	3.35E-04v	1.87E-04v
	Without Heel 2mph	4.73E-04v	2.69E-04v
	With Heel 3mph	7.56E-04v	4.38E-04v
	Without Heel 3mph	8.20E-04v	5.64E-04v
2	With Heel 2mph	3.00E-04v	1.32E-04v
	Without Heel 2mph	4.37E-04v	1.78E-04v
	With Heel 3mph	5.76E-04v	3.41E-04v
	Without Heel 3mph	8.44E-04v	5.37E-04v
3	With Heel 2mph	3.59E-04v	1.56E-04v
	Without Heel 2mph	5.72E-04v	2.59E-04v
	With Heel 3mph	2.77E-04v	1.57E-04v
	Without Heel 3mph	4.34E-04v	2.64E-04v
4	With Heel 2mph	2.83E-04v	1.17E-04v
	Without Heel 2mph	4.03E-04v	1.65E-04v
	With Heel 3mph	4.47E-04v	1.34E-04v
	Without Heel 3mph	7.35E-04v	2.09E-04v
5	With Heel 2mph	3.35E-04v	1.25E-04v
	Without Heel 2mph	5.03E-04v	1.59E-04v
	With Heel 3mph	7.06E-04v	4.58E-04v
	Without Heel 3mph	9.38E-04v	5.31E-04v
6	With Heel 2mph	2.26E-04v	1.10E-04v
	Without Heel 2mph	3.38E-04v	1.97E-04v
	With Heel 3mph	5.66E-04v	4.12E-04v
	Without Heel 3mph	7.65E-04v	5.47E-04v
7	With Heel 2mph	2.95E-04v	1.13E-04v
	Without Heel 2mph	4.23E-04v	1.69E-04v
	With Heel 3mph	6.06E-04v	4.38E-04v
	Without Heel 3mph	8.38E-04v	5.04E-04v
8	With Heel 2mph	1.26E-04v	2.22E-04v
	Without Heel 2mph	2.38E-04v	2.97E-04v
	With Heel 3mph	5.76E-04v	4.00E-04v
	Without Heel 3mph	6.79E-04v	5.57E-04v
9	With Heel 2mph	2.23E-04v	1.32E-04v
	Without Heel 2mph	3.42E-04v	2.07E-04v
	With Heel 3mph	5.36E-04v	4.00E-04v
	Without Heel 3mph	7.54E-04v	6.57E-04v

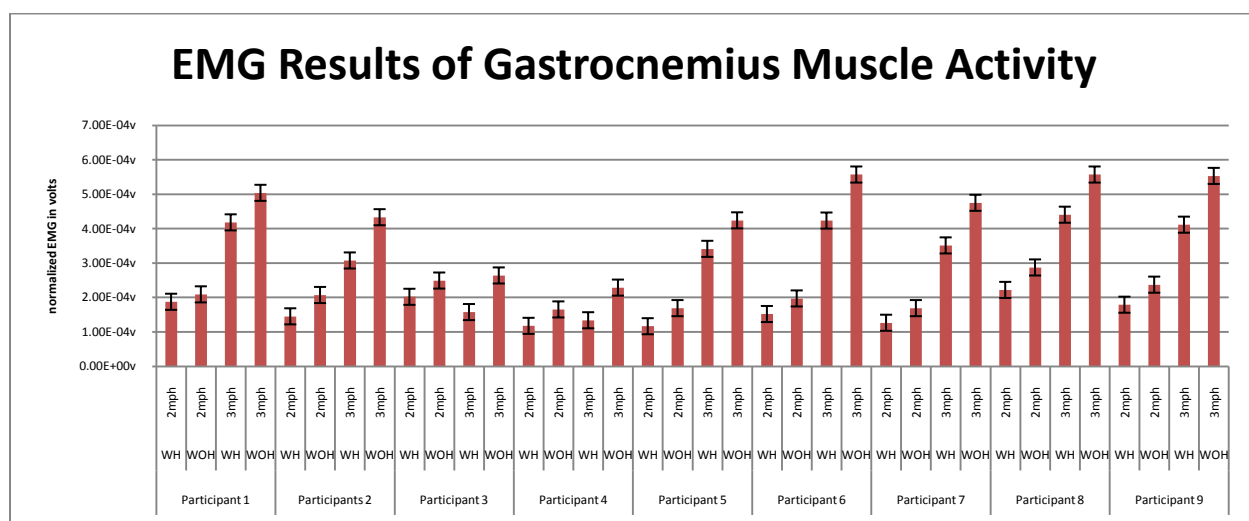


Figure A.1: Histogram of EMG Results of Gastrocnemius Activity for Each Participant

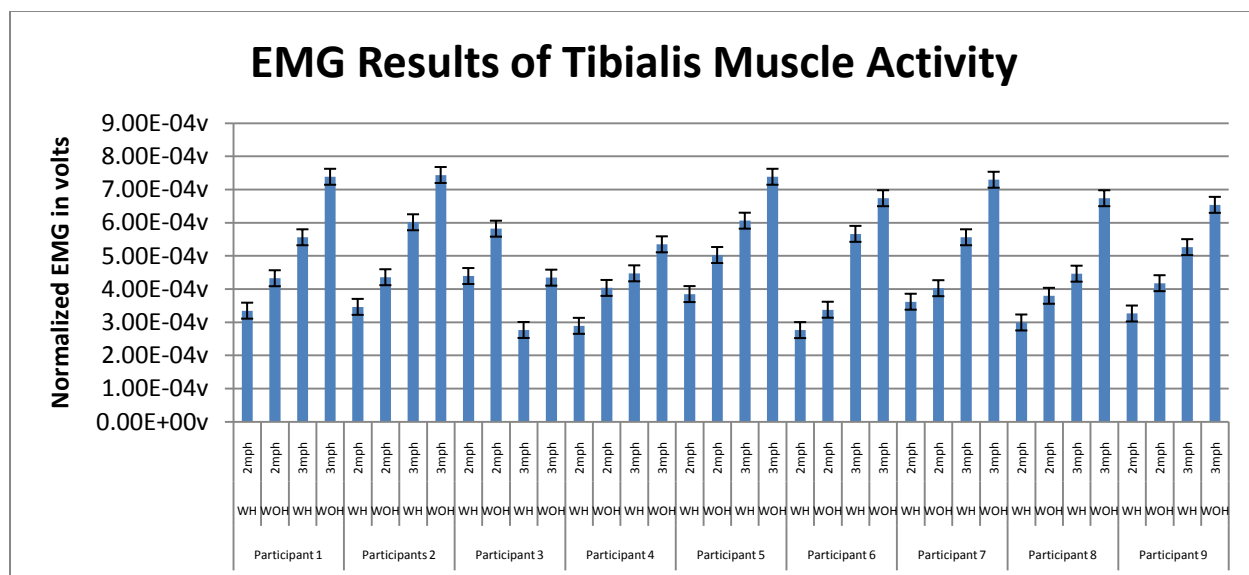


Figure A.2: Histogram of EMG Results of Tibialis Anterior Activity for Each Participant

For each subject, the first two sets of EMG histograms refer to the participant's walking with and without heels at 2 mph. The second set refers to walking with and without heels at 3

mph. The results are given in volts (v). The abbreviations WH and WOH stand for “with heels” and “without heels”, as a description of the participants’ walking conditions.

APPENDIX B: BODY MAPS

The individual ratings are presented in Tables B.0.1 and B.0.2, and then graphed for a more visual understanding of each subject's perception of his / her individual discomfort.

Table B.0.1: Discomfort values before and after heel installation

Discomfort Before Heel Installation									
Participant	1	2	3	4	5	6	7	8	9
Areas 20-21	5	3	5.5	7	6	4	5	6.5	5.5
Areas 22-23	4	3	7	6	5	5.5	4.5	6	6
Areas 24-25	6	5	8	7.5	7.5	6.5	6	7	7.5
Areas 26-27	7	5.5	7.5	7	7	6	6.5	7.5	7
Discomfort After Heel Installation									
Participant	1	2	3	4	5	6	7	8	9
Areas 20-21	3	3	3	4	2.5	2	1	2.5	2.5
Areas 22-23	3	3	3	4	3	1.5	1.5	2.5	2
Areas 24-25	4	2	3	4.5	2	1.5	2	3	4
Areas 26-27	3	1.5	1.5	2	3	2.5	1.5	3.5	2

Table B.0.2: Histogram of EMG Results of Tibialis Anterior Activity for Each Participant

Participant	Discomfort Decrease after Heel Installation								
	1	2	3	4	5	6	7	8	9
Areas 20-21	2	0	2.5	3	3.5	2	4	4	3
Areas 22-23	1	0	4	2	2	4	3	3.5	4
Areas 24-25	2	3	5	3	5.5	5	4	4	3.5
Areas 26-27	4	1.5	6	5	4	3.5	5	4	5

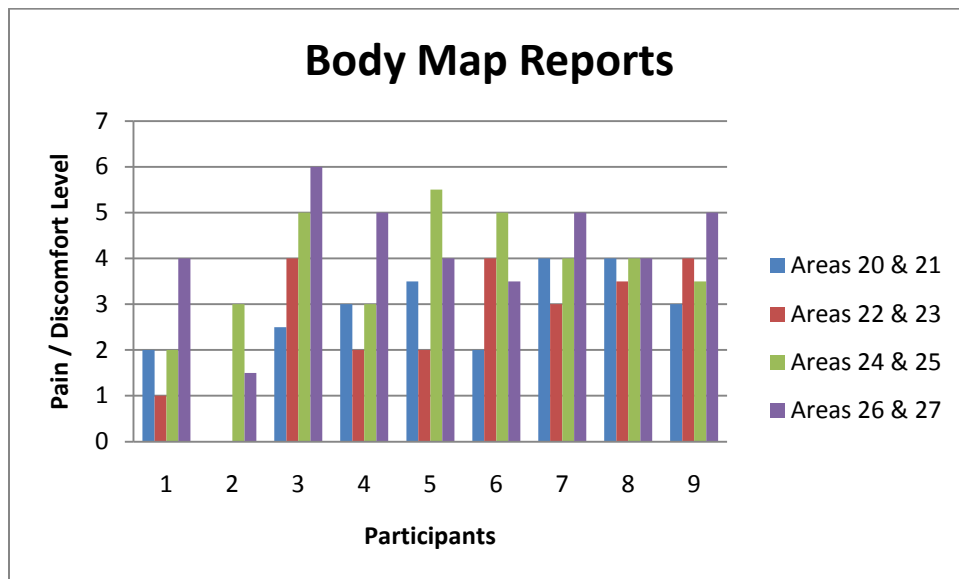


Figure B.1: Graph of Body Map Reports for Each Participant

Table B.0.3: SAS results for discomfort before and after heel installation

Model Information										
Data Set	WORK.ONE									
Dependent Variable	Y									
Covariance Structure	Variance Components									
Estimation Method	REML									
Residual Variance Method	Profile									
Fixed Effects SE Method	Model-Based									
Degrees of Freedom Method	Containment									
Class Level Information										
Class	Levels	Values								
Subject	9	1	2	3	4	5	6	7	8	9
Area	4	20	21	22	23	24	25	26	27	
Time	2	1	2							
Dimensions										
Covariance Parameters	2									
Columns in X	15									
Columns in Z	9									
Subjects	1									
Max Obs Per Subject	72									
Number of Observations										
Number of Observations Read	72									
Number of Observations Used	72									
Number of Observations Not Used	0									
Iteration History										
Iteration	Evaluations	-2	Res	Log	Like	Criterion				
0	1	195.01217681								
1	1	175.85920433								
Convergence criteria met.										
Discomfort, Marlon Greensword, Section 1										
2										
The Mixed Procedure										
Covariance Parameter										
Estimates										

Cov Parm	Estimate						
Subject	0.3890						
Residual	0.5476						
Fit Statistics							
-2 Res Log Likelihood	175.9						
AIC (smaller is better)	179.9						
AICC (smaller is better)	180.1						
BIC (smaller is better)	180						
Type 3 Tests of Fixed Effects							
Effect	Num DF	Den DF	F Value	Pr > F			
Area	3	56	6.68	0.0006			
Time	1	56	383.71	<.0001			
Area*Time	3	56	7.14	0.0004			
Least Squares Means							
Effect	Area	Time	Standard Estimate	Error	DF	t Value	Pr > t
Area*Time	2021	1	5.2778	0.3226	56	16.36	<.0001
Area*Time	2021	2	2.6111	0.3226	56	8.09	<.0001
Area*Time	2223	1	5.2222	0.3226	56	16.19	<.0001
Area*Time	2223	2	2.6111	0.3226	56	8.09	<.0001
Area*Time	2425	1	6.7778	0.3226	56	21.01	<.0001
Area*Time	2425	2	2.8889	0.3226	56	8.96	<.0001
Area*Time	2627	1	6.7778	0.3226	56	21.01	<.0001
Area*Time	2627	2	2.2778	0.3226	56	7.06	<.0001
Tests of Effect Slices							
Effect	Area	Num DF	Den DF	F Value	Pr > F		
Area*Time	2021	1	56	58.43	<.0001		
Area*Time	2223	1	56	56.03	<.0001		
Area*Time	2425	1	56	124.28	<.0001		

Area*Time	2627	1	56	166.40	<.0001
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VITA

Marlon Alberetos Greensword was born in 1979 in Spanish Town, Jamaica. He pursued his elementary education in Kitson Town All-Age School, and his secondary education at St. Catherine High School and St. Jago High School in Jamaica, where he received his high-school diploma. In 2000, he obtained a track-and-field scholarship to Gardner Webb University in Boiling Springs, North Carolina, where he majored in education. Two years later, he transferred to Louisiana State University, where he pursued his athletic activities while majoring in general studies. He obtained a Bachelor of Arts degree in general studies with concentrations in history, economics, and mechanical engineering in Spring 2005. He then pursued another bachelor's degree in industrial engineering at Louisiana State University, which he received in Fall 2007. He is now a candidate for the Master of Science in Industrial Engineering degree at Louisiana State University.