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**THE EFFECT OF THREE FOOT ORTHOSES ON PLANTAR PRESSURE
UNDER THE FIRST METATARSOPHALANGEAL JOINT OF PES PLANUS
FOOT TYPE DURING STANDING AND SLOW RUNNING**

By

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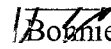
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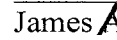
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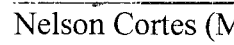
OLD DOMINION UNIVERSITY
May 2007

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ABSTRACT

THE EFFECT OF THREE FOOT ORTHOSES ON PLANTAR PRESSURE UNDER THE FIRST METATARSOPHALANGEAL JOINT OF PES PLANUS FOOT TYPE DURING STANDING AND SLOW RUNNING

Lacey Ann Nordsiden
Old Dominion University, 2007
Director: Dr. Bonnie L. Van Lunen

The purpose of this study was to examine the effect of three different foot orthoses on plantar pressure under the first metatarsophalangeal joint during standing and slow running. Twenty physically active participants, 12 males (19.7 ± 1.3 years, 181.5 ± 6.3 cm, 83.6 ± 12.3 kg) and 8 females (20.8 ± 1.5 years, 172.7 ± 11.2 cm, 69.9 ± 14.2 kg) with navicular drop greater than 10mm, no history of surgery to the lower extremity, and no history of pain or injury to the 1st metatarsophalangeal joint in the past six months volunteered for the study. Each subject performed standing and slow running tasks with four different orthosis conditions: no orthosis, metatarsal dome, U-shaped orthosis, and donut-shaped orthosis. The Pedar in-shoe pressure measurement system was used to examine the effects of each orthosis peak and mean pressure under four areas of the foot: rearfoot, lateral forefoot, medial forefoot, and the first metatarsophalangeal joint. Data were collected using Pedar-X Expert software and exported into an Excel spreadsheet for analysis. Separate 2X4X4 repeated measures ANOVAs were used to analyze peak plantar pressure and mean plantar pressure. The metatarsal dome significantly decreased peak running pressure compared to no orthosis and the donut-shaped orthosis, as well as mean standing and running pressure compared to all orthosis conditions. The U-shaped orthosis significantly reduced mean running pressure compared to no orthosis. The

donut-shaped orthosis significantly increased peak and mean standing pressure compared to all orthosis conditions; it similarly significantly increased peak and mean running pressure compared to the metatarsal dome and U-shaped orthosis. Findings suggest that the metatarsal dome is most effective in reducing both peak and mean plantar pressure during standing and slow running. Further research is needed to examine the application of these results to other foot types as well as symptomatic individuals.

Co-Directors of Advisory Committee:	Dr. James A Oñate
	Dr. Martha L. Walker
	Nelson Cortes

This thesis is dedicated to my loving family for
their never-ending support and encouragement.

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CHAPTER I

INTRODUCTION

The foot is a complex structure composed of numerous bones, joints, ligaments, muscles and tendons that all work together to form an intricate system of pulleys and levers (Mullen & O'Malley, 2004). This elaborate system allows the foot to adapt to ground surfaces, aid in shock absorption, and transition to a rigid lever for propulsion during gait (Tiberio, 1988; Miyahara, 1993). The foot is the base of the lower extremity kinetic chain, and faulty biomechanics or injury to any area of the foot can change postural-control strategies and muscle activation patterns, resulting in adverse affects throughout the entire body (Nawoczinski & Ludewig, 1999; Tomaro & Burdett, 1993; Rose, Shultz, Arnold, Gensneder & Perrin, 2002; Cote, Brunet, Gansneder & Shultz, 2005). The potential for injury to other parts of the kinetic chain has brought about the necessity to correctly recognize and treat injuries of the foot in order to restore the efficiency and effectiveness of not only the foot, but also the entire lower extremity (Franco, 1987; Hunter, Dolan & Davis, 1996).

The anatomical and biomechanical functions of a person's foot relate closely to the individual's foot type. The three commonly known classifications of foot types are a neutral foot, a pes cavus foot, and a pes planus foot type (Dahle, Mueller, Delitto, & Diamond, 1991). In general, a neutral foot is structurally sound and will allow the individual to carry out normal function with few problems. A pes cavus foot will have an abnormally high medial longitudinal arch and is generally associated with excessive foot supination and diffuse foot pain (Burns, Crosbie, Hunt, & Ouvier, 2005). Pes planus, or flatfoot, refers to a flattened or fallen medial longitudinal arch, commonly associated with

excessive foot pronation (Fiolkowski, Brunt, Bishop, Woo, & Horodyski, 2003).

Generally, the structures that support the arch become weakened, allowing an increase in forefoot mobility and, in turn, a decrease in ability to push off during the toe off phase of gait (Ledoux & Hillstrom, 2002).

As weight is transferred to the forefoot during the toe off phase of the gait cycle, the first metatarsophalangeal (MTP) joint and great toe assume a great amount of pressure (Hayafune, Hayafune & Jacob, 1999). If an individual sustains an injury to the first MTP joint, it can be extremely painful, debilitating and frustrating. Injuries such as turf toe and sesamoiditis may seem insignificant, but they can be extremely limiting for a patient, causing restrictions for participation up to two to six weeks or longer (Mullen & O'Malley, 2004). Treatment protocols for first MTP joint injuries are somewhat similar, including complete rest with a non-weight bearing gait, compression and elevation. Ice massage and non-steroidal anti-inflammatory drugs have also been shown to be effective in relieving pain (Churchill & Donley, 1998).

Once the patient is able to start bearing weight again, foot orthoses can be used to relieve pressure from the joint and make the joint more comfortable during gait (Hodge, Bach & Carter, 1999). Many variations of pressure-relieving pads such as metatarsal domes, metatarsal bars, donut-shaped orthoses, and U-shaped orthoses can be purchased or easily constructed (Goodman, 2004). While these devices are a common treatment for 1st MTP joint pain, the comparative effectiveness of pressure reduction and pain relief for each of these pads has not yet been studied.

In an effort to gain greater understanding of the anatomy and biomechanics of the foot, researchers have developed numerous tools to examine plantar pressure patterns of

the foot. These instruments have allowed investigators a great amount of flexibility in studying the biomechanics of the foot under unlimited conditions using numerous measurements (Mueller & Strobe, 1996; Barnett, Cunningham & West, 2001; Harrison & Folland, 1997; Kernozek, LaMott & Dancisak, 1996; Kernozek & Zimmer, 2000; Willson & Kernozek, 1999). Researchers are using these systems to study risk factors (Takagi, Nakagawa, Kondo & Tsuzuki, 1998), predict injury (Murphy, Beynnon, Michelson & Vacek, 2005), evaluate functional movement tasks (Willson & Kernozek, 1999; Warren, Maher & Higbie, 2004; Hessert, Vyas, Leach, Hu, Lipsitz & Novak, 2005; Santos, Carline, Flynn, Pitman, Feeney, Patterson & Westland, 2001; Eils, Streyl, Linnenbecker, Thorwesten, Volker & Rosenbaum, 2004; Hayafune et al, 1999), and develop foot orthoses to manage pain (Hsi, Kang & Lee, 2005; Hodge et al, 1999; Poon & Love, 1997; Raspovic, Newcombe, Lloyd & Dalton, 2000).

STATEMENT OF PROBLEM

The purpose of this study was to determine the effect of metatarsal domes, U-shaped orthoses and donut-shaped orthoses on plantar pressure under the first metatarsophalangeal joint of pes planus foot type during standing and slow running.

ALTERNATIVE HYPOTHESES

1. Plantar pressure will increase significantly from standing to slow running under all orthosis conditions.
2. All orthosis conditions will produce a statistically significant decrease in plantar pressure under the first MTP joint during slow running when compared to the “no orthosis” condition.

3. The donut-shaped orthosis condition will produce a statistically significant decrease in plantar pressure under the first MTP joint for all standing and running trials compared to all orthosis conditions.

NULL HYPOTHESES

1. Plantar pressure will not increase significantly from standing to slow running under all orthosis conditions.
2. There will be no statistically significant decrease in plantar pressure under the first MTP joint during slow running under all orthoses conditions when compared to the “no orthosis” condition.
3. The donut-shaped orthosis condition will not produce a statistically significant decrease in plantar pressure under the first MTP joint for all standing and running trials compared to all orthosis conditions.

DEPENDENT VARIABLES

1. Two measurements of plantar pressure were examined for each region of foot
 - a. Peak plantar pressure (kPa)
 - b. Mean plantar pressure (kPa)

INDEPENDENT VARIABLES

1. Plantar pressure was dependent upon the orthosis condition
 - a. Control (no orthosis)
 - b. Metatarsal dome
 - c. U-shaped orthosis
 - d. Donut-shaped orthosis
2. Plantar pressure was dependent upon the test condition

- a. Standing
- b. Slow running
- 3. Plantar pressure was dependent upon regions of the foot
 - a. Rearfoot
 - b. Lateral forefoot
 - c. Medial forefoot, excluding area under the first MTP joint
 - d. First MTP joint

OPERATIONAL DEFINITIONS

1. Pes planus was defined using a modification of the Brody technique as having a navicular drop greater than 10mm (Brody, 1982; Mueller & Strube, 1993).
2. Plantar pressure was defined as the distribution of contact area and contact stress on the plantar aspect of the foot (Murphy et al, 2005).
3. The metatarsal dome was a tear-shaped pad made of one-quarter inch adhesive felt (Figure 1). The edges of the felt were tapered, with the widest aspect measuring two and one-fourth inches, and the longest aspect measuring two and one-half inches. This pad was placed proximal to the head of first and second MTP joints (My Foot Shop, Granville, OH).
4. The U-shaped orthosis was made of one-quarter inch adhesive felt, which measured two inches in length and one and seven-eighths inches in width (Figure 2). The space at the distal end of the pad measured eleven-sixteenths of an inch in width and seven-eighths of an inch in depth. It formed half of a circle around the first MTP joint, and left a space between the joint and the shoe (My Foot Shop, Granville, OH).

Figure 1. Metatarsal Dome



Figure 2. U-Shaped Orthosis

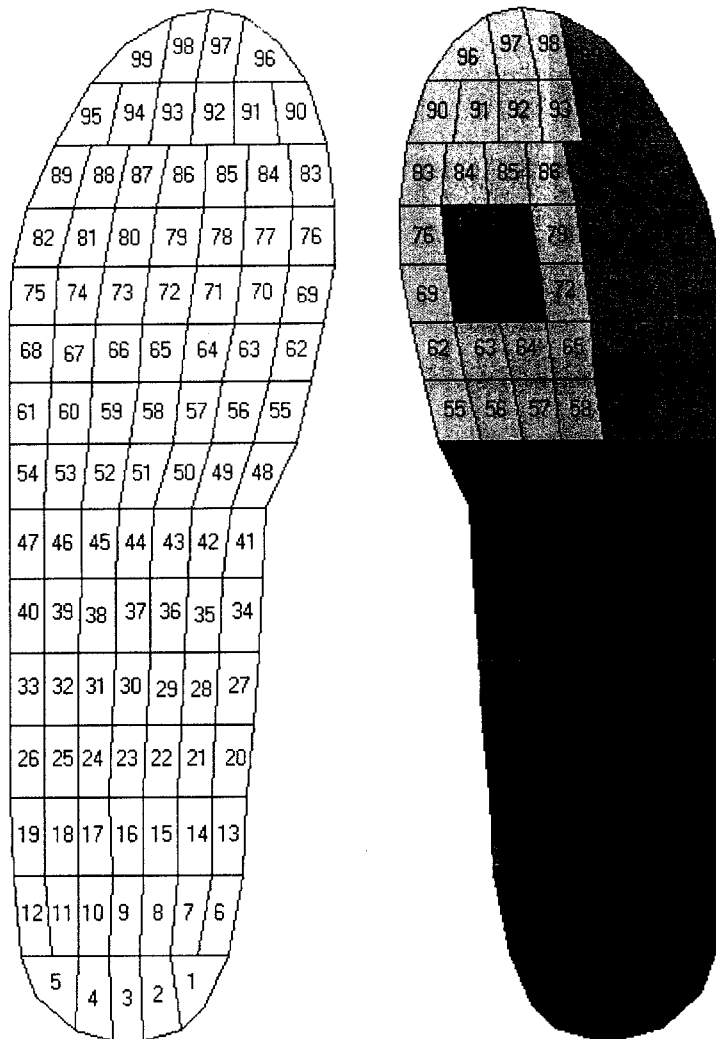


5. The donut-shaped orthosis was made of one-quarter inch adhesive felt, and measured two inches in diameter with a hole that measured one inch in diameter in the center (Figure 3). It formed an entire circle around the first MTP joint, leaving a space between the joint and the shoe. This orthosis was made by the researcher.
6. Slow running was defined as a comfortable pace between the range of 5.5 and 6.5 miles per hour (Murphy et al, 2005).
7. Regions of the foot were defined using the area of ninety-nine sensors on the pressure-sensing insoles (Figure 4). The rearfoot region was defined by the researcher as the sensors 1-54 on the Pedar pressure sensing insoles. This area on the plantar aspect of the foot spanned from the posterior aspect of the calcaneus to the proximal aspect of the metatarsal bones.
8. The lateral forefoot region was defined by the researcher as sensors 59-61, 66-68, 73-75, 80-82, 87-89, 94, 95 and 99. This area on the plantar aspect of the foot covered the shaft of the third, fourth and fifth metatarsals to the distal aspect of the third, fourth and fifth toes.
9. The medial forefoot was defined by the researcher as sensors 55-58, 62-65, 69, 72, 76, 79, 83-86, 90-93, and 96-98. This area on the plantar aspect of the foot covered the shaft of the first and second metatarsal to the distal aspect of the first and second toes, but excluded the area under the first metatarsophalangeal joint.

Figure 3. Donut-Shaped Orthosis



Figure 4. Pressure Sensor Area



10. The first metatarsophalangeal joint was defined by the researcher as sensors 70, 71, 77, and 78. This area on the plantar aspect of the foot covered the area directly under the first metatarsophalangeal joint.
11. Healthy, active college students referred to male and female individuals between ages 18-28 who reported no history of pain or injury to the first metatarsophalangeal joint in the past six months, reported no history of surgery to the lower extremity, and reported a physically active lifestyle of exercising at least 30 minutes 4-6 times per week for at least the past 2 months.

ASSUMPTIONS

1. The Pedar in-shoe pressure measurement system is a reliable and valid instrument for measuring pressure under the first MTP joint.
2. The insoles will properly fit all subjects who met the criteria for shoe size.
3. There will be a negligible amount of sensor movement within the shoes.
4. Each subject's running form will be similar across all trials with each pad.
5. Differences between treadmills of the same model will be negligible.
6. Fatigue will not be a factor and will be accounted for by counterbalancing the testing order of the orthoses.
7. Length of each subject's metatarsals will be proportional for all subjects.

LIMITATIONS

1. Only one type of material for each pad was tested in this study, so the results can not be generalized to the same shape of pads made with different material.
2. The insoles were designed to fit specific shoe size ranges; therefore, data could only be collected if the subject's shoe size matched the sensor size.

3. Software used in data collection allowed only four separate regions of the foot to be analyzed.
4. All subjects performed tests in the same brand and style of shoe, therefore limiting the results of the testing to this particular shoe.
5. All testing was performed on a treadmill, which limited the subjects to straight-line running and did not allow them to perform other functional movement patterns.

DELIMITATIONS

1. This study was generalized to male and female college student between ages 18-28 who reported a navicular drop greater than 10mm, reported no history of pain or injury to the 1st MTP joint in the past 6 months, reported no history of surgery to the lower extremity, and reported a physically active lifestyle of exercising at least 30 minutes 4-6 times per week for at least the past 2 months.

CHAPTER II

REVIEW OF LITERATURE

The use of plantar pressure measurement systems in clinical research has increased greatly over the past fifteen years, and new research opportunities continue to arise. These new tools have improved researchers' understanding of the anatomy and biomechanics of different foot types, allowed for inspection of factors that may leave individuals with specific conditions susceptible to injury, and provided an avenue for improved design of orthotic devices. While extensive research has been completed in the areas of diabetes and arthritis using plantar pressure measurement systems, the door has been opened relatively recently to using these systems in sports medicine research. This review of literature will begin by discussing the general anatomy and biomechanics of the foot, as well as three commonly described foot types. The second part of this review will explain the first metatarsophalangeal (MTP) joint, common injuries to this joint, and treatment methods that are currently used to treat these injuries. The final part of this literature review will focus on plantar pressure measurements, instrumentation, and its relevance to clinical research.

THE FOOT

Anatomy

The foot is comprised of 26 bones, which are held together by numerous ligaments and acted upon by multiple intrinsic and extrinsic muscles and tendons of the foot and lower leg (Gray, 2005). Further support is given to the foot via the plantar fascia, which is a thick band of tissue that spans the length of the plantar aspect of the foot, as well as numerous extrinsic and intrinsic muscles that are essential for gait. Several

bursae are also present in specific areas of the foot to decrease friction from muscle contraction and allow for smooth, coordinated movements of the ankle and foot (Gray, 2005).

The bones and joints of the foot are commonly divided into three regions: the hindfoot, the midfoot, and forefoot (Gray, 2005). The hindfoot consists of the calcaneus and talus bones, which form the subtalar joint. The midfoot region contains the rest of the tarsal bones (first, second, and third cuneiforms, cuboid, and navicular), as well as the transverse tarsal joint and the distal intertarsal joints. The forefoot region is comprised of the metatarsals, phalanges and sesamoid bones. Joints of the forefoot include the tarsometatarsal, intermetatarsal, metatarsophalangeal, and interphalangeal joints.

The foot also contains four arches that span multiple regions of the foot. These arches aid the foot in body weight acceptance and absorption, provide space for nerves and vessels of the foot, and increase the mechanical advantage of the muscles acting on the foot (Fiolkowski et al, 2003). The medial longitudinal arch spans the medial plantar aspect of the foot along the calcaneus, talus, navicular, first cuneiform and first metatarsal. This arch is supported by several soft tissue structures, including the posterior tibialis muscle (Willson et al, 1999), intrinsic muscles of the foot, and the plantar calcaneonavicular ligament (Fiolkowski et al, 2003). The lateral longitudinal arch, which is formed by the calcaneous, cuboid, and fifth metatarsal bones, is much lower and less flexible than the medial longitudinal arch, but it follows the same anterior/posterior pattern. The anterior metatarsal arch exists at the plantar aspect of the distal metatarsal heads, and is semiovoid in appearance (Hunter et al, 1996). The final arch, the transverse arch, forms a half dome, and can be found across the transverse tarsal bones, specifically

the cuboid and internal cuneiform bones. This arch protects the soft tissue structures of the foot and increases foot mobility (Hunter et al, 1996). Each of these arches plays an important role in the complex functions of the foot.

Biomechanics

The primary biomechanical functions of the foot are to adapt to ground surfaces (Miyahara, 1993), aid in shock absorption, and transition to a rigid lever in order to propel the body forward during push off (Neely, 1998). Previous studies have marked the importance of proper biomechanical function of the foot during gait, where even the slightest deviation can cause pain and injury further up the kinetic chain (Cote et al, 2005; Tiberio, 1988). While all joints of the foot are involved in the transition from flexible shock absorber to rigid lever arm, the two joints that account for the majority of the transition are the subtalar joint and the transverse tarsal joint (Neely, 1998).

As the heel contacts the ground, the subtalar joint is in a neutral or slightly supinated position. As it continues through the cycle, the supinated subtalar joint rapidly pronates to become flexible. This motion allows the foot to adapt to ground surfaces and to accept and absorb impact forces (Neely, 1998). During the mid to late stance phase, while the opposite leg is swinging through, the subtalar joint moves from pronation to supination and becomes a rigid lever to propel the body forward (Neely, 1998). While this is occurring, the midfoot and forefoot pronate relative to the rearfoot in order to maintain contact with the ground. By late stance, the transverse tarsal ligament follows the subtalar joint into supination, and forces are then transferred through the midfoot to the medial forefoot, and finally the great toe (Kato, Chao & Laughman, 1983).

Motions of the forefoot region are both dynamic and accessory.

Flexion/extension and abduction/adduction motions of the toes occur at the MTP and IP joints simultaneously, while the interosseous ligaments allow for gliding of the metatarsals when adapting to the ground surface (Glasoe, Yack & Saltzman, 1999). The forefoot is the only area of the foot in contact with the ground during the push-off phase of gait and has been found to sustain approximately three times the average load-bearing function of the heel (Alexander, Chao, & Johnson, 1990).

Foot Type Classifications

Morag and Cavanaugh (1999) found that foot morphology can affect foot function. Researchers and clinicians have made many attempts to classify different anatomical and biomechanical characteristics of the foot into foot types, using numerous descriptive terms and measurement instruments. The most commonly used classification is static alignment. Instruments, methods and techniques such as subtalar neutral, navicular drop (Brody, 1982), the Foot Posture Index (Yates & White, 2004), and radiographic evaluation (Younger, Sawatzky & Dryden, 2005) have been used to measure and describe static foot alignment. Another classification of foot type deals with the dynamic movement patterns of the foot. DeCock, Willems, Witvrouw, Vanrenterghem & DeClercq (2005) used plantar pressures to describe four dynamic foot type classifications in order to better understand functional foot behavior and found similar pressure distributions between jogging and walking. While these classifications are neither finite nor simple, they do allow researchers to distinguish between and make generalizations about the different foot types.

The neutral foot type has been described as having a navicular drop of 5 to 9mm (Brody, 1982). Typically, neutral foot type exhibits little or no structural deformities, and proper anatomical alignment allows for highly efficient movement during gait (Neely, 1998). At heel strike, the foot moves from supination into pronation to absorb impact forces. As weight is transferred to the midfoot, the neutral foot can adequately adapt to the ground surface, and this natural pronation helps to spread excessive forces over multiple structures, rather than a few isolated structures. During push-off phase, the neutral foot resupinates to transform from being an adaptable shock absorber to being a rigid lever arm that can exert a great amount of force against the ground surface (Katoh et al, 1983).

The pes cavus foot is most commonly associated with having an excessively high medial longitudinal arch. Also known as the cavoid and supinated foot type, pes cavus feet have a more rigid structure that is frequently associated with foot pain, which is both neurogenic and idiopathic in nature (Burns et al, 2005). Using plantar pressure measurements, Burns et al (2005) found a significant increase in peak pressure in only the rearfoot of pes cavus foot type when compared to normal foot type, as well as a significant, direct relationship between pressure-time integral and foot pain in pes cavus foot type. The rigid structure of pes cavus foot type can be explained by the constant supination of the foot through all phases of gait. Rigidity may also be correlated to stability. Cote et al (2005) found that supinators exhibited significantly less sway deviation around the center of balance than did pronators. Injuries that are commonly associated with this foot type include plantar fasciitis and metatarsalgia. Pes cavus feet are also known to be more susceptible to lateral ankle sprains, tibial stress syndrome,

peroneal tendonitis, iliotibial band friction syndrome, and trochanteric bursitis (Hunter et al, 1996).

Pes planus foot type is more commonly seen in the general population, and is associated with flatfoot, and pronated foot types. Structurally, forefoot valgus and a pronated hindfoot are common components of the pes planus foot. An everted calcaneus has also been used to describe pes planus foot type (LeDoux & Hillstrom, 2002). The continuous state of pronation shifts the center of pressure medially and creates a hypermobile first ray (Song, Hillstrom, Secord & Levitt, 1996). The inability of the first ray to become rigid and provide a lever arm for propulsion causes increased pressure upon the metatarsals. This loss of mechanical advantage has also been attributed to the decreased role of the posterior tibialis muscle in stabilizing the arch of pes planus feet (Thordarson, Schmotzer, Chon & Peters, 1995). Willson and Kernozek (1999) found that fatigue of the posterior tibialis allowed the foot to fall into a greater degree of pronation, which, in turn, may have led to significantly increased loading under the first metatarsal.

Plantar pressure analysis of pes planus feet revealed increased loading in the subhallucal area when compared to neutrally aligned feet (LeDoux & Hillstrom, 2002); however, Hargrave et al (2003) found that pronation does not influence impact in single-leg landing. Common injuries associated with pes planus feet include Achilles tendonitis, stress fractures of the second metatarsal, plantar fasciitis, posterior tibialis tendonitis, and medial knee pain (Hunter et al, 1996).

FIRST METATARSOPHALANGEAL JOINT

Anatomy and Motion

The first MTP joint has been found to play a key role in the push-off phase of gait, transferring pressures up to 462kPa during walking (Hayafune et al, 1999). The joint itself is formed by the articulation of the first metatarsal and the proximal phalanx of the great toe. The surrounding capsuloligamentous structure provides most of the stability for this joint. This structure is comprised of the plantar plate, which is anchored firmly to the proximal phalanx and loosely to the neck of the metatarsal; the medial and lateral sesamoid bones; the collateral ligaments on the medial and lateral aspect of the joint; and the deep transverse metatarsal ligament, which attaches to the lateral sesamoid bone (Gray, 2005; Mullen & O'Malley, 2004). The joint is also stabilized by the tendons that cross or insert at this joint. The extensor hallucis longus tendon supports the joint dorsally, while the abductor hallucis tendon supports the medial plantar aspect of the joint at the medial sesamoid. The adductor hallucis brevis tendon stabilizes the lateral plantar aspect of the joint at the lateral sesamoid, and the double tendon of flexor hallucis brevis adds support along the plantar aspect of the joint. The sesamoid bones act not only as muscle attachment sites, but also as fulcrums to increase the mechanical advantage of the flexor hallucis brevis tendon (Mullen & O'Malley, 2004). Buell, Green and Risser (1988) determined the average range of motion for this joint to be approximately eighty degrees of dorsiflexion and approximately forty-five degrees of plantarflexion.

Injuries to the First Metatarsophalangeal Joint

Injuries to the first MTP joint have increased since the introduction of artificial turf and lighter weight, more flexible shoes to athletic competition (Coker, Arnold &

Weber, 1978). One type of injury to the first MTP joint is sesamoiditis. Patients with this injury will often present with increased tenderness and decreased range of motion (ROM) in dorsiflexion, along with weak and painful active plantarflexion (Churchill & Donley, 1998). Pain will generally decrease with rest and elevation (Churchill & Donley, 1998; Mullen & O'Malley, 2004).

Another, more commonly noted injury is "turf toe." This term has somewhat become a catch-all term used to describe pain of the great toe; however, is specifically described to be a hyperextension injury of the great toe (Churchill & Donley, 1998). Additionally, three mechanisms of turf toe injury have been identified and include hyperextension, hyperflexion, and valgus mechanism (Mullen & O'Malley, 2004). Rodeo, O'Brien, Warren, Barnes, Wickiewicz & Dillingham (1990) found that pes planus foot type may predispose an athlete to turf toe due to the rearfoot valgus and increased medial strain of the foot. Similarly, Bryant, Tinley & Singer (1999) linked increased incidence of hallux valgus deformity to excessive foot pronation. Patients with turf toe will present with many of the same symptoms as sesamoiditis, as well as an antalgic gait pattern (Churchill & Donley, 1998).

Other conditions, such as hallux valgus, metatarsalgia, blisters, calluses, and metatarsal fractures and dislocations complicate the first MTP joint, making normal gait difficult and usually rather painful. Proper treatment of all injuries to the first MTP joint is necessary to prevent potential long term sequelae, including hallux rigidus, dorsal osteophyte, calcification of periarticular soft tissue, and chondromalacia of the first metatarsal (Mullen & O'Malley, 2004).

Interventions for First Metatarsophalangeal Joint Pathologies

Traditional treatment of injuries to the first MTP joint is similar among all injuries. Initially, rest, ice, compression, and elevation are implemented in an effort to control swelling and pain. Rest can be achieved through the use of crutches if the injury warrants them, in a non-weight bearing or partial weight bearing situation. In severe cases, surgery may be necessary to repair damaged tissues (Churchill & Donley, 1998).

As the patient returns to normal activity, foot orthoses are commonly designed to decrease pressure on areas that are still painful. Poon & Love (1997) found that metatarsal domes are effective in decreasing pressure and pain of metatarsalgia. Similarly, Hsi et al (2005) found that proper positioning of metatarsal pads can significantly affect pressure relief. Raspovic et al (2000) also demonstrated the effectiveness of a customized U-shaped orthoses in relieving plantar pressure and pain in patients with diabetic foot ulceration and neuropathy. Research concerning other types of commonly used orthoses, such as donut-shaped orthoses, as well as commonly used orthotic materials, such as felt and foam rubber, is limited.

Another consideration with the use of orthoses in managing injuries to the first MTP joint is the sensation of the orthosis on the patient's foot. Chen, Nigg, Hullinger & Koning (1995) revealed that increased sensory inputs can alter pressure patterns on the plantar aspect of the foot. This suggests that significant differences related to orthotic usage may be, in part, due to the change of sensation on the plantar aspect of the foot.

One final consideration in using orthoses to manage first MTP injuries is the possible shift of the center of pressure from the first and second metatarsals to the third, fourth and fifth metatarsals, also known as lateralization. Takagi et al (1998) showed a

significant lateralization of center of pressure in subjects with metatarsophalangeal lesions caused by rheumatoid arthritis. The lateral shift of center of pressure also increased the difficulty of forward thrust during gait. In designing orthoses for the first MTP joint, lateralization must be taken into consideration. If the material of the orthosis is so thick that the center of plantar pressure deviates laterally, the positive effects of the orthosis may be negated by the negative effects of lateralization.

PLANTAR PRESSURE MEASUREMENT SYSTEMS

Instrumentation

Plantar pressure is described as the distribution of contact area and contact stress on the plantar aspect of the foot (Murphy et al, 2005). The study of plantar pressure is becoming more prevalent to the research community, and technology has advanced greatly since the introduction of plantar pressure measurement systems. Multiple tools for conducting plantar pressure research currently exist. One type of system used for studies on plantar pressure is the pressure platform (EMED-SF system, Novel GmbH, Munich Germany), which are similar to force plates. With these tools, plantar pressures during stance and gait can be easily analyzed.

Pressure platforms allow researchers to easily collect data on standing pressure measurements. Gait analysis, on the other hand, requires subjects to time their gait so that their foot strike lands precisely in the middle of the pad. Because the subjects have to think about the timing and location of their foot strike, the reality of catching the foot strike during “normal” gait has been questioned (Bryant et al, 1999; Taylor, Menz & Keenan, 2004). Efforts have been made to disguise the plate within a “runway,” but many trials have had to be discarded due to partial or improper landing on the pad. In

these and other studies, subjects were required to be barefoot and as a result, researchers questioned whether the results of barefoot pressures correlated to and could be applied to in-shoe pressures (Chen, Tang & Ju, 2001).

In response to the need for a different system, in-shoe pressure measurement systems were designed and implemented (F-scan, Tekscan, Boston, MA; Pedar, Novel GMBH, St. Paul, MN). These systems place a set of insoles within the subject's shoes and are connected to a microcomputer that can be worn at the subject's waist or back. The microcomputer is then connected to a laptop computer via hard wire or wireless connection, making the system extremely portable. This portability also allows tremendous freedom to both researchers and subjects in regards to the dynamic tasks that can be examined and performed. The systems also give researchers a more realistic picture of the foot while in a shoe; therefore, presenting a more realistic environment for assessment (Kernozek et al, 1996; Kernozek & Zimmer, 2000; Murphy et al, 2005).

Numerous companies have developed these systems for measurement, and research has been done to determine the validity and reliability of each system (Murphy et al, 2005; Mueller & Strube, 1996). While the systems may vary slightly, the values that are measured by each system are standard. The most common measurement that is examined is peak pressure, measured in kilopascals (kPa). This value quantifies the maximum amount of pressure under a specific area of the foot during any given segment of the gait cycle. Average pressure is very similar, except that it looks at values for multiple steps. Researchers have used this value in examining the role of pressure in development of overuse injuries. Pressure distributions have been used to explain the variance in pressure between different areas of the foot. Integration of values for contact

area and time into pressure analysis have also been useful in studying shoe type and shoe fit (Santos et al, 2001).

The plethora of systems to measure plantar pressure permits researchers to conduct experiments using countless protocols. Static plantar pressure is commonly used as a baseline measure for dynamic testing. Previous studies have compared these values to radiographic anatomical alignments, muscular activity, and comfort level to determine if any relationships exist. A study by Bryant, Tinley & Singer (2000) found no correlation between radiographic measurements of normal, hallux valgus, and hallux limitus feet and mean peak pressure recording of any region of the foot. In a study on muscle activity and plantar pressure, Warren et al (2004) found that temporal changes in pressures over the forefoot and toe regions closely paralleled temporal changes in medial gastrocnemius muscle activity. A study by Hodge et al (1999) on relationships of peak plantar pressure and pain with orthotic management of rheumatoid arthritis found a significant correlation between ratings of pain and average pressure beneath the second metatarsal head. These subjects reported a reduction in pain with the use of a custom-molded metatarsal dome.

Assessment of dynamic plantar pressure with these systems has also been done for walking, slow running, and other functional movement tasks. Hessert et al (2005) compared dynamic walking between young and old adults, and found that lateral deviation in the gait of older adults may affect their stability during walking. In their study on slow treadmill running, Kernozek and Zimmer (2000) found that peak plantar pressures significantly increased as speed of gait increased. More recent research has also included evaluation of sport-specific movement. Eils et al (2004) compared plantar

pressures of in-line running to the soccer-specific movements of cutting, sprinting and kicking. They also compared grass playing surfaces to cinder playing surfaces. While the playing surfaces had no significant effect on plantar pressure, each task caused significant increases in peak plantar pressure under specific areas of the foot. They suggested that the combination of high plantar pressures in conjunction with repetition of the analyzed tasks may predispose athletes to overuse injuries.

These systems also give researchers the ability to analyze specific phases of the gait cycle, as well as specific areas of the foot. Hayafune et al (1999) examined pressure during the push-off phase of the gait cycle. They used the software to define ten different anatomical areas, or masks, of the foot. Each mask was then individually analyzed and compared against the other masks to determine statistical significance. They found that the areas under the great toe and second metatarsal head experience the highest pressures during this phase of gait (Hayafune et al, 1999).

The research that has been performed with plantar pressure measurement systems has greatly furthered knowledge of anatomy, injury, and biomechanics of the foot. However, with the extensive variability of measurement systems, the numerous values that can be obtained with these systems and the number of gait analysis protocols that have been developed; cross-study comparisons of plantar pressure distributions have become very difficult. Ideally, as research with these tools progresses, standardized protocols will be developed.

Clinical Research

Plantar pressure measurement systems have already been widely utilized in research studies dealing with diabetic and arthritic abnormalities of the foot. In the

diabetic foot, loss of sensation and increased plantar pressures leads to ulcerations under specific areas of the foot (Boulton, Kubrusly, Bowker, Gadia, Quintero, Becker, Skyler & Sosenko, 1986). If these areas become ulcerated, patients run an extremely high risk of infection, which could in turn lead to amputation. In order to prevent this occurrence, researchers have examined plantar pressure in diabetic feet to identify areas of increased pressure, and alterations in gait that may be caused by progression of the disease. Biomechanical gait analysis in diabetic neuropathic patients indicated an alteration in the neuropathic patient's movement structure (Sacco & Amadio, 2000). While the actual cause of the deviation could not be identified, the researchers speculated that the musculoskeletal mechanisms were used to compensate for the sensory deficit of their condition.

Researchers and podiatrists have used this information to design foot orthosis in an effort to reduce areas of high pressure and disperse plantar pressure more evenly across the foot. Raspovic et al (2000) studied the effect of customized insoles on plantar pressure in diabetic neuropathy and ulceration. They found significant decreases in peak vertical plantar pressures, decreases in the pressure/time integral, and increases in total contact surface areas when comparing insole to no insole conditions. Research on arthritic conditions has evaluated plantar pressure in a similar fashion. Hodge et al (1999) performed a similar study on orthotic management of plantar pressure and pain associated with rheumatoid arthritis and found that all orthoses significantly reduced both pressure and pain under the first and second metatarsal head when compared to the control group.

Sports medicine is the newest field that has incorporated plantar pressure measurements into research. Like other fields, pressure values have been studied in

relation to athletic injury. Current research is preparing to explore correlations between plantar pressure patterns and predicting athletic injuries (Murphy et al, 2005). Another study found peak plantar pressure to provide a quantitative analysis for normal and pathological foot motion (Chen et al, 2001). These values have been used in looking at the effect of playing surface, shoe wear, shoe fit, and types of activity on plantar pressure patterns. Results of these studies can aid in the design of shoes and surfaces that help to reduce peak pressures on susceptible areas of the foot. Several studies have also described the effects of orthoses in reducing joint pressures and pain in subjects with metatarsalgia (Poon & Love, 1997; Hsi et al, 2005). Poon and Love (1997) found that the use of a metatarsal dome significantly reduced pain and peak pressure associated with metatarsalgia. Furthermore, Hsi et al (2005) found that properly positioning a metatarsal dome just proximal to the metatarsal head significantly reduced peak pressure and increased comfort under the affected metatarsal head. Few studies were found regarding the effectiveness of other commonly used foot orthoses.

SUMMARY

The use of plantar pressure measurement systems in research is a relatively new trend. Studies involving plantar pressure involve various systems, utilize multiple protocols, and examine numerous values, which has led to a discrepancy in making cross-study comparisons. While significant research has already been done in diabetics and arthritis, the door is just beginning to open for plantar pressure research in sports medicine, with examination of functionality of foot types and common athletic injuries. Plantar pressure research can aid in better understanding the anatomy, function,

biomechanics and injuries that occur to the foot, as well as the use of orthotic devices in treating abnormalities.

CHAPTER III

METHODOLOGY

DESIGN

A repeated measures design was utilized to assess two different activities (standing and slow running) under four different orthoses conditions: metatarsal dome, U-shaped orthosis, donut-shaped orthosis, and no orthosis. The dependent variables were the peak and mean plantar pressures of the rearfoot, lateral forefoot, medial forefoot excluding the area under the first MTP joint, and the first MTP joint, measured in kilopascals by the Pedar in-shoe pressure measurement system (Novel GMBH, St. Paul MN, USA).

SUBJECT CHARACTERISTICS

Twenty subjects, 12 males (19.7 ± 1.3 years, 181.5 ± 6.3 cm, 83.6 ± 12.3 kg) and 8 females (20.8 ± 1.5 years, 172.7 ± 11.2 cm, 69.9 ± 14.2 kg) with no history of pain or injury to the 1st metatarsophalangeal joint in the past 6 months participated in the study. Subjects were required to wear between sizes 6 and 12 in a men's shoe, had no history of surgery to the lower extremity, had a navicular drop greater than 10mm, and participated in physical activity for at least 30 minutes, 4-6 times per week for at least the past 2 months. Subjects were instructed to refrain from activity the day of testing. Each subject signed an informed consent before participating in this study, which was approved by the University institutional review board.

INSTRUMENTATION

The Pedar in-shoe pressure measurement system (Novel GMBH, St. Paul MN, USA) was used to collect plantar pressure data during all trials. A pair of pressure-

sensing insoles were placed into a standardized pair of shoes (Nike Air Max Glide, Beaverton OR, USA) and connected directly to a microcomputer (Novel GMBH, St. Paul MN, USA) that was worn in a camelback backpack securely strapped to the subject's back. The microcomputer was connected to a laptop computer (Sony Vaio, Tokyo, Japan), where data from each trial was viewed and recorded. Each insole was 2mm in thickness and contained ninety-nine individual sensors dispersed evenly throughout the insole. Insoles were calibrated using the Trublu^R calibration device at the beginning of each subject's session. A sampling rate of 100Hz was used, and pressure was recorded in the range of 0 to 600kPa. The Pedar in-shoe system had been previously determined to be a reliable instrument in measuring plantar pressure during gait with *r* values calculated at 0.84-0.99 (Kernozek & Zimmer, 2000) and 0.98, (Kernozek et al, 1996).

All jogging trials for each subject were performed on a Life Fitness 9500HRT treadmill (Life Fitness, Schiller Park IL, USA) in a university fitness center. This treadmill was calibrated to determine accuracy of speed prior to testing.

TESTING PROCEDURES

Subjects reported to the athletic training clinic wearing a t-shirt and athletic shorts for one session. The subject's navicular drop, height, age, and weight were recorded. Subjects were given a standard pair of socks (Russell Corporation Brand, Alexander City AL, USA) to wear during testing. The pair of insoles was secured using double-sided carpet tape in a pair of Nike Air Max Glide shoes. Wiring from the insoles to the microcomputer was secured to each leg using hook and loop tape around the ankle and just below the knee. The microcomputer was worn in a camelback backpack that was tightened to prevent excessive bouncing, yet allow the subject to breathe comfortably.

Subjects were allowed a two-minute period to warm up at a self-selected pace and become familiar and comfortable with the application of the Pedar system. The insoles were then initialized to zero by having the subject lift his or her foot off the ground to remove pressure from the insole while the computer recorded the zero setting. Next, data collection began. Standing measurements were recorded prior to running measurements, and counterbalancing determined the order in which the orthoses were tested. The condition of no orthosis was always tested first. Each trial was performed three times, and the average of five dominant foot strikes was recorded and used for statistical analyses. A five minute rest period was allowed between orthosis conditions to allow the subject to rest and allow the researcher to change orthoses and initialize the insoles to zero. The insoles were calibrated at the beginning of each testing day, and all data were recorded using the Pedar-X Expert software package (Novel, St. Paul MN, USA).

Navicular Drop

Pes planus was defined using weight-bearing navicular drop, which has been found to adequately represent subtalar motion during gait (Mueller, Host & Norton, 1998). A single examiner performed all tests using a modification of the Brody technique (Brody, 1982). Subjects stood in a comfortable position with feet shoulder width apart. They were then instructed to sit down without moving or lifting their feet off the ground. The dominant foot (foot used to kick a ball) was placed in non-weight bearing subtalar neutral, and the navicular tubercle was marked using a permanent marker. A mark was placed on an index card at the height of the navicular tubercle from the ground, and this measurement was recorded as the baseline for navicular drop. Subjects were then asked to stand, bearing weight equally on both feet. At this time, the

navicular tubercle was again marked with a permanent marker, and distance to the floor was measured again. The difference between the first and second measurements was determined and recorded. This process was repeated three times, and the average of the three measurements was used as the subject's navicular drop (Cote et al, 2005). The subject was considered to have pes planus foot type if the average difference between the first and second measurement was greater than 10mm.

Metatarsophalangeal Orthoses

The three different orthoses that were utilized during this investigation included a metatarsal dome, a U-shaped orthosis, and a donut-shaped orthosis. The prefabricated metatarsal dome was made of self-adhesive, one quarter inch orthopedic felt, and had tapered edges all the way around (My Foot Shop, Granville OH, USA). The U-shaped orthosis was also prefabricated and made of self-adhesive one eighth inch orthopedic felt. To control for orthosis height, two U-shaped orthoses were placed one on top of the other to make the pad one quarter inch in height. This pad was shaped to contact the skin proximal, lateral, and medial to the metatarsal head, but left the area distal to and under the metatarsal head open (My Foot Shop, Granville OH, USA). The donut-shaped orthosis was fabricated by the researcher. One quarter inch self adhesive felt was cut into circles that measured two inches in diameter. A smaller circle measuring one inch in diameter was cut directly in the center of this circle. This orthosis formed a complete circle around the joint, leaving a space between the shoe and the joint itself. Each orthosis was secured directly to the dominant foot, worn underneath the sock, and discarded after one use.

Orthoses Placement

The metatarsal dome was placed immediately proximal to the head of the first metatarsal, where it has been found to be most effective (Hsi et al, 2005). This placement was expected to transfer pressure proximal to the first MTP joint. The U-shaped orthosis was also placed proximal to the first MTP joint, with the joint itself in the open area of the pad. This placement was expected to transfer pressure proximally, medially and laterally away from the joint. The donut-shaped orthosis was placed with the first MTP joint in the center of the cut out circle. This placement was expected to transfer pressure to tissues that surround the first MTP joint.

Pressure Measurements

Following application of the Pedar system, instructions were given for the subject to maintain an upright posture for sixty seconds in a free stance and gaze at a target placed at eye level two meters directly in front of the subject. During this time, standing measurements were taken for five seconds at ten, thirty and fifty seconds (Takagi et al, 1998). Data from the second measurement were used in statistical analysis. This process was repeated to obtain standing plantar pressure under each of the four conditions (no orthosis, metatarsal dome, U-shaped orthosis, and donut-shaped orthosis).

To obtain plantar pressure while jogging, the subject was positioned on a treadmill in the University's fitness facility. The subject was allowed to warm up at a self-selected pace for two minutes. After the warm-up period, the subject jogged at a self-selected pace between 5.5 and 6.5 miles per hour for two minutes (Murphy et al, 2005). Data were collected at three separate ten-second intervals at thirty, sixty, and ninety seconds under each condition. In order to prevent the subjects from altering their

gait during data collection, they were not notified when the data collection intervals took place.

The midstance phases (middle forty-five percent of the entire foot contact) of five dominant foot strikes were analyzed (Murphy et al, 2005). Peak pressure was defined as the highest pressure value within that mask during the midstance phase. Mean pressure was defined as the average of all pressure values within each mask during the midstance phase. An average of the peak and mean pressure values for the five foot strikes were calculated and recorded for use in statistical comparison. This method was repeated under each of the four conditions. After all trials under all conditions were completed, the subject was allowed to perform a self-determined cool down.

DATA ANALYSIS

Data from each of four areas of the foot were exported from the Pedar-X Expert software package into an Excel spreadsheet. Data were then reduced to average peak and mean pressures and imported into SPSS 12.0 for Windows (SPSS, Inc. Chicago IL, USA) for statistical analysis.

Descriptive statistics were performed to calculate the means and standard deviations. Separate 2x4x4 repeated measures ANOVAs were used to determine any significant differences in peak and mean pressure under the first MTP joint between orthosis conditions during each activity. Results were considered statistically significant at an alpha level of 0.05 or less. Tukey's post hoc analysis was performed to determine where the significant relationships existed.

CHAPTER IV

RESULTS

Descriptive statistics (mean \pm SD) for all data can be found in Tables 1-4.

Separate 2X4X4 repeated measures analyses of variance (ANOVA) were used to determine differences for the measures related to mean and peak plantar pressure.

Analysis of mean pressure revealed a significant main effect for conditions (standing and slow running), with slow running having a significantly higher mean pressure than standing ($F=441.11$, $df=1$, $p\leq.001$). A significant interaction was also found between condition, orthosis, and mask ($F=3.99$, $df=9$, $p\leq.001$). Tukey's post hoc testing for mean running pressure revealed no significant difference between the no orthosis condition and the donut-shaped orthosis. However, the metatarsal dome and the U-shaped orthosis both significantly decreased mean running pressures when compared to the no orthosis condition (Figure 5).

When comparing mean pressure between the three orthoses during running, Tukey's post hoc testing revealed that the donut-shaped orthosis produced significantly higher pressures than both the U-shaped orthosis and metatarsal dome (Figure 5). The metatarsal dome also produced a significantly lower mean running pressure compared to the U-shaped orthosis. Comparing the three orthoses during standing, the donut-shaped orthosis produced significantly higher pressures than the u-shaped orthosis and the metatarsal dome (Figure 6). Again, the metatarsal dome produced a significantly lower mean standing pressure compared to the U-shaped orthosis.

Table 1. Running Mean Pressure (Mean \pm SD) measured in kPa

	Rearfoot	Lateral FF	Medial FF	First MTP
No orthosis	32.86 \pm 9.39	111.12 \pm 29.99	120.19 \pm 30.84	180.44 \pm 53.77
Metatarsal Dome	35.20 \pm 7.70	112.37 \pm 30.97	119.63 \pm 31.58	163.07 \pm 49.46
U-shaped Orthosis	32.10 \pm 8.41	110.62 \pm 28.46	120.85 \pm 28.88	168.68 \pm 50.26
Donut-shaped Orthosis	32.30 \pm 11.57	110.14 \pm 31.19	117.50 \pm 28.94	178.85 \pm 53.25

Table 2. Standing Mean Pressure (Mean \pm SD) measured in kPa

	Rearfoot	Lateral FF	Medial FF	First MTP
No Orthosis	19.70 \pm 7.37	9.70 \pm 8.53	7.57 \pm 9.18	16.44 \pm 18.64
Metatarsal Dome	19.52 \pm 7.48	10.06 \pm 10.18	7.69 \pm 8.98	10.25 \pm 14.84
U-Shaped Orthosis	17.44 \pm 7.07	11.39 \pm 9.97	10.50 \pm 9.28	15.64 \pm 15.75
Donut-Shaped Orthosis	18.51 \pm 8.00	11.95 \pm 9.27	10.30 \pm 8.15	22.65 \pm 15.92

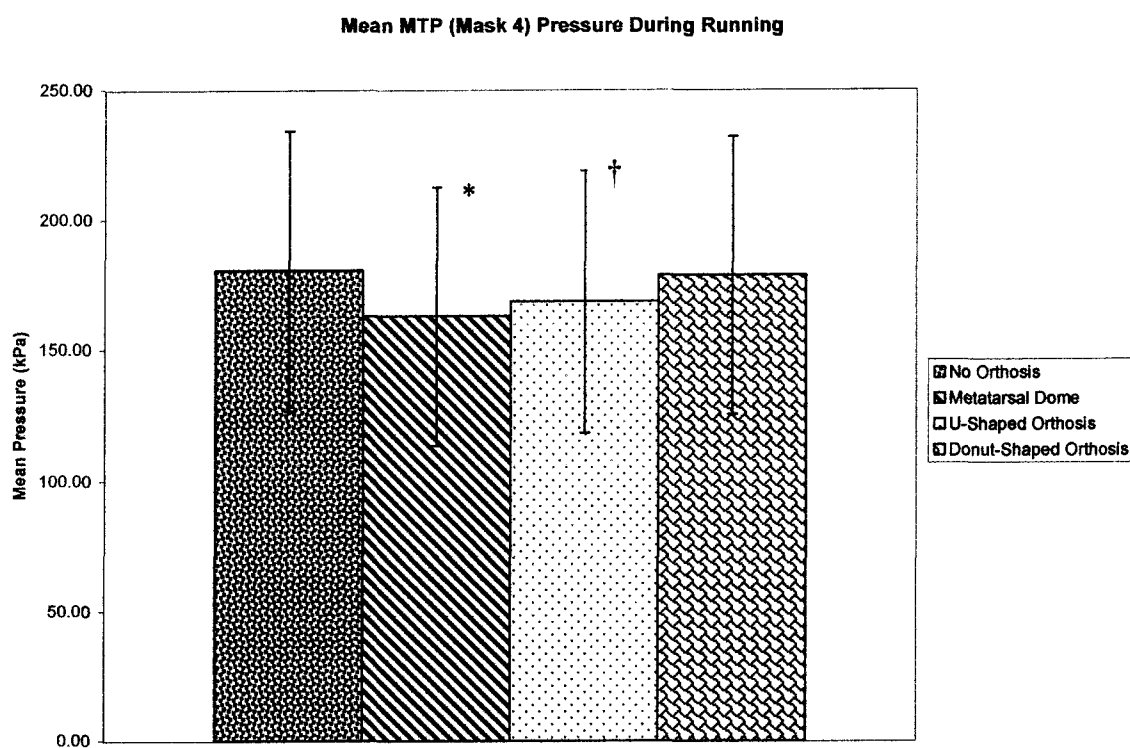
Table 3. Running Peak Pressure (Mean \pm SD) measured in kPa

	Rearfoot	Lateral FF	Medial FF	First MTP
No Orthosis	160.95 \pm 48.35	257.53 \pm 71.21	317.60 \pm 69.11	249.75 \pm 67.01
Metatarsal Dome	169.18 \pm 44.16	252.70 \pm 77.40	301.40 \pm 74.13	228.73 \pm 63.41
U-Shaped Orthosis	169.28 \pm 44.22	249.38 \pm 67.77	297.03 \pm 74.40	240.63 \pm 68.89
Donut-Shaped Orthosis	166.18 \pm 50.23	247.73 \pm 73.57	308.25 \pm 75.03	258.53 \pm 72.31

Table 4. Standing Peak Pressure (Mean \pm SD) measured in kPa

	Rearfoot	Lateral FF	Medial FF	First MTP
No Orthosis	72.00 \pm 19.02	38.25 \pm 15.48	41.38 \pm 24.55	31.00 \pm 27.65
Metatarsal Dome	65.50 \pm 15.97	39.00 \pm 20.46	35.75 \pm 20.92	24.13 \pm 23.36
U-Shaped Orthosis	63.38 \pm 15.90	42.00 \pm 19.48	49.13 \pm 21.45	32.50 \pm 24.83
Donut-Shaped Orthosis	64.38 \pm 15.79	43.00 \pm 16.13	50.50 \pm 20.61	45.75 \pm 19.38

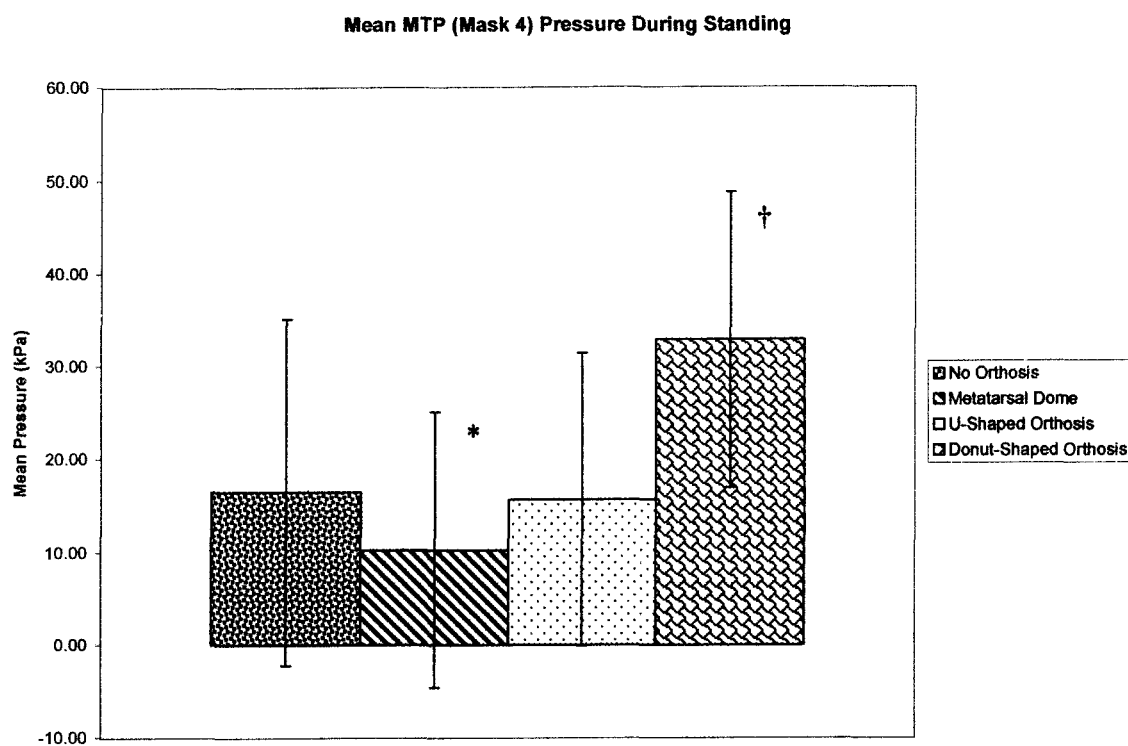
Figure 5.



* The metatarsal dome produced a significant decrease in mean pressure compared to all other orthoses conditions.

† The U-shaped orthosis produced a significant decrease in mean pressure compared to no orthosis and donut-shaped orthosis conditions.

Figure 6.



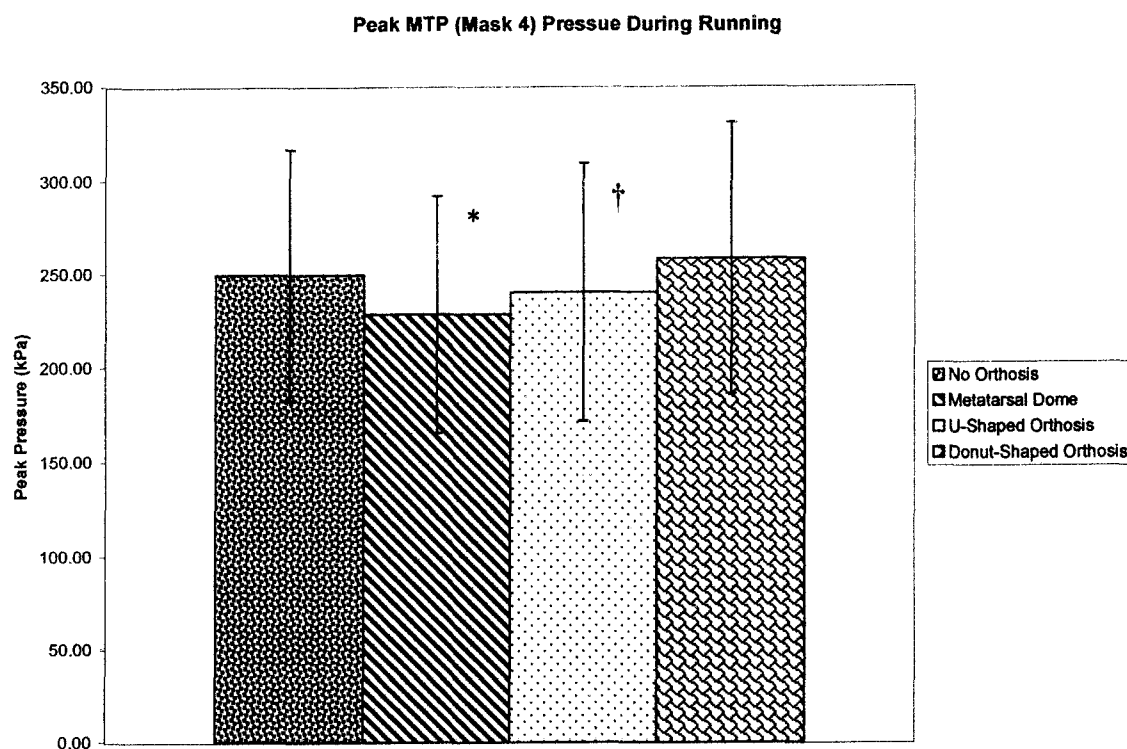
* The metatarsal dome significantly decreased mean pressure compared to all other orthoses conditions.

† The donut-shaped orthosis produced a significantly higher mean pressure compared to all other orthosis conditions.

Analysis of peak pressure revealed a significantly higher values for slow running when compared to standing ($F=383.745$, $df=1$, $p\leq.001$). Similar to analysis of mean pressure, analysis of peak pressure revealed a significant interaction for condition, orthosis, and mask ($F=5.912$, $df=4.919$, $p\leq.001$). Tukey's post hoc testing for slow running revealed that the metatarsal dome was the only orthosis to significantly decrease peak plantar pressure under the first MTP joint compared to the no orthosis condition (Figure 7). There was no significant difference between the U-shaped orthosis and the no orthosis condition; the donut-shaped orthosis significantly increased peak pressure during running (Figure 7).

When comparing the three orthoses to each other during running, Tukey's post hoc testing showed significantly lower pressure for both the U-shaped orthosis and the metatarsal dome when compared to the donut-shaped orthosis (Figure 7). No significant difference was found between the metatarsal dome and the U-shaped orthosis for peak running pressure. During standing, Tukey's post hoc testing similarly showed that both the U-shaped orthosis and the metatarsal dome significantly decreased peak pressure when compared to the donut-shaped orthosis (Figure 8). Again, no significant difference in peak pressure was found between the metatarsal dome and the U-shaped orthosis during standing.

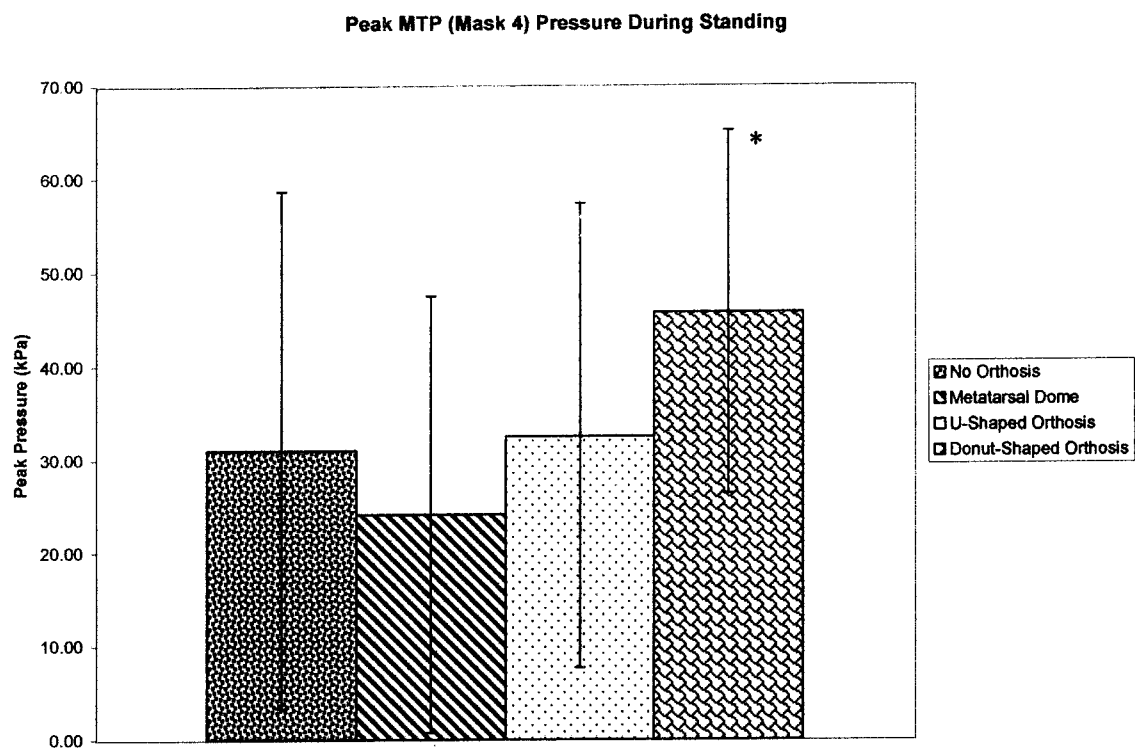
Figure 7.



* The metatarsal dome produced a significant decrease in peak pressure compared to no orthosis and the donut-shaped orthosis.

† The U-shaped orthosis produced a significant decrease in peak pressure compared to the donut-shaped orthosis.

Figure 8.



* The donut-shaped orthosis produced a significantly higher peak pressure compared to all other orthosis conditions.

CHAPTER V

DISCUSSION & CONCLUSIONS

DISCUSSION

We hypothesized that plantar pressure would increase significantly from standing to slow running under all orthosis conditions. Results of both mean pressure and peak pressure showed significant increases from standing to slow running. These changes in pressure can be attributed to increased force transmission that is associated with increased running speed and are concurrent with results from previous research on plantar loading during gait (Kernozek & Zimmer, 2000). Running speed components during in-shoe loading measurements revealed that all plantar loading variables, including peak pressure, peak pressure time impulse, peak force, and force time impulse, increased as treadmill running speed increased (Kernozek & Zimmer, 2000). Eils et al (2004) found similar increases when comparing peak pressures for running and sprinting.

We also hypothesized that application of any orthosis would decrease plantar pressure under the first MTP joint during slow running when compared to no orthosis application. Of the three orthoses, the metatarsal dome was found to be most effective in reducing both peak and mean plantar pressure, followed by the U-shaped orthosis. In contrast, the donut-shaped orthosis showed no significant difference in peak pressure under the first MTP joint compared to no orthosis application.

Lastly, we hypothesized that the donut-shaped orthosis would produce the most significant decrease in plantar pressure under the first MTP joint for all standing and slow running trials. Contrary to what was expected, the donut-shaped orthosis produced

significantly higher peak and mean pressures during all standing and slow running trials when compared to both the metatarsal dome and U-shaped orthosis.

The results of this study are in agreement with existing research on the use of foot orthoses in reducing plantar pressure. Previous research has proven the effectiveness of both the metatarsal dome (Hodge et al, 1999; Poon & Love, 1997) and U-shaped orthosis (Raspovic et al, 2000) in reducing plantar pressure at areas of illness or injury, whereas evidence to support the use of donut-shaped orthoses in the reduction of plantar pressure does not exist. Hodge et al (1999) demonstrated that a custom-molded orthosis with a metatarsal dome was the most effective of four different orthosis conditions in reducing pain and pressure in subjects with rheumatoid arthritis, while Poon and Love (1997) found that a similar custom-made metatarsal dome reduced mean plantar pressure under the metatarsal head by 13%. Another study on the use of custom-made U-shaped orthoses in subjects with diabetic foot ulceration demonstrated a significant but variable reduction in peak pressures when comparing the insole to a non-insole control group (Raspovic et al, 2000).

Despite the lack of research on donut-shaped orthoses, they are used fairly often in clinical practice to reduce areas of friction and pressure. Previous clinical use of the donut-shaped orthoses in reducing areas of high friction and pressure at various areas of the foot formulated the need to question the effectiveness of this orthosis at the first MTP joint. We therefore based our third hypothesis on its clinical success. However, the results of this study suggest that our clinical practice may not be accomplishing its intended purpose, and other types of foot orthoses should be considered before the donut-shaped orthosis is utilized.

There are a few limiting factors to consider when comparing this study to previous studies on foot orthoses. First, the orthoses used in this study were pre-fabricated, and individual foot variations were not taken into consideration in their construction. Secondly, the orthosis materials used in each study varied in density, and the ability for each material to absorb shock may negate our ability to compare them across studies. Thirdly, researchers from each study developed their own masks specific to the needs of his/her study, and very few studies actually use the same masks in evaluating plantar pressure.

Pressure Distribution

Significant differences in first MTP joint pressure were expected between orthosis conditions, but as the study progressed we began to question the effect of the orthoses on plantar pressure under the rest of the foot. The thickness of the orthoses and its application on the medial aspect of the foot brought about the concern of causing forefoot varus and therefore increasing pressure on the lateral aspect of the foot. The effect of the orthosis on sensation at the bottom of the foot was another issue taken into consideration when comparing pressure under each mask. Previous research has indicated a causative relationship between sensory input and plantar pressure. Chen et al (1995) determined that sensory input can alter plantar pressure depending on comfort. Pressure under the midfoot increased and pressure under the toes decreased as the stimuli became more uncomfortable, causing a centralization of pressure. Another study observed the effects of ice application on plantar pressure and muscle activity (Nurse & Nigg, 2001). Results showed that peak pressures were significantly higher in areas of regular sensation, whereas center of pressure shifted away from areas of decreased sensation (Nurse & Nigg,

2001). If the results of these studies held true for the current study, then increased pressure would be expected where the orthoses contacted the foot.

Comparison of pressures between the four orthosis conditions for each mask revealed no significant differences in pressure values across conditions (Tables 1-4). This indicated that plantar pressure did not increase on the lateral aspect of the foot, nor did they increase under the areas where the orthoses contacted the foot. Since changes in pressure were expected under areas of the foot other than the first MTP joint and only few changes were noted, the conclusion was made that the orthoses were doing what they were designed to do by absorbing some of the pressure and dispersing it over a greater surface area away from the joint.

Limitations

Several limiting factors were also observed within this study. While shoe type was standardized, the results may still have been affected by it. All subjects had a pes planus foot type, but individual variations in foot structure and function, as well as the fit of the shoe may have affected the results. The quality and flexibility of the shoes used in this study may not be realistic for an individual with first MTP pain or injury. Broad-last shoes with a firm insole are commonly used to prevent extension at the first MTP joint (Mullen & O'Malley, 2004); the test shoes allowed a rather significant amount of MTP extension.

Individual running form was another factor that may have affected the results of the slow running activity. Subjects were instructed to perform a slow run at a comfortable pace, and we assumed that a heel-to-toe gait cycle would be noted. However, several of the subjects still performed the slow running activity primarily on their toes,

almost eliminating the heel strike phase of gait. Since midstance was defined as the middle forty-five percent of the foot contact with the ground, overall values of forefoot pressure were increased by the individuals who performed toe running. Realizing the increased loading seen in these individuals, we began to consider the evaluation of other phases of the gait cycle, specifically the toe off phase. Patients with an injury to the first MTP joint would need the most protection during the toe off phase due to the increased pressure under the joint, as well as the increased range of motion experienced at the first MTP joint as the body is propelled forward. Additional research is indicated to examine whether these orthoses can relieve pressure during the phase of the gait cycle that experiences the highest plantar pressures (Eils et al, 2004).

The size of the sensors was the final factor that may have affected the results, particularly for the donut-shaped orthosis. Only one set of masks was developed and used for all subjects, regardless of individual foot variations, and these masks may not have been sufficient in representing the area directly under the first MTP joint in all subjects. The donut-shaped orthosis was designed to distribute pressure around the joint, and if the orthosis infringed upon the sensor area, that may have caused an increase in pressure under those sensors, but the orthosis may have been doing what it was designed to do.

Clinical Application

The results of this study contribute to the increasing breadth of knowledge that is being applied to clinical practice in sports medicine, and it supports the use of foot orthoses as an effective method of reducing plantar pressure during physical activity. The results agree with previous research that the metatarsal dome and U-shaped orthosis

are effective in reducing plantar pressure under the first MTP joint, but other factors must still be taken into consideration when choosing or constructing the proper orthosis.

Location and intensity of foot pain; shoe type, quality and fit; duration and type of activity being performed; comfort of the orthosis; and the availability of materials used in orthosis construction will play a role in the clinician's choice of orthosis.

Further Research

Due to the variations in biomechanics and plantar pressure patterns of different foot types, the results of this study can only be applied to individuals with pes planus foot type. This study should be repeated for pes cavus and neutral foot types to determine if the orthoses are equally effective for all foot types. Other phases of the gait cycle and more sport-specific skills, such as sprinting and cutting could also be analyzed to further determine the effectiveness of each of these orthoses. Different styles of foot orthoses and types of materials that are used to construct them could also be examined for relative effectiveness. Different types of shoes that offer different levels of support for the foot as well as shoes for different athletic activities, such as football cleats and track spikes, and their interaction with the orthoses could also be observed.

Further research is also warranted to determine the applicability of studies on asymptomatic individuals to symptomatic cases. Results of previous studies have shown a significant positive correlation between pain scale ratings and average & peak plantar pressure measurements (Hodge et al, 1999; Poon & Love, 1997), indicating that the results from studies with asymptomatic individuals may be applicable to symptomatic cases. Anecdotal evidence on comfort from the current study also supports this theory. Fourteen out of twenty subjects stated that the metatarsal dome was the most comfortable

of the three foot orthoses. The metatarsal dome was also the most effective of the three orthoses.

CONCLUSIONS

The purpose of this study was to exam the effect of three different foot orthoses on plantar pressure under the first metatarsophalangeal joint during standing and slow running. Twenty physically active participants (12 males, 8 females) with navicular drop greater than 10mm, no history of surgery to the lower extremity, no history of pain or injury to the first MTP joint in the past six months volunteered for the study. Each subject performed standing and slow running tasks with four different orthosis conditions: no orthosis, metatarsal dome, U-shaped orthosis, and donut-shaped orthosis. The Pedar in-shoe pressure measurement system measured the effects of each orthosis on peak and mean pressure under four areas of the foot: rearfoot, lateral forefoot, medial forefoot, and the first MTP joint. Data were collected using Pedar-X Expert software and exported into an Excel spreadsheet.

Separate 2X4X4 repeated measures ANOVAs revealed that the metatarsal dome significantly decreased peak running pressure compared to no orthosis and the donut-shaped orthosis, as well as mean standing and running pressure compared to all orthosis conditions. The U-shaped orthosis significantly reduced mean running pressure compared to no orthosis. The donut-shaped orthosis significantly increased peak and mean standing pressure compared to all orthosis conditions; it similarly significantly increased peak and mean running pressure compared to the metatarsal dome and U-shaped orthosis. Findings suggest that the metatarsal dome is most effective in reducing both peak and mean plantar pressure during standing and slow running. Further research

is needed to examine the application of these results to other foot types as well as symptomatic individuals. Findings suggest that the metatarsal dome is most effective of the three foot orthoses in reducing plantar pressure during standing and slow running tasks. Further research is needed to examine the application of these results to other foot types as well as symptomatic individuals.

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APPENDIX A
WITHIN-SUBJECT VARIANCE FOR PEAK PRESSURE

ANOVA SUMMARY TABLE

	df	MSQ	F	p
Condition	1.00	6151166.86	383.75	.000
Error	19.00	16029.31		
Orthosis	2.19	3033.64	5.70	.004
Error	41.55	508.23		
Mask	3	94097.35	13.71	.000
Error	57	214.41		
Cond*Orth	3	538.19	2.51	.068
Error	57	3675.34		
Cond*Mask	3	186676.50	50.79	.000
Error	57	3675.34		
Orth*Mask	4.74	2220.97	6.90	.000
Error	89.97	321.83		
Cond*Orth*Mask	4.92	1392.64	5.91	.000
Error	171	128.76		

APPENDIX B

WITHIN-SUBJECT VARIANCE FOR MEAN PRESSURE

ANOVA SUMMARY TABLE

	df	MSQ	F	p
Condition	1.00	1456546.71	441.11	.000
Error	19.00	3302.04		
Orthosis	2.05	442.34	3.25	.049
Error	38.96	136.24		
Mask	1.77	213840.11	61.16	.000
Error	33.56	3496.65		
Cond*Orth	3	125.56	1.62	.195
Error	57	77.63		
Cond*Mask	2.01	210132.31	112.97	.000
Error	38.20	1860.14		
Orth*Mask	4.19	1009.58	14.72	.000
Error	79.51	68.59		
Cond*Orth*Mask	9	84.48	3.99	.000
Error	171	21.16		

APPENDIX C

INFORMED CONSENT DOCUMENT OLD DOMINION UNIVERSITY

PROJECT TITLE: The Effect of Three Foot Orthoses on Plantar Pressure of the Pes Planus Foot Type

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES. This project will attempt to determine the effect of three different foot pads on foot pressures during standing and slow running. Research will be conducted in the Freeman Center on the campus of Christopher Newport University, and the sports medicine research lab in Spong Hall at Old Dominion University.

RESEARCHERS

Dr. Bonnie Van Lunen, PhD, ATC, Graduate Athletic Training Program Director in the Department of ESPER at Old Dominion University, will be the responsible project investigator. Other investigators include Dr. James Oñate, PhD, ATC, Sports Medicine Research Laboratory Director, Assistant Professor in the Department of ESPER at Old Dominion University; Dr. Martha Walker, PT, PhD, Associate Professor in the School of Physical Therapy at Old Dominion University; and Lacey Nordsiden, BA, ATC, graduate athletic training student in the Department of ESPER at Old Dominion University

DESCRIPTION OF RESEARCH STUDY

Several studies have been conducted looking into the subject of foot pressure patterns during different movements, as well as using and positioning padding and cushioning to decrease pain and pressure on the bottom of the foot. None of them have explained which type of pad is most valuable in relieving pain and pressure under the big toe joint.

If you decide to participate, then you will join a study involving research on foot pads that are used to relieve pressure underneath the big toe joint. You will report to the athletic training clinic wearing a t-shirt and athletic shorts and your height, age, and weight will be recorded, and your foot type will be determined by measurements taken of your foot. You will be given a standard pair of socks and athletic shoes to wear during testing. A pair of insole sensors will be secured inside the shoes and will be used to measure pressure changes during activity. Wiring from the insoles to the microcomputer will be secured to each leg using hook and loop tape around the ankle and just below the knee. The microcomputer will be worn in a backpack that will be tightened to prevent excessive bouncing, yet allow you to breathe comfortably. At this point, you will be allowed a two minute period to warm up on a treadmill at a self-selected pace and become familiar with the insoles and backpack computer system. Three different foot pads will be used for testing, and one additional testing condition (no foot pad insert) will also be performed. The foot pads are made of felt and are of different shapes. The foot pads are self adhesive and will be placed on your foot prior to testing. Standing and slow

running will be recorded for each condition. The condition of no foot pad will always be tested first, followed by each of the remaining conditions. For each standing measurement, you will be asked to assume a free stance for one minute and gaze at a target, which will be placed at eye level two meters in front of you. Pressure measurements will be recorded at 10, 30, and 50 seconds. For each running measurement, you will be placed on a treadmill, and be asked to run at a slow running pace (about 5.5 miles per hour) for three minutes. During this time, data will be collected at three, ten-second intervals. In order to prevent any intentional change in gait during data collection, you will not be notified of the data collection periods. If you say YES, then your participation will last for one, two-hour session. Approximately forty healthy, active college students will be participating in this study.

EXCLUSIONARY CRITERIA

You must have flat feet in order to participate in this study. Additionally, you should have no history of surgery to your lower extremity, be between ages 18-28, and participate in physical activity for at least 30 minutes of activity 4-6 times per week. You are eligible for the study if you have no current pathologies in the area of the 1st toe, or if you have had pain to the 1st toe are that has lasted longer than three days.

RISKS AND BENEFITS

RISKS: This is a relatively safe study, but if you decide to participate in this study, then you may face a risk of falling while performing tasks on the treadmill. The researcher will try to reduce these risks by enforcing the rule of wearing the safety clip (kill switch) on the treadmill and by providing a spotter while you are on the treadmill. And, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: There is no direct benefit to you as a subject. However, the results of this study may benefit others and expand the knowledge in the profession of athletic training by revealing the most effective type of padding to use for pain and pressure under the ball of the foot.

COSTS AND PAYMENTS

The researchers are unable to give you any payment for participating in this study.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

All information obtained about you in this study is strictly confidential unless disclosure is required by law. The results of this study may be used in reports, presentations and publications, but the researcher will not identify you.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your

relationship with Old Dominion University or Christopher Newport University, or otherwise cause a loss of benefits to which you might otherwise be entitled. The researchers also reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of harm or injury arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in this research project, you may contact Dr. Bonnie Van Lunen at 757-683-3516 or Dr. David Swain the current IRB chair at 757-683-6028 at Old Dominion University, who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:

Dr. Bonnie Van Lunen	757-683-3516	Dr. James Onate	757-683-4351
Dr. Martha Walker	757-683-3309	Lacey Nordsiden	757-642-2052

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. David Swain, the current IRB chair, at 757-683-6028, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Subject's Printed Name & Signature	Date
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INVESTIGATOR'S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

Investigator's Printed Name & Signature	Date
---	------

VITA

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Education

May 2007 Master of Science in Education
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May 2005 Bachelor of Arts
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Professional Experience

01/07 - 05/07 Old Dominion University; Norfolk, VA
Co-Instructor: Prevention and Care of Athletic Injuries (EXSC340, 3 credits)

- Created lesson plans, skill laboratories and practice sessions, assignments, and examinations; responsible for daily teaching responsibilities and administrative duties

8/05 – 5/07 Christopher Newport University; Newport News, VA
Graduate Assistant Athletic Trainer

- Certified athletic trainer assignments with Football, Indoor & Outdoor Track & Field, and Men's Lacrosse
- Performed daily evaluations of athletic injuries, created and supervised treatment and rehabilitative protocols for athletes, and assisted staff ATC with administrative duties