Do Portable Anti-Fatigue Mats Affect the Mechanics or Discomfort of Walking

by

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Abstract

Prolonged periods of standing and walking creates loading on the muscles of the back and legs causing pain and discomfort to many employees who stand on hard surfaces such as cement floors. Portable anti-fatigue mats are an ergonomic intervention that is thought to be a solution for musculoskeletal injuries. Thirteen healthy subjects ranging from 18-55 years of age were recruited for the study to represent a working population. Subject completed two 3 hour sessions, one with work boots, and the other with the combination of work boots and portable anti-fatigue mats. Subjects walked for a 3 hour period to simulate a prolonged walking period. Participants were instrumented with reflective marker to collect kinematic data and walked on the force plate to collect kinetic forces acting on the body. They also completed a discomfort questionnaire for "pre", "during" and "post" exercise. Results showed no significant differences in mechanical variables, and showed significant differences in discomfort ratings for the ankle/foot and knee between conditions; while showing significant differences for the ankle/foot and low back over time.

Keywords

kinematics, kinetics, anti-fatigue matting, insole, low back, lower limb, discomfort

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1 Literature Review

1.1 Introduction

Prolonged periods of standing and walking creates loading on the muscles of the back and legs causing pain and discomfort to many employees who stand on hard surfaces such as cement floors (Redfern & Cham, 2000) . Preventing musculoskeletal disorders caused in the workplace prevention has become one of the top health and safety priorities in many countries (King, 2002). Ergonomics interventions are often presented as solutions for such injuries. An example of an intervention is anti-fatigue mats. Anti-fatigue mats are designed to reduce fatigue that is caused by standing on hard surfaces for long periods of time (King, 2002). Anti-fatigue mats have been generally studied; however most of these studies have concentrated on static work (staying in one place during a shift) (Hansen, Winkel, & Jorgensen, 1998; King, 2002; Rys & Konz, 1994). There are not many interventions addressing the foot to floor interface in place for mobile workers. Walking is considered a form of exercise (Whittle, 1999); however over the course of a shift, walking while on the job can lead to fatigue and discomfort (Whittle, 1999). A fairly new design of anti–fatigue mats have been developed where a worker's feet are fastened to a mat-type outsole. This should allow the mobile worker to have the same comfort as anti-fatigue mats provide however it is not yet proven.

***Figure 1**: Portable mats fixed to a work boot (Ergos Canada)*

1.2 Injuries associated with prolonged standing or walking

In many work conditions such as nursing, custodial work and postal delivery, workers are in prolonged standing or walking conditions (Rys & Konz, 1994). The ground reaction force (GRF) plays an important role in the discomfort and muscle pain that workers who walk for prolonged periods experience (Whittle, 1999). The repetitive striking of the heel against the floor sends impact shocks equal to two times a person's body weight upwards through the body (Brownjohn, Pavic, & Omenzetter, 2004), affecting the feet, knees, hips, and lower back. Impact shock can cause long-term damage in the surrounding joint tissues which may eventually limit activity and, in some cases, require joint replacement (Whittle, 1999). The most common symptom in prolonged standing or walking is discomfort and fatigue in the legs (Zander, King, & Ezenwa, 2004). The closer the body part to the contact point, the more likely it will be affected by prolonged standing and walking (King, 2002; Redfern & Cham, 2000). Beyond fatigue and discomfort, more serious health effects can result from prolonged standing or walking. This includes low back pain (Cham & Redfern, 2001; Hansen et al., 1998; Nelson-Wong, Howarth, & Callaghan, 2010; Whittle, 1999), painful feet and other foot problems (Cham & Redfern, 2001; Hansen et al., 1998), plantar fasciitis and heel spurs (Lutter, 1997), orthopedic changes in the foot(Cham & Redfern, 2001; Leber & Evanski, 1986), restricted blood flow (Hansen et al., 1998), swelling of the feet and legs (Hansen et al., 1998), and increased chance of arthritis in the knees and hips (Coggon et al., 2000; Rossignol et al., 2005).

1.2.1 Musculoskeletal disorders

Injuries or disorders of the muscle, tendons, ligaments, nerves, joints, or bones are caused by prolonged or sustained repetitive motions, awkward postures, forceful exertions, or limitations in motion or action (Herington & Morse, 1995). These injuries can range from mild periodic symptoms to chronic and debilitating conditions (Palmer, Walsh, Bendall, Cooper, & Coggon, 2000).

Plantar Fasciitis

Plantar Fasciitis is one of the most common causes of heel pain, which accounts for approximately 15% of all foot-related complaints (Lutter, 1997). It is understood to be an overuse injury to the plantar fascia and the perifascial structures, which over time will cause microtears and inflammation of the tissues involved (Schepsis, Leach, & Gorzyca, 1991). This MSD refers to the inflammation of the plantar fascia, which is a thick, broad, inelastic band of fibrous tissue that is connected to the heel bone and to the metatarsal bones. The inflammation to the plantar fascia is typically due to repeated trauma at the heel bone (Lutter, 1997). Inflammation and pain start in the fascia either as a result of an increase in activity level (as in initiating a walking or running program), or in association with the normal aging process (Riddle, Pulisic, Pidcoe, & Johnson, 2003).

Tendonitis

Tendonitis is a form of tendon inflammation that occurs when a muscle/tendon unit is repeatedly tensed. With further exertion, some of the fibers that make up the tendon can actually fray or tear apart. The tendon becomes thickened, bumpy and irregular. Without rest and sufficient time for the tissues to heal, the tendon may be permanently weakened (Hagberg, 1995). There are many different types of tendon inflammations associated with prolonged walking such as patellar tendinopathy (tendonitis of the knee), Achilles tendinopathy and tendonitis at the hip (Collins & Whittle, 1989).

Osteoarthritis

Osteoarthritis is the progressive loss of joint cartilage and any risk factor that results in the wear and tear of the cartilage is a risk factor in its development (Marieb, 1995). Rossignol (2005) determined that repetitive motion is a significant risk factor for the development of hip Osteoarthritis in men (Rossignol et al., 2005). Since the joints are in constant use during repetitive movements, the muscles and synovial fluid warm up. The increase in temperature causes the synovial fluid to become less viscous and thus less effective. Other risk factors contributing to the development of osteoarthritis are static postures, vibration exposure, heavy loads, trauma, and age (Rossignol et al., 2005). Therefore, it is important to understand that reducing or eliminating these risk factors will help diminish the likelihood of developing osteoarthritis.

1.2.2 Low back pain

Low Back Pain is the most commonly reported injury in the workplace (Spengler et al., 1986). It is the most common and the most expensive source of compensated work related injury in modern industrialized countries (Feyer et al., 2000). Some sources of LBP include muscle/ligament strain, disc degeneration, disc prolapse and disc bulging (herniation) (McGill, 1997). Walking long distances has been shown to cause low back pain (Shabat, Gefen, Nyska, Folman, & Gepstein, 2005). This particular study examined the difference in LBP in postmen for two conditions, insoles and no insole. All subject reported low back pain with the no insole condition, 10% everyday, 64% often, and 26% seldom (Shabat et al., 2005). LBP can arise from disease processes or functional disorders however, peak and cumulative mechanical loading constitute by far the greatest known risk factors for acute disc prolapse and for LBP in general (Adams & Dolan, 1995). Factors that can cause low back pain include high force, awkward postures and excessive repetition. Repeated loading to the spine can result in cumulative fatigue, rendering the spine less able to bear future stresses and possibly fail (Shelerud, 1998). This can potentially be a result of walking for prolonged periods. Cromwell et al (1989) found that while walking on level surfaces peak spine compressions during each step is equal to 1.2 times a person's body weight thus creating stress on the spine with each step (Cromwell, Schultz, Beck, & Warwick, 1989). Walking is a form of exercise, however too much of it may result muscle fatigue causing low back pain (Whittle, 1999). In terms of standing, research has shown that LBP can arise over time (Gregory & Callaghan, 2008). Gregory and Callaghan (2008) stated that low back discomfort overtime can be cause by the creep associated with the disc height loss which eventually results in nerve impingement thus increasing discomfort (Gregory & Callaghan, 2008).

1.3 Ergonomic Risk Factors for injury

There are many risk factors, such as force, repetition, and awkward postures that can lead to lower limb disorders when involving prolonged standing and walking. Ergonomic risk factors can lead to a great deal of stress on a person's body thus increasing the chance of developing musculoskeletal disorders (MSD). Minimizing the use excessive force, awkward postures, and repeated movements has become one of the biggest health and safety concerns in the workplace today (Holtermann et al., 2010; Hughes & Nelson, 2009; van Oostrom et al., 2009).

1.3.1 Force

In physics, a **force** is any influence that causes a free body to undergo a change in speed, a change in direction, or a change in shape. In ergonomics terms, force refers to the amount of physical effort that is required to accomplish a task or motion (Herington & Morse, 1995). Tasks or motions that require application of higher force place higher mechanical loads on muscles, tendons, ligaments, and joints (Herington & Morse, 1995). Tasks involving high forces may cause muscles to fatigue more quickly (Herington & Morse, 1995). High forces also may lead to irritation, inflammation, strains and tears of muscles, tendons and other tissues(Garrett, 1996). McGill (1997) has proposed a general theory which explores how peak and cumulative loading may differ in the way that they apply trauma to the lumbar spine region. This theory can be re-interpreted for most of the body's joints and muscles. He suggests that a peak load above the injury tolerance level of supporting tissues may result in one or all of those tissues being damaged (McGill, 1997). When a person is walking, the reaction force applied to the body from the ground is typically equal to approximately two times a person's body weight (Brownjohn et al., 2004). Impulse is determined by the propulsion forces exerted over time (Ns) (Stoggl, Haudum, Birklbauer, Murrer, & Muller, 2010). Forces generated on the body during walking are altered depending on the type of surface on which the person is walking. Although not proven yet, softer surfaces may produce higher impulse when trying to maintain the same speed as walking on hard surfaces. Due to the softer materials, the body needs to generate more propulsive force to maintain the same speed as walking on harder materials. Although soft surfaces may increase impulse, walking on hard surfaces creates higher impact shock than walking on a softer surface (Whittle, 1999). If the surface is hard such as cement floors, or tile floors, the force transmitted through the body will be generally higher than walking on a soft rubber or carpet floor (Brownjohn et al., 2004). Impact force with the ground may cause injury or posture changes unless the impact force is reduced. A recent study found that the softer materials alter the loading rate of the force being transmitted to the body during a step thus reducing the impact shock (O'Leary, Vorpahl, & Heiderscheit, 2008). A study done by Russell et al. (2007) shows that by altering the kinematics of walking, a person can reduce the impact forces. If they increase their stride length and decrease the acceleration, the impact forces will decrease.

1.3.2 Repetition

Repetition is defined as the number of similar movements in a given period of time (McGill, 1997). In ergonomics, safe limits of repetition depend on frequency, speed and duration. However, there is no specific repetition limit or threshold value (cycles/unit of time, movements/unit of time) associated with injury. The more repetitive the task, the more rapid and frequent are the muscle contractions (Proto & Zimbalatti, 2010; Putz-Anderson, 1988). Physiologically this results in a greater amount of muscular fatigue, which in turn requires a longer recovery period. During walking, there is a repetitive heel strike motion. When the heel strikes the ground repetitively, this causes a high rate of impact shock passing throughout the body. If a muscle group is not given enough time to recover between repetitions, muscle and joint soreness will escalate and can lead to a cumulative trauma injury (Folman, Wosk, Voloshin, & Liberty, 1986).

1.3.3 Awkward postures

Awkward postures include any posture away from a neutral anatomical position. These postures can be present while completing many tasks, for example, working overhead or bending down to pick up an object on the floor. While walking, awkward postures are not often present unless a person is carrying a heavy object. However, standing for long periods of time is considered to be a static posture. Static Postures can be considered as awkward postures as the individual is holding a certain position for a long period of time. When a person is in a static position, there is a reduced blood flow to tissues reducing clearance of waste products from the joint. This results in discomfort and fatigue of tissues from having to hold tensed muscles in fixed or awkward position, for a long period of time (Chiu & Wang, 2007). Static postures are stressful because they require continuous exertion of the same muscles (Gallagher, 2005). Having more stress on these muscles may eventually cause changes in posture while standing and it may also alter posture while walking (Gallagher, 2005). Clearly maintenance of tissues depends on normal loading patterns of the joint for joint nutrition.

1.3.4 Injury Mechanisms Acute/Chronic

Musculoskeletal disorders from both acute and chronic stress also cause considerable disability where work is strenuous and workers typically handle heavy loads and experience both static and dynamic postural stresses (Holmstrom, Moritz, & Andersson, 1992). Skeletal muscles degenerate over time when a load is constantly or repetitively applied to them if there no time allowed for recovery. When the muscles have degenerated, they become unable to sustain what was once a “normal” load and as a result they are more prone to failure or susceptible to an acute injury (McGill, 1997). Acute trauma (Figure 2) refers to the application of force that exceeds the tolerance of the structure during an infrequent application of force.

A study by Hunting et al.(1994) addressed the role of acute (or intense) injury that occurs instantaneously as opposed to a chronic (over time) injury (Hunting, Nessel-Stephens, Sanford, Shesser, & Welch, 1994). It should be noted that a musculoskeletal symptom cannot always be attributed to either acute or chronic stressors and is often due to a combination of the two.

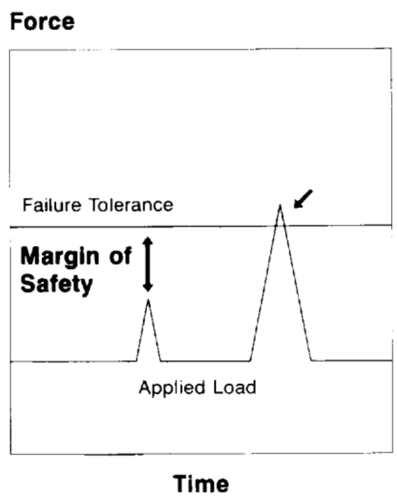


Figure 2: Acute loading (McGill, 1997).

Chronic loading or loading over time (Figure 3) refers to the repeated application of force to a structure that tends to wear down a structure, thus lowering the structure tolerance to the point where the tolerance is exceeded through a reduction of the tolerance limit (McGill, 1997). Therefore, chronic trauma represents more of a “wear and tear” on the structure.

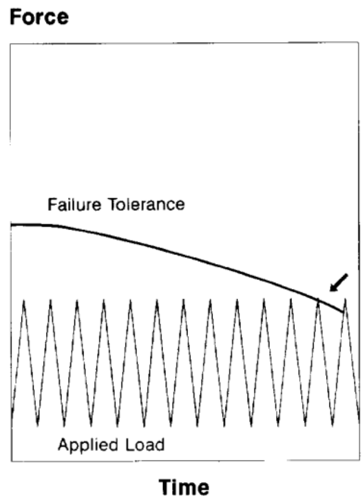


Figure 3: Chronic loading over time (McGill, 1997).

Another way to produce an injury is to induce stresses over a sustained period of time (McGill, 1997). An example of this can be standing for prolonged periods of time. The constant stress applied to the back and legs could eventually cause the tissue tolerance to weaken to the point of failure creating an injury (Gregory & Callaghan, 2008) (Figure 4). It is also important to note that a single acute insult may surpass a failure tolerance that has been lowered by chronic exposure.

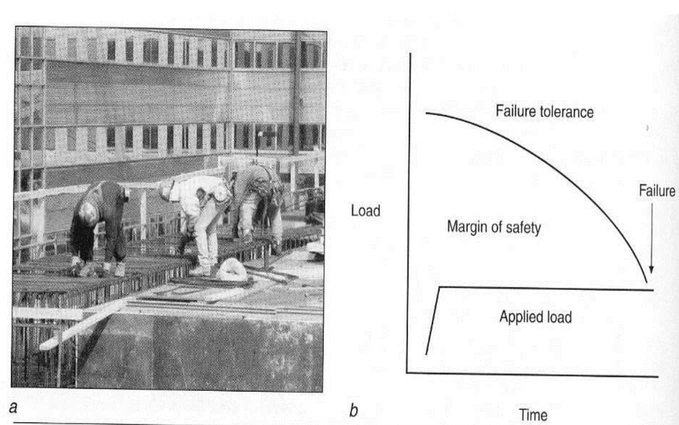


Figure 4: Sustained loading over time (McGill, 2002)

1.4 Gait

Walking is the most convenient way to travel short distances. Free body locomotion requires appropriate muscle force to increase walking efficiency {{182 Winter,David A. 2009;}}(D. A. Winter, Patla, Frank, & Walt, 1990). As the body moves forward, one limb typically provides support while the other limb is advanced in preparation for its role as the support limb. The gait cycle naturally has two phases; the stance phase and the swing phase (Sutherland, Kaufman, & Moitoza, 1994).

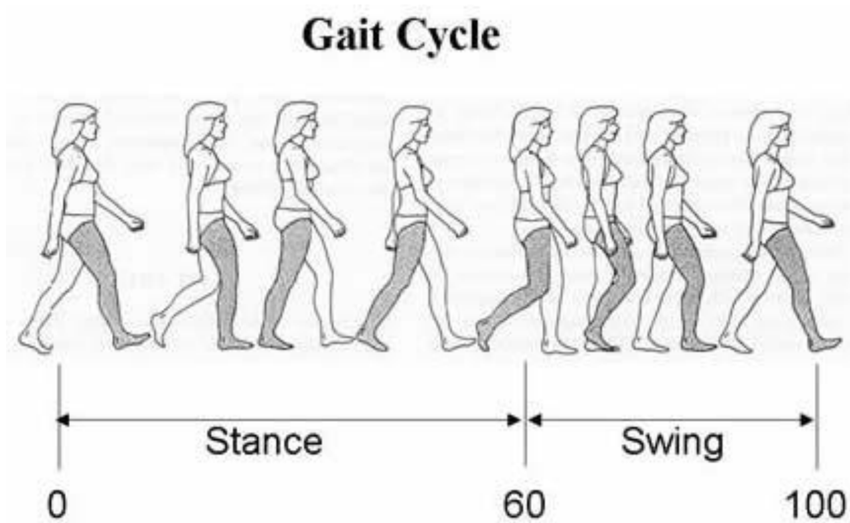


Figure 5: Gait cycle using the right leg first. (Sutherland et al., 1994)

Each phase of the gait cycle is divided into three periods. The stance phase includes (1) the initial double support, (2) the single limb stance, and (3) the second double support (Sutherland et al., 1994). The swing phase is composed of (1) the initial swing, (2) the mid swing, and (3) the terminal swing (Sutherland et al., 1994). Walking is a cyclic process; therefore, the relevant information can be captured during one complete gait cycle. Kinematics of the gait cycle can be measured using a video motion analysis system. Kadaba et al. (1990) performed a three dimensional gait analysis on 40 normal young adults measuring angular motion of the hip, knee, and ankle joints, as well as the pelvis for one gait cycle. The goal of this study was to have a normal representation of lower extremity gait data to use as a reference for describing and or comparing pathologic gait patterns (Kadaba, Ramakrishnan, & Wootten, 1990). Kinetics of the gait cycle can be measured by using pressure sensors or force platform. Researchers used these methods to measure the reaction of force acting on the body with each step (Brownjohn et al., 2004).

1.4.1 Cumulative Loading

Walking on hard surfaces for a long period of time creates cyclic loading to the joints of the lower limbs as well as the spine (Chiu & Wang, 2007; Gregory & Callaghan, 2008). Cumulative loading is associated with back pain which is the most common injury in occupational health (Marras et al., 2006; McGill, 1997). Cumulative loading can be defined as “applied loads to a structure, built up over a period of time” (Daynard et al., 2001). According to McGill (1997) when structures are subjected to cumulative loading the injury tolerance level of joints decrease over time, to the point that a lighter load may exceed the reduced tolerance level thus damaging the surrounding tissues. The load applied to the spine depends on the speed at which the person is walking (Callaghan, Patla, & McGill, 1999). When walking at slower speeds, the load applied to the spine produces more of a static load, which could be a significant risk for low back injuries and tissues (Callaghan et al., 1999). Walking at normal speeds was proven to be beneficial as the tissue loading in the spine appeared to be below levels caused by many rehabilitation tasks for the lower back (Callaghan et al., 1999). Although walking may be recommended as a rehabilitation task for low back pain, Whittle (1999) conducted a review examining the heel strike in walking and discovered that prolonged walking does create cumulative loading to other joints (ankle, knee and hip) which can be detrimental in the causation of lower limb injury (Whittle, 1999). The transient force resulted in a shock wave passing through the body, which may produce damage leading to degenerative disease in the joints of the lower limbs. The study concluded that materials used in shoe construction and viscoelastic materials can protect against transient forces produced at heel strike while walking (Whittle, 1999).

1.5 Fatigue

Fatigue can be defined as "an acute impairment of performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force" (Enoka & Stuart, 1992). Prolonged standing has been assumed to increase discomfort and overall body fatigue due to reduced blood circulation in the lower legs and static muscle fatigue (Gregory & Callaghan, 2008). This reduced circulation results in venous pooling that causes foot and lower leg swelling (Rys & Konz, 1994; Zander et al., 2004), while increasing the workload of the heart (Rys & Konz, 1994). Physiologically, as a person walks, the leg muscle action assists the heart by moving blood through the lower legs and back to the heart, therefore decreasing this venous pooling (Rys & Konz, 1994). In terms of testing fatigue, Cham et al. (2001) used EMG recordings, Center of Pressure (COP) displacement and a perceived fatigue questionnaire to determine difference in fatigue using 7 different types of flooring, hard and soft. They found significant differences in fatigue with the questionnaire and COP displacement; however the EMG recordings were not found to be sensitive enough to detect local muscle fatigue (Cham & Redfern, 2001; Redfern & Cham, 2000). As the muscles (active system) in the body become weaker or fatigued, the body starts to rely on the passive system for stabilization. The passive system consists of bones, ligaments and tendons. As the muscles begin to fail, the feedback to the neuromuscular control unit and mechanoreceptors may be negatively affected thus corrupting the normal muscle response pattern (Panjabi, 2006). This can have several adverse effects. The corrupted muscle response may create higher stresses and strains which can eventually develop into injuries to the ligaments and mechanoreceptors (Panjabi, 2006).

1.5.1 Balance and control

Balance and control is significantly influenced by the Central Nervous System (CNS). For example, the upright human body is inherently unstable and is continuously stabilized through the integration of sensory inputs such as visual, vestibular, proprioceptive and other body senses (O'Connor & Kuo, 2009). Automatically, the CNS balances the head, trunk, and legs while standing with corrective measure based on sensory feedback (O'Connor & Kuo, 2009). The reduction of a person’s senses can reduce the postural control and a greater amount of sensory loss results in greater instability although propriocetive inputs are still present (O'Connor & Kuo, 2009). Fatigue is also associated with a person’s balance and control as fatigue is known to affect the CNS (Mair, Seaber, Glisson, & Garrett, 1996). The development of localized muscle fatigue has also been observed to decrease performance in standing balance (Lepers, Bigard, Diard, Gouteyron, & Guezennec, 1997; Springer & Pincivero, 2009). In prolonged walking, there is a variation of load applied to the joints where over the period of ones work shift may have an effect on a workers balance and pain perception (Madeleine, Voigt, & Arendt-Nielsen, 1998; Windle, Gregory, & Dixon, 1999). Also, balance and stability may be influenced when standing on softer materials due to the different sensations of the softer materials (Patel et al., 2008). Humans have sensory receptors located at the bottom of their feet which contribute to maintaining postural stability (Patel et al., 2008). When standing on softer surfaces, such as foam, the information transmitted from the receptors from the feet are assumed to be less reliable. This is known to increase postural sway and change the standing strategy (Patel et al., 2008), thus influencing postural control. The softer materials offer less reflexive resistance for applied corrective movement, which makes it more difficult to control the loss of balance (Patel et al., 2008).

1.6 Interventions

According to the Canadian Centre of Occupational Health and Safety (CCOHS), there are four main types of controls that were created to minimize and control ergonomic risk factors. There is Personal Protective Equipment (PPE) which is considered the least effective form of control. There are administrative controls to deal with how the work is structured, for example, proper work practice and sufficient breaks. And most importantly, there are engineering controls and elimination and/or substitution. **Engineering Controls** are more permanent and effective. They include modifying, redesigning or replacing workstations, materials, hand tools, equipment and many other objects. Elimination and/or substitution are the most preferred method for controlling ergonomic risk factors because these controls completely remove the hazard from the workplace. This section will emphasize certain controls that were created to try to prevent injury cause by prolonged standing and walking.

1.6.1 Insoles

Insoles are common PPE engineered to fit the worker according to their body positioning. These interventions have been used for many years because they result in greater comfort (Basford & Smith, 1988; Shabat et al., 2005). Shabat et al. (2005) stated that insoles can decrease the point pressure in the foot by 30-50%, depending on the materials of the insole, thus increasing comfort. It was also shown by subjective fatigue questionnaire that insoles decrease fatigue in the lower back muscles (Cham & Redfern, 2001). Windle et al. (1999) have shown that insoles placed in shoes would attenuate the peak pressure at heel strike during running and long distance walking compared to no insoles (Windle et al., 1999). This has been proposed as a reason for the reduction of low back pain during the use of insoles (Shabat et al., 2005). Through kinetic and kinematic measurements, O'Leary et al. (2008) showed that using cushioned insoles while running significantly reduced peak impact forces and loading rate without altering knee flexion between running shoes and shoes with insole. Windel et al. (1999) examined the difference between four different types of insoles in shock attenuation while military running and marching. Using pressure sensors in the boot beneath the insole, they found an insole that provided a 23% reduction in shock attenuation while marching and 27% reduction while running (Windle et al., 1999). Pratt et al. (1986) examined five different types of insoles using force plate recordings and an accelerometer to record shock absorption. The viscoelastic materials were determined to be superior in shock attenuation.

1.6.2 Anti-fatigue matting

Anti-fatigue mats are a common ergonomic intervention to avoid worker pain and discomfort related with lower limb swelling in prolonged standing. "They have been widely accepted as an adequate remedy to reduce worker pain and discomfort" (Zander et al., 2004). Despite a limited number of studies addressing the effectiveness of anti-fatigue mats. A study conducted at the University of Pittsburgh concluded that anti-fatigue matting can significantly reduce fatigue (Cham & Redfern, 2001). This study examined 7 types of flooring mats objectively looking at COP position, EMG recordings and skin temperature, as well as a subjective perceived discomfort rating. The mats were made of various types of materials including rubber, vinyl, or carpeting. Softer materials have been found to successfully alleviate pressure, stimulate blood circulation, decrease impact shock, and dramatically reduce stress to the lower back, leg joints, and major muscle groups (Cham & Redfern, 2001; Hansen et al., 1998; Whittle, 1999). Cham & Redfern, (2001) found that harder floors and one mat condition consistently had the worst discomfort and fatigue and that in general, floor mats characterized by increased elasticity, decreased energy absorption, and increased stiffness resulted in less discomfort and fatigue (Cham & Redfern, 2001). With this in mind, anti-fatigue matting may reduce the risk of injury by decreasing the impact shock and stresses place on the body while walking for prolonged periods. Studies have shown that when comparing hard vs soft materials, generally softer materials reduce both muscle and general fatigue (Cham & Redfern, 2001; Windle et al., 1999; Zander et al., 2004). Conversely, higher ratings of fatigue are common when the materials are extremely soft. The stiffness of the materials plays a role in the discomfort and fatigue that the workers may experience. However, the ideal stiffness of the material depends on the comfort of the worker (King, 2002). In addition to comfort, cushioning has also been shown to affect kinetics. Keenan et al. (2011) found significant differences between walking with a running shoe compared to barefoot walking for kinetic variables at the hip, knee and ankle. The differences were found for hip flexion moment, hip extension moment and knee flexion (Keenan, Franz, Dicharry, Della Croce, & Kerrigan, 2011).

1.6.3 Portable anti-fatigue mats

Many occupations require workers to walk frequently (i.e. nurses, nurses' aides, welders, custodians, etc.). Unfortunately, the only apparent solution has been shoe insoles or orthotics, which can be very expensive. Since anti-fatigue mats are immobile, many of these workers suffer from many foot disorders due to standing and walking tasks away from the mat. To alleviate this , a new mat-type outsole was designed for the mobile worker. According to the manufacturer, this portable anti-fatigue product is designed to provide the same benefits as an anti-fatigue mat, while being more cost effective than insoles and orthotics (Ergos Canada). This outsole comes in different sizes and fits over regular footwear and is held in place with a series of straps. They have several styles for different environmental conditions including indoor, outdoor, snow and ice. The material used in the portable mats holds similar properties to materials used in regular anti-fatigue matting, using an anti-fatigue EVA foam cushion. To date, all the studies have examined static standing work on anti-fatigue mats(Cham & Redfern, 2001; Ellenbecker, 1996; Hansen et al., 1998; Kim, Stuart-Buttle, & Marras, 1994; King, 2002; Madeleine et al., 1998; Nelson-Wong et al., 2010; Patel et al., 2008; Redfern & Cham, 2000; Rys & Konz, 1994; Wiggermann & Keyserling, 2013; Zander et al., 2004). One study has shown the effects of portable anti-fatigue mats on ground reaction forces. In this study, subjects were required to walk on a force plate with their own running shoes and then again with their running shoes in combination with the portable anti-fatigue mats. GRF were compared between conditions and the results stated that the portable mats do reduce the loading rate thus reducing the impact shock; however this study only included acute effects of the product and did not include any long term use effect. The main limitation of the study was that there was no uniformity in the running shoes worn by the subjects, where different types of shoes could have amplified or reduced the impact shock absorption (Gauvin, Grenier, Schell, & MacDonald, 2009)(OBC 2009, Conference proceedings). Unfortunately, there are no peer reviewed studies that have examined the portable anti-fatigue mats. Therefore, no studies have examined the effects of the portable mats during prolonged walking and standing tasks while wearing work boots.

1.6.4 MSD relation to portable mats

Softer materials have been proven to reduce foot pressure and increase overall comfort (Redfern & Cham, 2000) however if the material is too soft, the mechanoreceptors in our feet become less reliable thus making it more difficult to control standing equilibrium (Patel et al., 2008). The portable mats have a softer material and therefore this mat-type outsole and similar products may be new alternatives to reducing musculoskeletal disorders of the lower body caused by prolonged walking. However, it is unknown how the softer materials of the portable mats will affect walking mechanics.

Walking mechanics and perceived discomfort in long distance walking have been widely studied with the use of insole and orthotics (Basford & Smith, 1988; Nester, van der Linden, & Bowker, 2003; O'Leary et al., 2008; Pratt, 1990; Shabat et al., 2005; Simons, van Asseldonk, van der Kooij, Geurts, & Buurke, 2009; Sobel, Levitz, Caselli, Christos, & Rosenblum, 2001; Windle et al., 1999) and other interventions such as the unstable shoe Masai Barefoot Technology (MBT) (Buchecker, Wagner, Pfusterschmied, Stoggl, & Muller, 2010; B. Nigg, Hintzen, & Ferber, 2006; B. M. Nigg, Emery, & Hiemstra, 2006; B. M. Nigg, G, Federolf, & Landry, 2010), however no studies to date have examined the use of portable anti-fatigue mats. The objective of this thesis is to determine how portable anti-fatigue mats affect the gait mechanics compared to wearing work boots using kinematic and kinetic analysis. This study also looks at the perceived discomfort ratings over time between work boots and portable anti-fatigue mats.

Chapter 2

2 *Article 1 - Measuring the effectiveness of portable anti-fatigue mat outsoles on gait kinematics and kinetics of the lower limbs.*

2.1 Introduction

Prolonged periods of standing and walking create loading on the muscles of the back and legs causing pain and discomfort to many employees who stand on hard surfaces such as cement floors (Redfern & Cham, 2000) . Preventing musculoskeletal disorders caused in the workplace prevention has become one of the top health and safety priorities in many countries (King, 2002). Ergonomics interventions, such as an anti-fatigue mat, are often presented as solutions for such injuries. Anti-fatigue mats are designed to reduce fatigue that is caused by standing on hard surfaces for long periods of time (King, 2002). Anti-fatigue mats have been generally studied; however most of these studies have concentrated on static work (staying in one place during a shift) (Hansen et al., 1998; King, 2002; Rys & Konz, 1994). There are not many studies addressing the foot to floor interface in place for mobile workers. To date, all studies found have examined static standing work on anti-fatigue mats (Cham & Redfern, 2001; Ellenbecker, 1996; Hansen et al., 1998; Kim et al., 1994; King, 2002; Madeleine et al., 1998; Nelson-Wong et al., 2010; Patel et al., 2008; Redfern & Cham, 2000; Rys & Konz, 1994; Wiggermann & Keyserling, 2013; Zander et al., 2004). A fairly new design of anti–fatigue mats have been developed where a worker's feet are fastened to a mat-type outsole. This should allow the mobile worker to have the same comfort as anti-fatigue mats provide however, this has not been not yet proven to be the case. According to the manufacturer, this portable anti-fatigue product is designed to provide the same benefits as an anti-fatigue mat (Ergos Canada). The outsole fits over regular footwear and is held in place with a series of straps. Several styles exist for different environmental conditions including indoor, outdoor, snow and ice.

Only one study has shown the effects of portable anti-fatigue mats on ground reaction forces. This study stated that the portable mats do reduce the loading rate of the forces being applied thus reducing the impact shock, however this study only included acute effects of the product and did not include any effect of long term use ((Gauvin et al., 2009)OBC 2009, Conference proceedings). Research has shown that other interventions such as insoles and running shoes can have an effect on gait kinematics and kinetics (Keenan et al., 2011; Nester et al., 2003). Windle et al. (1999) have shown that insoles placed in shoes would attenuate the peak pressure at heel strike during running and long distance walking compared to no insoles (Windle et al., 1999). Some speculate that this may be the reason for the reduction of low back pain during the use of insoles (Shabat et al., 2005). Through kinetics and kinematics measurements, O'Leary et al. (2008) showed that using cushioned insoles while running significantly reduced peak impact forces and loading rate without altering knee flexion between running shoes and shoes with insole. No studies to date have measured the effect of anti-fatigue mats on gait kinematics and kinetics.

Softer materials have been proven to reduce foot pressure and increase overall comfort (Cham & Redfern, 2001; Redfern & Cham, 2000) however if the material is too soft, the mechanoreceptors in the feet become less reliable thus making it more difficult to control standing equilibrium (Hansen et al., 1998; Patel et al., 2008; Zander et al., 2004). Controlling equilibrium while standing on soft surface was shown to increase movements at the knee to maintain postural stability (Patel et al., 2008) , however, it is unknown how the softer materials of the portable anti-fatigue mats will affect walking mechanics.

The aim of this study was to describe the effects of portable anti-fatigue mat outsoles on the kinematics, joint moments, and joint loading patterns of the hip, knee and ankle; before, during and after a prolonged walking exercise compared to wearing a work boots. It was hypothesized that (1) during gait, joint angles and moments at the hip, knee and ankle would change with the portable anti-fatigue mats compared to work boots. (2) Medio-lateral centre of pressure and anterior-posterior centre of pressure displacement would decrease while wearing the mat-type outsole. (3) GRF and joint loading rate would decrease while wearing the portable anti-fatigue mats.

2.1 Methods

Thirteen participants (n=13) who were physically active and free from any known musculoskeletal disorders were recruited to participate in the study. Due to problems during the collection process, data could not be used for three (n=3) subjects, therefore, data were collected for ten (n=10) subjects. The participants represented a random sample drawn from a healthy university and community population. Participants were a mix of males (n=5) and females (n=5), ages ranging from 18-55 years old, with a weight of 77 kg ± 16 kg, to represent a working population.

During the testing session, participants were instrumented with reflective markers on their upper and lower body segments to enable three-dimensional tracking of kinematic information with an infra-red camera system (Vicon Peak Motus 9.0.1, Denver, US). The participants were asked to wear tight black clothing to which the reflective markers were adhered using double-sided tape. Markers were positioned using a modified Helene Hayes Marker set up (Kadaba et al., 1990). Markers were placed bilaterally over the acromion process, the highest point of the iliac crest, anterior superior iliac spine, posterior superior iliac spine, greater trochanter of the femur, lateral femoral condyle, lateral malleolus, posterior aspect of the calcaneum, and the base of the 5th metatarsal. Two AMTI force plates (Advanced Mechanical Technology Inc., Watertown, USA) were used to record ground reaction forces and centre of pressure while walking.

The participants completed testing on two separate days with a minimum of 48 hour between sessions to allow for an adequate rest period. Attempting to avoid day to day variability, testing was completed at the same time of the day for both sessions. Session 1, subjects were required to walk over the force platforms under one of the two conditions: (1) Work boots, or (2) Portable anti-fatigue mat outsole. The footwear selection was randomized for the first session. Three trials were completed for each segment of both sessions, before, during and after the walking exercise. According to Cham et al. (2001) there were no signs of any changes in low back discomfort/fatigue until the 3rd hour of standing, while Gregory et al. (2008) found that there was a 78% variance of low back discomfort after 2h of standing. Hansen et al. (1995) found significant increases in low back pain, leg pain, and foot pain in prolonged standing/walking conditions after a 2h. Therefore in this study, the subjects were required to walk for approximately 3 hours to represent a prolonged walking period. The 3 hour walk was completed on a walking course created in the Ben Avery Building of the Laurentian University. This walking course was on hard flooring with a series of stairs and distance walking to mimic normal working conditions. Subjects would walk the course at their chosen pace. During the testing the subjects wore their own work boots. All work boots had similar characteristics, they were all steel toed, high cut and leather. One session was completed with the work boots only and the other session was completed with the work boots in combination with the portable anti-fatigue outsole. A metronome was not used as during the mock trials, it was observed that while trying to follow the metronome, subjects would change their gait. Therefore, the subject asked to walk at their chosen pace for the pre, during, and post walking examination. Practice trials were given for each subject to become familiarized with the placement of the force plates and to try and land on the force plates during the walk.

2.2 Data Processing

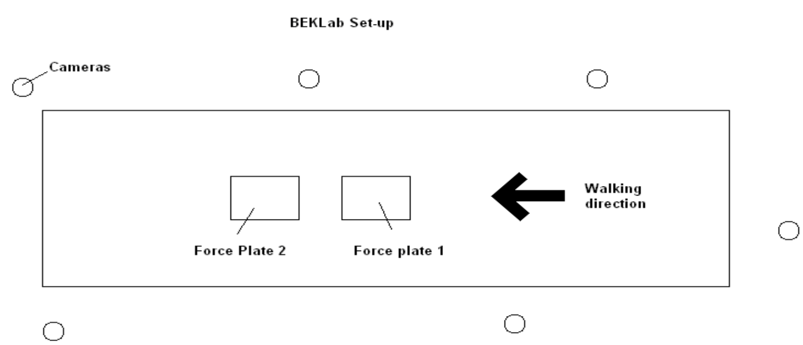


Figure 6 : Laboratory set up

Force platform data for each trial was filtered with a low pass Butterworth filter with a frequency cut-off of 10 Hz (Gregory & Callaghan, 2008; Nelson-Wong et al., 2010). Anterio-posterior (AP) and medio-lateral (ML) centers of pressure (COP) were calculated using the following equations:

$$COP_{A-P} = \frac{M_x}{F_z} \qquad COP_{M-L} = -\frac{M_y}{F_z}$$

These calculations were performed according to the force platform coordinate system, x, y, z, where the positive for y is anterior with regards to the subjects position, positive for x is to the subjects left, and positive for z is vertically downwards. COP difference was calculated by taking the difference between the minimum and maximum values for COP_{AP} and COP_{ML} with and without the portable mats.

Two dimensional motions of the feet, legs, trunk, arms, head and the body as a whole were recorded at a sampling rate of 60 Hz. Through the postural data, joint angles were calculated. Angles of the hip, knee, and ankle were compared in work boot and mat-type outsole condition at the right heel strike during one step of the gait cycle before, during and after exercise. Calculated segment masses, moments of inertia, and segment velocities and accelerations were combined with the positions of the joint centres and the kinetic data, to derive the external joint moments at the ankle, knee and hip using inverse dynamics from the ground moving up the kinetic chain. GRF loading rate was calculated using the vertical GRF (z-axis) from the time of initial loading (heel strike) to the time of the peak force of the initial stance phase in newtons/second. Segment masses, moments of inertia and centres of gravity were calculated using anthropometric tables of Winter (D. A. Winter & Wiley InterScience, 2009) while all other calculations were completed through the Peak Motus gait protocol. Joint moments were normalized to each subject's body mass (kg).

There are two experimental conditions: (1) Work boots, (2) Portable anti-fatigue outsole; testing order was randomized.

2.3 Statistical analysis

The kinematic and kinetic data from each trial for pre, during and post exercise for each subject were averaged for the right limb to determine the effect of the portable anti-fatigue mats on gait compared to wearing only a work boot. The dependant variables were derived from the data of the right limb of each subject and these include; GRF loading rate, joint loading rate at the ankle, knee and hip, peak force at the ankle, knee, and hip, COP_{AP} differences, COP_{ML} differences, maximum joint moment at the ankle, knee, and hip, maximum and minimum angles at the ankle, knee and hip, and the angle of the ankle, knee, and hip at heal strike. A 2x3 ANOVA with repeated measures were performed to compare the two experimental conditions for pre, during, and post exercise on all dependant variables. All data were tested for normality. The normality test showed that some of the kinematic variables did not have a normal distribution. Therefore, variables that did not have an approximately normal distribution were analysed using the Kruskal-Wallis test. Level of significance for each test was set at a p-value of 0.05

2.4 Results

The hypothesis that joint moments, joint loading rate and COP differences will significantly change while wearing the portable anti-fatigue mats is not supported.

Kinetics

There were small changes in GRF loading rate and COP_{AL} and COP_{ML} differences, however none were statistically significant. There were small changes in peak forces and joint loading rates at the hip, knee, and ankle but none of them were statistically significant. None of the changes in moments of force at the hip, knee, and ankle were significant. The mean kinetic data for the right hip, knee, and ankle in each experimental condition are presented in *Appendix 3 Figure 11 to 19* and mean moment data for the hip, knee, and ankle in each experimental condition is presented in *Appendix 3 Figure 20 to 24. Table 1* details the mean and standard deviation of all kinetic variables between experimental conditions, time (pre, during, and post), and condition and time interaction.

Kinematics

The effect of the portable anti-fatigue mats was more consistent for maximum angles pre exercise however was not significant. At the hip, knee, and ankle there were small angular changes minimum and maximum angles but none of which were statistically significant. Joint angle changes at heel strike at for the hip, knee and ankle were small pre, during and post exercise between conditions, and for condition and time interactions, and none were statistically significant. The mean kinematic data for the right hip, knee, and ankle for each experimental condition are presented in *Figure 3. Table 1* details the mean and standard deviations of the kinematic variables between experimental conditions.

2.5 Discussion

Kinetics

The kinetic variables include the GRF loading rate, which is the rate of the initial impact force that is transmitted to the body from the ground; the joint loading rate, which is the rate of the initial impact force acting on the joint; the COP difference, which is an indication of balance as it measures the difference between the medio-lateral and anterio-posterior COP in relation to the body's centre of gravity; and the joint moment, which is the moment of force acting on the joint. These variables should give us a good measurement of gait kinetics to determine the effect that the portable anti-fatigue mats have on the forces acting on the body during gait.

The hypothesis that joint moments, joint loading rate and COP differences will significantly change while wearing the portable anti-fatigue mats is not supported. Joint moments and joint loading rate at the hip, knee, and ankle saw minimal changes which suggest that the added portable anti-fatigue mat does not change gait mechanics during normal walking. It would be interesting to see the effect of the portable anti-fatigue mats at different walking speeds; however only subjects' normal walking speed was measured during this study.

COP differences also only had minimal changes suggesting that the portable anti-fatigue mat did not alter balance thus allowing the user to normal gait stability and not effecting walking mechanics over the 3 hours of walking.

Shock absorption is an important factor when observing cushioned footwear. We found minimal changes in loading rates which is not consistent with the study completed by O'Leary et al. (2008). They found that the use of cushioned insoles significantly reduced the mean of vertical ground reaction forces peak impact and loading rate compared to a shoe only condition, although their study observed the effect of cushioned insoles while running (O'Leary et al., 2008). However, in this study plotting the GRF loading rate means showed that "pre" and "post" exercise, the portable anti-fatigue mats improved shock absorption the most, although not significant, while "during" there was no difference (*Figure 8*). Contrary to this, our previous work examining the effects of the portable mats in its acute phase showed that portable mats had less loading rate than a regular running shoe (Gauvin et al., 2009). In this study the subjects wore a pair of work boots rather than running shoes. The difference between the two studies may be related to the type of footwear.

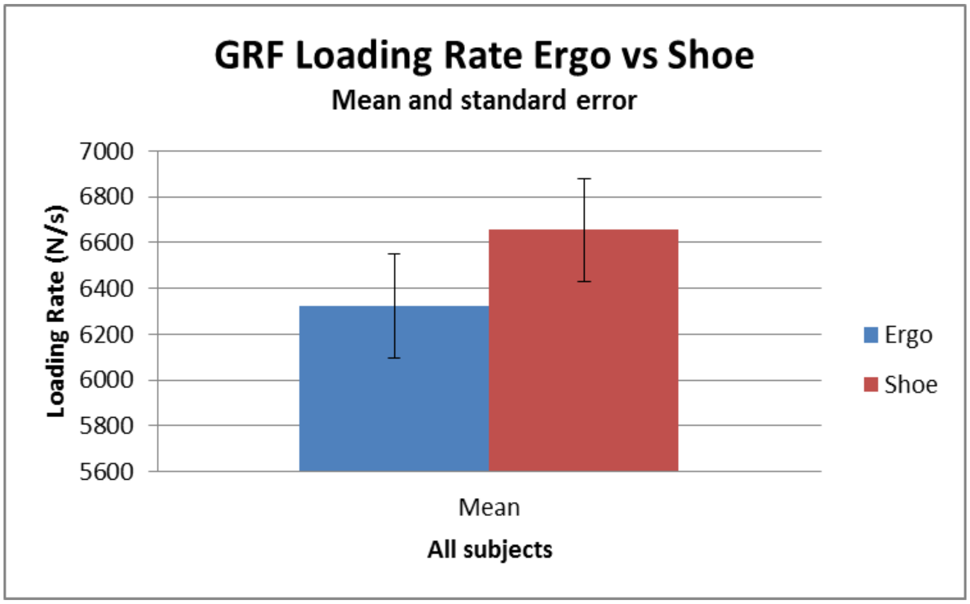


Figure 7: GRF Loading Rate in acute phases (Gauvin at al., 2009)

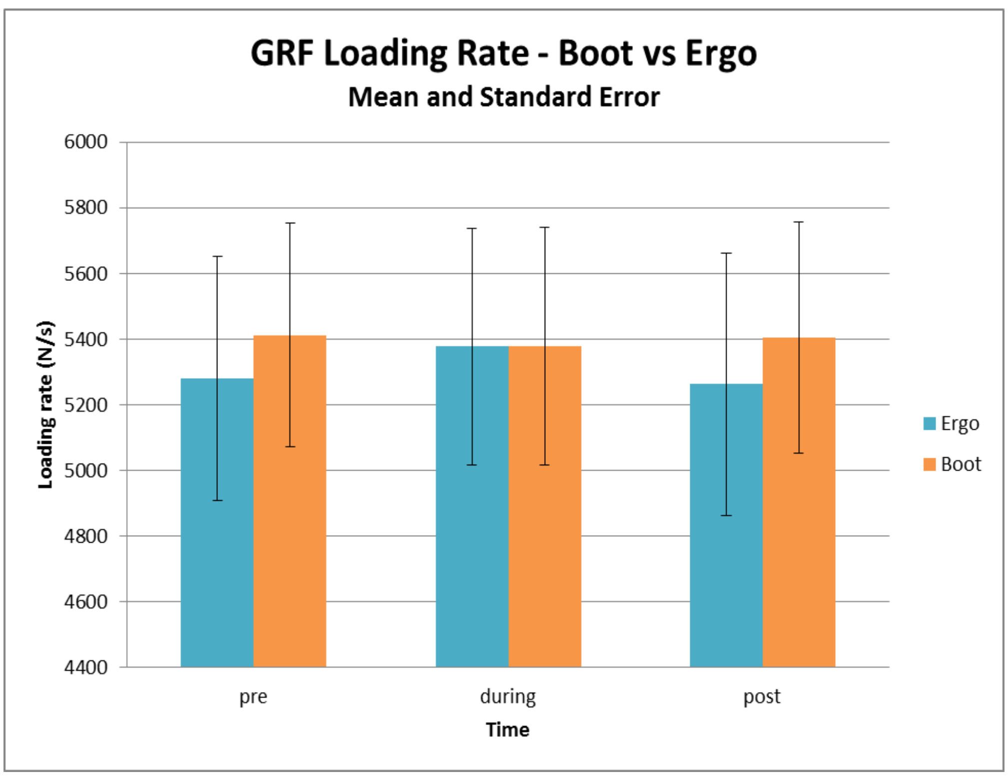


Figure 8: GRF Loading Rate in pre, during, and post exercise

When observing the results for joint loading rate for the ankle (*Figure 14*), knee (*Figure 15*), and hip (*Figure 16*) in Appendix 3, none were significant, however the results were interesting. There were small differences between the conditions where the portable anti-fatigue mats showed better shock absorption using the portable anti-fatigue mats; however over time the body seems to become acclimatised to wearing the different materials thus creating minimal effects. Before the exercise (in the acute phase) the joint loading rate at the ankle was 4525 N/s for the work boot and 3837 N/s for the portable anti-fatigue mat; at the knee the loading rate was 4467 N/s for work boot and 4465 N/s for the portable mats; and at the hip the loading rate was 4498 N/s for the work boot and 4485 N/s for the portable mats. The results were very similar when looking at the knee and hip when comparing the two conditions over time. The loading rate was less with the portable anti-fatigue mats in all cases except for the hip after the exercise, where the difference was slightly less while wearing the work boot. In order to truly understand what is happening, EMG testing would have to be completed.

The results are consistent with other studies examining loading rate, however many of the studies examined the loading rate in % of body weight per second (BW/s)(Chan, Huang, Shih, Chen, & Shiang, 2013; Keenan et al., 2011) when we measured loading rate in Newton's per second (N/s). When converting our measurements to BW/s we get very similar results. A study completed by Winiarski et al. (2009) examined the ground reaction forces in normal and pathological gait and they found that in normal gait the loading rate was 7.6 BW/s (Winiarski & Rutkowska-Kucharska, 2009). In this study we found a loading rate of 7.16 BW/s in pre, 7.11 BW/s during, and 7.15 BW/s post, while wearing work boots; and 6.98 BW/s in pre, 7.11 BW/s during, and 6.96 BW/s post. For more detail please refer to *table 1*. Speed is also a factor when examining loading rate. In this study we examine the gait mechanics at a normal walking speed. A metronome was not used as the subjects would alter their gait, therefore speed was not recorded. The average gait speed for men is 1.37 m/s and 1.23 m/s for women (Waters & Mulroy, 1999). Chan et al. (2013) found that vertical GRF and loading rate increases as speed increases. They also suggest that different sole groove design can change the loading rate under certain gait conditions (Chan et al., 2013). The effectiveness of the portable anti-fatigue mats at different speeds is unknown as this was not examined during this study.

One of the concerns we had was that the added weight of the portable anti-fatigue mats would have increased the peak force in the joints and in turn increase the moments of force acting on the joint. As there were no significant differences, it is safe to say that the added weight of the portable mats does not affect the forces acting on the hip, knee and ankle.

Kinematics

The kinematic variables include the maximum and minimum joint angles, which allow us to determine if there are differences in gait posture while walking; and joint angles at heel strike, which provides the joint angles at which the heel strikes the ground providing us with information on how the portable mats effect gait mechanics at heel strike.

The hypothesis that joint angles would change while wearing the portable anti-fatigue mats is not supported. There were minimal changes in the hip, knee, and ankle joints while wearing the portable anti-fatigue mats compared to wearing the work boots for pre, during, and post exercise. This suggests that walking mechanics are not affected while walking with portable anti-fatigue matting. Therefore, the portable anti-fatigue mats do not change the sole of the boot. This can be an advantage in the use of the product as the portable anti-fatigue mats can be used with other interventions such as custom orthotics without changing benefits that the customised insoles provide. This theory would have to be further researched in order to truly confirm the effects of custom orthotics in combination with the portable anti-fatigue mats.

Joint angle of the hip, knee, and ankle have been observed to change in studies investigating other interventions such as insoles (Hansen et al., 1998; Hardin, van den Bogert, & Hamill, 2004; Keenan et al., 2011; Nester et al., 2003; O'Leary et al., 2008) and Masai barefoot technology (MBT) shoes(Buchecker et al., 2010; Kadaba et al., 1990; B. Nigg et al., 2006; B. M. Nigg et al., 2010) most of which changes occurred at the ankle or rear foot complex. Nester et al. (2003) has significant differences at the rear foot complex while measuring the effect of orthotics however he also states that this can be an artefact of the foot being lifted inside the shoe by the depth of the orthotic and altering the angular value of the rear foot complex. When observing the MBT shoe, Nigg et al. (2006) showed a difference in the plantar-dorsiflexion angle, where the MBT shoe forced the subject to land more towards the midfoot rather than the heel. However, the changes in kinematics were around the neutral axis and consequently, no increased joint loading was found.

The results of the studies referenced above are consistent with the results of this study as there were no significant differences in joint angles of the hip and knee, as well as no significant difference in joint loading and joint moments at the hip, knee, and ankle.

Limitations

There are methodological issues regarding this study that may have played a pertinent role to the results. The reliability of gait data has been shown to be generally good (Kadaba et al., 1990; Nester et al., 2003), but some variation between the two experimental conditions is to be expected (Nester et al., 2003). Therefore, averaging the data for each pre, during, and post trials was completed to remove the minor differences from variations in gait. Another factor affecting the data is the use of skin mounted markers and their effect on kinematic and joint moment data (Kadaba et al., 1990). In this study, most of the markers were mounted on the skin, however to respect the privacy of subjects, some of the markers were mounted on skin tight clothing. Clothed and skin mounted markers are known to exaggerate joint angles (J. P. Holden, Chou, & Stanhope, 1997; J. P. Holden et al., 1997), markers where placed on the work boot as there was no way to place a marker directly on the malleolus, which may produce errors in the data. However, for the purpose of this study, although the absolute angles and kinetics may not be completely valid, as a relative measure they remain valuable.

In addition to the issues regarding gait data, our study has only evaluated the immediate effect of the portable anti-fatigue mats and although there are some immediate effects, the long term and possibly more beneficial effects may only be apparent after several weeks to months of wearing the portable anti-fatigue mats. It could also be argued that a more appropriate study design would involve all participants wearing the same footwear, in this case the same work boot. This would make a more controlled study design and would allow for a more exact representation for the effect of the portable anti-fatigue mats. Finally, subjects were instructed to maintain a similar walking speed for all test conditions. Alterations in walking speed have been shown to affect knee joint loading (Browning & Kram, 2007), although changes were not significant in this study. During the pilot study a metronome was used and the device created an apparent change in gait during the test trials. Therefore, subjects were instructed to walk at their normal walking speed and the metronome was not used in this study.

Future Research

In order to collect a true representation of joint loading it would be important to collect electromyography (EMG) data to include muscle contractions acting on the joint. EMG in combination with joint loading rate and joint moments would provide the complete effect that the portable anti-fatigue mats may have on joint loading. EMG measure would also show any inconsistencies in muscle activation, thus giving us a better understanding of muscle fatigue in a prolonged walking exercise.

Adding another control shoe to this study would also allow for a better comparison between wearing the portable anti-fatigue mats in combination with different shoe or boot types. Results may differ depending on the cushioning properties of the footwear.

Ergonomics

In many cases, workers who are on their feet for prolonged periods have sore feet and joints and turn to interventions such as anti-fatigue matting. The portable anti-fatigue mats claim to have the same properties as standard anti-fatigue mats, making matting available for the mobile worker. According to our findings, gait mechanics are unchanged with the use of the portable anti-fatigue mats. In this study, there was no significant difference in impact shock when comparing the portable anti-fatigue mats to work boots and therefore there is no decrease in risk for developing MSDs related to prolonged walking. However, a previous study by Gauvin et al. (2009) confirmed that there is a reduction in impact shock between the portable mats and the use of running shoes. The results of this study suggest that the risk of injuries related to prolonged walking does not change. Therefore, for ergonomic practitioners, based on the findings of this study it would be difficult to recommend this product for workers required to walk prolonged periods while wearing work boots. As different types of footwear in combination with the portable anti-fatigue mats may reduce the impact shock, as suggested in our previous work, the recommendation of this product should be given careful consideration in its application to specific industries. The portable anti-fatigue mats are for indoor use only as the materials would deteriorate very quickly with outdoor use.

2.6 Conclusion

In summary, the portable anti-fatigue mats did not produce significant changes in kinetic and kinematic characteristics of the lower limb which could be advantageous for the regular user of the product as it does not change the sole of the shoe or boot. This suggests that people who wear prescription orthotics can still use this product. Based on these results, it seems to be warranted that further studies investigate aspects such as orthotic use and/or different footwear in combination with the portable anti-fatigue mats.

Table 1: Details the Kinetic and Kinematic variables with the mean, standard deviation, and P-value

	Boot Mean (SD)			Portable Anti-Fatigue Mat Mean (SD)			P-Value		
Variables	**Pre**	**During**	**Post**	**Pre**	**During**	**Post**	**Condition**	**Time**	**Condition* Time**
Kinetics									
GRF Loading Rate (N/s)	5412.12 (1019.38)	5377.86 (1085.92)	5404.05 (1057.31)	5279.26 (1115.34)	5377.72 (1080.48)	5262.98 (1200.22)	0.736	0.99	0.972
GRF LR (BW/s)	7.16	7.12	7.15	6.99	7.12	6.97			
COP AP difference	0.655 (0.0967)	0.683 (0.0918)	0.693 (0.109)	0.649 (0.093)	0.714 (0.076)	0.67 (0.075)	0.975	0.193	0.562
COP ML difference	0.179 (0.112)	0.194 (0.13)	0.185 (0.07)	0.186 (0.111)	0.211 (0.118)	0.161 (0.085)	1	0.668	0.815
Ankle									
Joint Loading Rate (N/s)	4525.37 (908.82)	4467.23 (865.78)	4498.68 (840.98)	3837.78 (1494.98)	4435.76 (775.21)	4485.4 (888.02)	0.675	0.952	0.894
Joint LR (BW/s)	5.95	5.93	5.94	5.17	5.83	5.91			
Peak Force (N)	1097.02 (224.84)	1092.76 (230.7)	1094.25 (223.85)	963.85 (387.32)	1088.24 (214.84)	1102.67 (223.59)	0.925	0.986	0.978
Knee									
Joint Loading Rate (N/s)	4487.72 (904.96)	4408.32 (877.38)	4465.59 (835.55)	3794.12 (1481.06)	4351.76 (791.09)	4421.85 (884.89)	0.605	0.954	0.908
Joint LR (BW/s)	5.90	5.88	5.89	5.11	5.78	5.86			
Peak Force (N)	1087.97 (224.17)	1083.52 (229.20)	1085.55 (222.71)	952.86 (383.64)	1078.97 (213.63)	1093.57 (222.63)	0.909	0.982	0.974
Hip									
Joint Loading Rate (N/s)	4237.10 (747.28)	4210.75 (798.85)	4105.18 (791.97)	3619.96 (1438.85)	4153.57 (775.90)	4179.89 (709.94)	0.776	0.982	0.859
Joint LR (BW/s)	5.71	5.67	5.60	4.94	5.59	5.60			
Peak Force (N)	1052.77 (217.55)	1045.80 (227.18)	1032.55 (218.39)	921.34 (372.41)	1042.45 (207.67)	1045.67 (209.95)	0.933	0.997	0.964
Kinematics									
Ankle									
Max Moment (Nm)	24.022 (4.77)	24.84 (5.57)	25.656 (7.92)	22.536 (8.22)	23.8 (7.77)	25.344 (6.83)	0.626	0.62	0.966
Max Angle (°)	100.801 (17.81)	95.203 (8.12)	90.975 (5.26)	90.478 (6.60)	96.323 (13.30)	93.249 (4.82)	0.417	0.45	0.127
Min Angle (°)	68.214 (4.02)	69.509 (7.17)	65.787 (5.40)	66.272 (5.00)	64.773 (5.57)	67.058 (5.06)	0.212	0.878	0.235
Angle at Heel Strike (°)	90.879 (23.1)	77.643 (12.44)	77.643 (5.18)	79.52556 (4.36)	84.07 (17.63)	80.488 (8.16)	0.405	0.308	0.245
Knee									
Max Moment (Nm)	23.475 (7.79)	22.681 (7.85)	20.604 (5.04)	23.109 (6.41)	20.237 (8.64)	23.219 (8.32)	0.946	0.731	0.547
Max moment 1st half	18.918 (12.29)	22.113 (16.33)	16.922 (8.59)	19.692 (9.72)	16.993 (10.34)	19.502 (10.69)	0.835	0.931	0.559
Max Moment 2nd half	18.807 (3.62)	18.975 (3.27)	18.507 (5.01)	17.031 (6.29)	16.243 (7.14)	18.029 (3.30)	0.184	0.909	0.757
Max Angle (°)	70.292 (16.71)	66.086 (13.43)	63.988 (5.24)	69.792 (18.12)	68.847 (16.40)	67.333 (14.50)	0.621	0.604	0.869
Min Angle (°)	7.976 (4.14)	7.351 (3.67)	6.775 (3.74)	5.896 (3.06)	7.339 (3.52)	5.954 (1.68)	0.291	0.663	0.643
Angle at Heel Strike (°)	24.128 (32.82)	18.857 (28.85)	7.024 (3.54)	18.898 (36.56)	18.016 (34.02)	16.593 (31.84)	0.899	0.524	0.651
Hip									
Max Moment (Nm)	20.425 (12.23)	22.873 (13.49)	18.386 (8.24)	18.45667 (10.16)	20.619 (9.71)	22.056 (18.27)	0.975	0.851	0.708
Max Angle (°)	44.437 (10.36)	42.591 (18.74)	38.779 (10.24)	45.802 (20.80)	47.254 (20.98)	39.944 (15.87)	0.597	0.47	0.929
Min Angle (°)	12.459 (4.19)	12.01 (5.93)	13.164 (5.84)	15.691 (9.88)	13.909 (6.20)	13.058 (5.72)	0.282	0.838	0.668
Angle at Heel Strike (°)	44.747 (10.54)	40.735 (19.56)	37.429 (11.93)	44.951 (21.9)	46.811 (21.5)	39.384 (16.66)	0.56	0.464	0.856

Chapter 3

3 Article 2 - *Perceived discomfort while wearing portable anti-fatigue mats during a prolonged walk*

3.1 Introduction

In many work conditions such as nursing, custodial work and postal delivery, workers are in prolonged standing or walking conditions (Rys & Konz, 1994). The ground reaction force (GRF) plays an important role in the discomfort and muscle pain that workers who walk for prolonged periods experience (Whittle, 1999). The repetitive striking of the heel against the floor sends impact shocks potentially equal to two times a person's body weight upwards through the body (Brownjohn et al., 2004), affecting the feet, knees, hips, and lower back. Impact shock can cause long-term damage in the surrounding joint tissues which may eventually limit activity and, in some cases, require joint replacement (Whittle, 1999). The most common symptom in prolonged standing or walking is discomfort and fatigue in the legs (Zander et al., 2004). The closer the body part to the contact point, the more likely it will be affected by prolonged standing and walking (King, 2002; Redfern & Cham, 2000). Beyond fatigue and discomfort, more serious health effects can result from prolonged standing or walking. This includes low back pain (Cham & Redfern, 2001; Hansen et al., 1998; Nelson-Wong et al., 2010; Whittle, 1999), foot pain (Cham & Redfern, 2001; Hansen et al., 1998), plantar fasciitis and heel spurs (Lutter, 1997), orthopedic changes in the foot (Cham & Redfern, 2001; Leber & Evanski, 1986), restricted blood flow (Hansen et al., 1998), swelling of the feet and legs (Hansen et al., 1998), and increased chance of arthritis in the knees and hips (Coggon et al., 2000; Rossignol et al., 2005).

Walking long distances has been shown to cause low back pain (Shabat et al., 2005). Low Back Pain is the most commonly reported injury in the workplace (Spengler et al., 1986) (Spengler et al., 1986). It is the most common and the most expensive source of compensated work related injury in modern industrialized countries (Feyer et al., 2000). Some sources of LBP include muscle/ligament strain, disc degeneration, disc prolapse and disc bulging (herniation) (McGill, 1997). Shabat et al. (2005) examined the difference in LBP in postmen for two conditions, insoles and no insole. All subjects reported low back pain with the no insole condition, 10% everyday, 64% often, and 26% seldom (Shabat et al., 2005). LBP can arise from disease processes or functional disorders however, peak and cumulative mechanical loading constitute by far the greatest known risk factors for acute disc prolapse and for LBP in general (Adams & Dolan, 1995). Factors that can cause low back pain include high force, awkward postures and excessive repetition, although it is difficult to predict how much force, repetition, and time spent in an awkward posture will cause injury to the low back(Adams & Dolan, 2005). Repeated loading to the spine can result in cumulative fatigue, rendering the spine less able to bear future stresses and possibly fail (Shelerud, 1998). This can potentially be a result of walking for prolonged periods. Cromwell et al (1989) found that while walking on level surfaces peak spine compressions during each step is equal to 1.2 times a person's body weight thus creating stress on the spine with each step (Cromwell et al., 1989). Walking is a form of exercise, however too much of it may result muscle fatigue causing low back pain (Whittle, 1999). In terms of standing, research has shown that LBP can arise over time (Gregory & Callaghan, 2008). Gregory and Callaghan (2008) stated that low back discomfort overtime can be cause by the creep associated with the disc height loss which eventually results in nerve impingement thus increasing discomfort (Gregory & Callaghan, 2008).

Walking on hard surfaces for a long period of time creates cyclic loading to the joints of the lower limbs as well as the spine (Chiu & Wang, 2007; Gregory & Callaghan, 2008). Cumulative loading is associated with back pain which is the most common injury in occupational health (Marras et al., 2006; McGill, 1997). Cumulative loading can be defined as “applied loads to a structure, built up over a period of time” (Daynard et al., 2001). According to McGill (1997) when structures are subjected to cumulative loading the injury tolerance level of tissues decreases over time, to the point that a lighter load may exceed the reduced tolerance level thus damaging the surrounding tissues. In prolonged walking, there is a variation of load applied to the joints where over the period of a work shift there may be an effect on a workers balance and pain perception (Madeleine et al., 1998; Windle et al., 1999). The load applied to the spine depends on the speed at which the person is walking (Callaghan et al., 1999). When walking at slower speeds, the load applied to the spine produces more of a static load, which could be a significant risk for low back injuries and tissues (Callaghan et al., 1999). Walking at normal speeds was proven to be beneficial as the tissue loading in the spine appeared to be below levels caused by many rehabilitation tasks for the lower back (Callaghan et al., 1999). Although walking may be recommended as a rehabilitation task for low back pain, Whittle (1999) conducted a review and discovered that prolonged walking does create cumulative loading to other joints (ankle, knee and hip) which can be detrimental in the causation of lower limb injury (Whittle, 1999). Prolonged standing has been assumed to increase discomfort and overall body fatigue due to reduced blood circulation in the lower legs and static muscle fatigue (Gregory & Callaghan, 2008). This reduced circulation results in venous pooling that causes foot and lower leg swelling (Rys & Konz, 1994; Zander et al., 2004), while increasing the workload of the heart (Rys & Konz, 1994). Physiologically, as a person walks, the leg muscle action assists the heart by moving blood through the lower legs and back to the heart, therefore decreasing this venous pooling (Rys & Konz, 1994).

Fatigue is also associated with a person's balance and control as fatigue is known to affect the central nervous system (Mair et al., 1996). The development of localized muscle fatigue has also been observed to decrease performance in standing balance (Lepers et al., 1997; Springer & Pincivero, 2009) . As the muscles (active system) in the body become weaker or fatigued, the body starts to rely on the passive system for stabilization. The passive system consists of bones, ligaments and tendons. As the muscles begin to fail, the feedback to the neuromuscular control unit and mechanoreceptors may be negatively affected thus corrupting the normal muscle response pattern (Panjabi, 2006). When standing or sitting for prolonged periods the muscles of the low back become fatigued (Callaghan & McGill, 2001). Therefore, the corrupted muscle response may create higher stresses and strains which can eventually develop into injuries to the ligaments of the low back (Panjabi, 2006). Also, balance and stability may be influenced when standing on softer materials due to the different sensations of the softer materials (Patel et al., 2008). Humans have sensory receptors located on the soles of the feet which contribute to maintaining postural stability (Patel et al., 2008). When standing on softer surfaces, such as foam, the information transmitted from the receptors from the feet are assumed to be less reliable. This is known to increase postural sway and change the standing strategy (Patel et al., 2008), thus influencing postural control. The softer materials offer less reflexive resistance for applied corrective movement, which makes it more difficult to control the loss of balance (Patel et al., 2008). While a material may work to prevent fatigue in one system (muscle) it may, simultaneously impair another (sensory). Therefore the benefit of applying these materials while walking for prolonged periods is not clear.

The term discomfort is used widely in ergonomics. Discomfort is a lack of physical comfort or slight pain and therefore can be applied to many signs and symptoms for musculoskeletal injury. Many researchers have studied discomfort while standing or walking and this includes standing or walking with insoles (Basford & Smith, 1988; King, 2002; Mattila et al., 2011; Sobel et al., 2001), on different surfaces(Cham & Redfern, 2001; Hansen et al., 1998; Hardin et al., 2004; Kim et al., 1994; Madeleine et al., 1998; Redfern & Cham, 2000; Shabat et al., 2005; Wiggermann & Keyserling, 2013; Zander et al., 2004), and with different types of shoes (Chiu & Wang, 2007; B. M. Nigg et al., 2006). This study is the first to measure the effect of portable anti-fatigue mats to determine the perceived discomfort while walking. Basford et al. (1988) evaluated the effectiveness of insoles in reducing back, leg, and foot discomfort and they found that insole do effectively reduce discomfort in workers who must stand or walk for extended periods (Basford & Smith, 1988). Hansel et al. (1998) studied the effect of floor and shoe softness while standing and during work test and found no significant differences when completing the protocol on a softer floor however softer shoe did slightly improve discomfort ratings. However, this study only simulated the work tasks for a 2 hour period thus resulting in negligible data (Hansen et al., 1998). Other types of footwear have also be examined and this includes the Masai Barefoot Technology (MBT). Nigg et al. (2006) examined if the MTB shoe can reduce knee pain in subject with osteoarthritis (OA) and the results indicate that special shoe interventions can reduce pain in subjects with moderate knee OA. The control group showed no significant differences in knee pain (B. M. Nigg et al., 2006).

Anti-fatigue mats are a common ergonomic intervention to avoid worker pain and discomfort related with lower limb swelling in prolonged standing. “They have been widely accepted as an adequate remedy to reduce worker pain and discomfort” (Zander et al., 2004). With this in mind, anti-fatigue matting may reduce the risk of injury by decreasing the impact shock and stresses place on the body while walking for prolonged periods. Studies have shown that generally softer materials reduce both muscle and general fatigue (Cham & Redfern, 2001; Windle et al., 1999; Zander et al., 2004). Since anti-fatigue mats limit worker movement, many of these workers suffer from many foot disorders due to standing and walking tasks. To alleviate this stress, a new mat-type outsole designed for the mobile worker was explored.

The aim of this study is to determine whether the portable anti-fatigue mats prevent or reduce back pain and foot discomfort when walking for long periods of time compared to a work boot. It was hypothesized that low back and lower limb discomfort would decrease while wearing the portable mats as compared to work boots.

3.2 Methods

Thirteen physically active participants (n=13), free from any known musculoskeletal disorders were recruited for the study and data was collected for all thirteen (n=13) subjects. The participants represented a random sample drawn from a healthy university and community population. Participants were a mix of males (n=8) and females (n=5), ages ranging from 18-55 years old to represent a working population.

The participants were instructed to complete testing on two separate days. Both sessions were completed with a minimum of 48 hours apart to allow for an adequate rest period. According to Cham et al. (2001) there were no signs of any changes in low back discomfort or fatigue until the 3rd hour of standing, therefore in this study, the subjects were required to walk for approximately 3 hours to represent a prolonged walking period. In session 1, subjects were required to walk with one of the two randomly assigned conditions: (1) Work boots, (2) Portable anti-fatigue mat outsole. During Each session, a discomfort survey was to be completed at three different times during the session, before, during and after the walking exercise. The 3 hour walk was completed on a walking course created in the Ben Avery Building at Laurentian University. This walking course was on concrete flooring with a series of stairs and distance walking to mimic normal working conditions. During the testing participants wore their own work boots. One session was completed with the work boots only and the other session was completed with the work boots in combination with the portable anti-fatigue outsole. Subjects were required to answer a perceived discomfort survey (Occupational Health and Safety Council of Ontario, 2007). This survey has been used widely in the field to determine worker perceived discomfort. The survey was derived from previous postural discomfort surveys and has high face validity (Occupational Health and Safety Council of Ontario, 2007). The survey is meant to be a screening tool, as used for the purpose of this study, and not a diagnostic instrument. The subjects were required to answer questions before, during and after the walk to estimate their perceived localized muscle/joint discomfort based on a scale of 1 to 10. A copy of the survey is located in the Appendices.

For each variable of interest a 2x3 ANOVA with repeated measures was performed within subjects to compare the two experimental conditions for pre, during, and post exercise. Level of significance for each test was set at a p-value of 0.05. The data was normalized by re-scaling with a coefficient of three (c=3) with no change in statistical results after normalization.

3.3 Results

The hypothesis that subject low back discomfort and lower limb discomfort would decrease while wearing the portable anti-fatigue mats is supported.

The mean perceived discomfort for the ankle/foot while wearing the work boots was 1.08 ± 0.277 pre, 2.69 ± 1.316 during, and 3.92 ± 1.935 post, and while wearing the portable anti-fatigue mats was 1.08 ± 0.277 pre, 1.38 ± 0.650 during, and 1.92 ± 1.038 post. The mean discomfort rating for the knee was 1.77 ± 1.301 pre, 1.77 ± 1.481 during, and 2.08 ± 1.656 post while wearing the work boots, and 1.08 ± 0.277 pre, 1.15 ± 0.375 during, and 1.31 ± 0.751 post while wearing the portable anti-fatigue mats. The mean discomfort rating for the hip was 1.08 ± 0.277 pre, 1.54 ± 0.877 during, and 1.46 ± 0.776 post while wearing the work boot, and 1.15 ± 0.555 pre, 1.15 ± 0.555 during, and 1.15 ± 0.555 post while wearing the portable anti-fatigue mats. Discomfort ratings for the low back were 1.77 ± 1.964 pre, 2.15 ± 2.267 during, and 2.92 ± 2.397 post while wearing the work boot, and 1.62 ± 1.325 pre, 2.00 ± 1.354 during, and 1.85 ± 1.144 post while wearing the portable anti-fatigue mats. While discomfort ratings for the upper back were 1.15 ± 3.76 pre, 1.38 ± 0.768 during, and 1.38 ± 0.768 post while wearing the work boot, and 1.08 ± 0.277 pre, 1.08 ± 0.277 during, and 1.08 ± 0.277 post while wearing the portable anti-fatigue mats. Refer to *Table 2* for further detail.

There were significant changes between conditions for the knees ($p < 0.05$) and feet/ankles ($p<0.05$) where subjects perceived having less discomfort while wearing the portable anti-fatigue mats compared to wearing the work boots. There was also a significant difference in time for the feet/ankles ($p<0.05$) and the lower back ($p<0.05$), where subject felt an increase in discomfort over time while wearing the work boots. For the lower back, subject felt an increase in discomfort from pre (1.62 ± 1.325) to during (2.00 ±1.354), and then a decrease in discomfort from during to post exercise (1.85 ± 1.144) while wearing the portable anti-fatigue mats. Condition and time interaction was also significant for the feet/ankles and the low back ($p<0.05$). This shows that the subjects felt less discomfort over time while wearing the portable anti-fatigue mats. *Figure 9* and *Figure 10* show the perceived discomfort ratings over time for the low back and the ankles/feet.

Table 2: Details the perceived discomfort variables with the mean, standard deviation, and P-value

	Boot Mean (SD)			Portable Anti-Fatigue Mat Mean (SD)			P-Value Sig (p < 0.05)		
Variables	Pre	During	Post	Pre	During	Post	Condition	Time	Condition*Time
Hip	1.08 (0.277)	1.54 (0.877)	1.46 (0.776)	1.15 (0.555)	1.15 (0.555)	1.15 (0.555)	0.231	0.127	0.127
Knee	1.77 (1.301)	1.77 (1.481)	2.08 (1.656)	1.08 (0.277)	1.15 (0.376)	1.31 (0.751)	0.047 *	0.266	0.791
Ankle/Foot	1.08 (0.277)	2.69 (1.316)	3.92 (1.935)	1.08 (0.277)	1.38 (0.650)	1.92 (1.038)	0.000 *	0.000 *	0.000 *
Upper Back	1.15 (3.760)	1.38 (0.768)	1.38 (0.768)	1.08 (0.277)	1.08 (0.277)	1.08 (0.277)	0.121	0.372	0.372
Lower Back	1.77 (1.964)	2.15 (2.267)	2.92 (2.397)	1.62 (1.325)	2.00 (1.354)	1.85 (1.144)	0.343	0.035 *	0.010 *

3.4 Discussion

Subjective discomfort and pain ratings decreased, in the knees and feet/ankles while wearing portable anti-fatigue mats compared to work boots for a 3-hour walking exercise. These decreases could be attributed to the added cushioning provided by the portable anti-fatigue mats, however, this cannot be quantified. Shoe insoles are often used by workers who both walk and stand at work. Insoles have been referred to as mobile mats that are effective at improving comfort while reducing back, leg and foot pain, most of which were measured in standing conditions(Cham & Redfern, 2001; King, 2002). In walking conditions, studies show a reduction in foot and ankle pain, however no improvement in leg or low back pain (Sobel et al., 2001). The portable anti-fatigue mats do seem to provide the same type of perceived comfort as insoles, while providing improved discomfort ratings for the low back, ankle/foot over time. However, to truly understand the difference, more research comparing the portable anti-fatigue mats to insoles would have to be completed.

Subjects found that they had less discomfort in the knees and ankle/foot between conditions while for the lower back they found they had less discomfort over time while wearing the portable anti-fatigue mats. When observing the means of the low back, pre exercise was 1.62 ± 1.325, during exercise was 2.00 ± 1.354, and post exercise was 1.85 ± 1.144. This suggests that subjects felt less discomfort in their low back as the exercise progressed. This may have been due to the cushioning properties of the portable anti-fatigue mats. Subjects felt less fatigue and in turn had less discomfort over time. Shabat et al. (2005) found that during a blinded study people who must walk long distances for work preferred wearing regular cushioned insoles as opposed to the placebo insole utilized in the study as they felt less low back pain. This study is the first to compare portable anti-fatigue mat outsoles in long distance walking and the results are similar to those shown in the study by Shabat et al. (2005). This suggests that the portable anti-fatigue mats can be an alternative intervention to insoles in terms of perceived comfort.

Lower limb discomfort has been shown to increase while walking, however according to many studies, pain and discomfort travels up the kinetic chain, meaning that discomfort would affect the ankle/foot first and travel upward affecting the knees, hip, and the lower back (Cham & Redfern, 2001; Hansen et al., 1998; Hansen et al., 1998; King, 2002; Redfern & Cham, 2000). This study does not support these findings as there were significant differences in discomfort over time, and condition and time interaction for only the ankle/foot and the lower back differing from following the usual discomfort path of affecting the knees, then the hips, and then affecting the lower back. It would be interesting to find out what is causing this type of effect on the lower limbs.

Low back discomfort has been show to increase while standing for prolonged periods (Gregory & Callaghan, 2008; Gregory & Callaghan, 2008). Gregory and Callaghan (2008) found that back flexion significantly increased over a 2h period corresponding with the increases in low back discomfort over time. Although this was not measured in the current study, low back posture differences may be the reason for the increased low back discomfort.

A study completed by Wigermann and Keyserling (2013) showed significant increases discomfort over time for the lower limbs while standing on hard surfaces compared to anti-fatigue mats. There were minimal changes in low back discomfort over time, however not significant (Wiggermann & Keyserling, 2013). As stated by Refern and Cham (2000) and King (2002), the closer the body part to the contact point, the more likely it will be affected by prolonged standing and walking (King, 2002; Redfern & Cham, 2000). These studies do not support the current study as significant differences were found in the low back and the ankle/foot, while no significant differences were found in the knee and hip over time.

Limitations

Currently there are some physiological explanations for differences in discomfort among flooring surfaces (Cham & Redfern, 2001; Redfern & Cham, 2000) however this was not measured during this study. Without physiological measurements that can differentiate effects of different flooring surfaces or material stiffness, subjective ratings of discomfort represent the only measurement available. These subjective ratings have high variability, making them sensitive only to very large differences in discomfort between the work boot and the portable anti-fatigue mats.

The large variability of subjective ratings of discomfort makes it difficult to find significant discomfort differences between work boots and anti-fatigue mats in trials of 3-hour duration. While the 3 hours of standing time in this study, as well as others (Cham & Redfern, 2001; Redfern & Cham, 2000; Wiggermann & Keyserling, 2013) have been shown to capture significant differences, the time duration may not capture all of the effects that might otherwise be seen with repeated days of exposure to 8- to 12-hour work shifts as could be experienced in most industries.

Finally, a larger population would have increased the validity and reliability of the discomfort data. It would have also allowed us to group our scale of 1 to 10, to low (1-3), medium (4-6), and high (7-10) discomfort ratings, giving us a more general concept of the perceived discomfort subjects are experiencing.

Future Research

Further research is needed to explain the differences in physiological and biomechanical factors effecting low back and lower limb discomfort while walking with portable anti-fatigue mats. Adding a control shoe to the study would allow better comparison between wearing the portable anti-fatigue mats in combination with different type shoes or boots. Completing the test in the field would also increase the validity of the results as workers could wear the portable anti-fatigue mats for the length of their shift, over several days, thus capturing the effect that the portable mats would have if used on a daily basis.

Ergonomics

In many cases, workers who are on their feet for prolonged periods have sore feet and joints and turn to interventions such as anti-fatigue matting. The portable anti-fatigue mats claim to have the same properties as standard anti-fatigue mats, making matting available for the mobile worker. According to our findings, the portable anti-fatigue mats do reduce perceived discomfort in the low back, knees and ankle/foot while walking for a 3 hour period. Therefore, for ergonomic practitioners, based on the findings of this study, we would recommend this product for workers required to walk prolonged periods while wearing work boots. The portable anti-fatigue mats are for indoor use only as the materials would deteriorate very quickly with outdoor use. Therefore, the efficiency of this product is limited to specific industries.

3.5 Conclusion

In summary, the portable anti-fatigue mats did produce significant differences in discomfort ratings of the low back and ankle/foot over time, while no difference were found for the knees and hip over time. This suggests that this product can be beneficial to workers who work on their feet for prolonged periods of time. Based on the results from this study, additional research seems to be justified in order to investigate aspects such as physiological differences and to understand effect of the portable anti-fatigue mats on the lower limbs, specifically the knee and hip over a longer period of time.

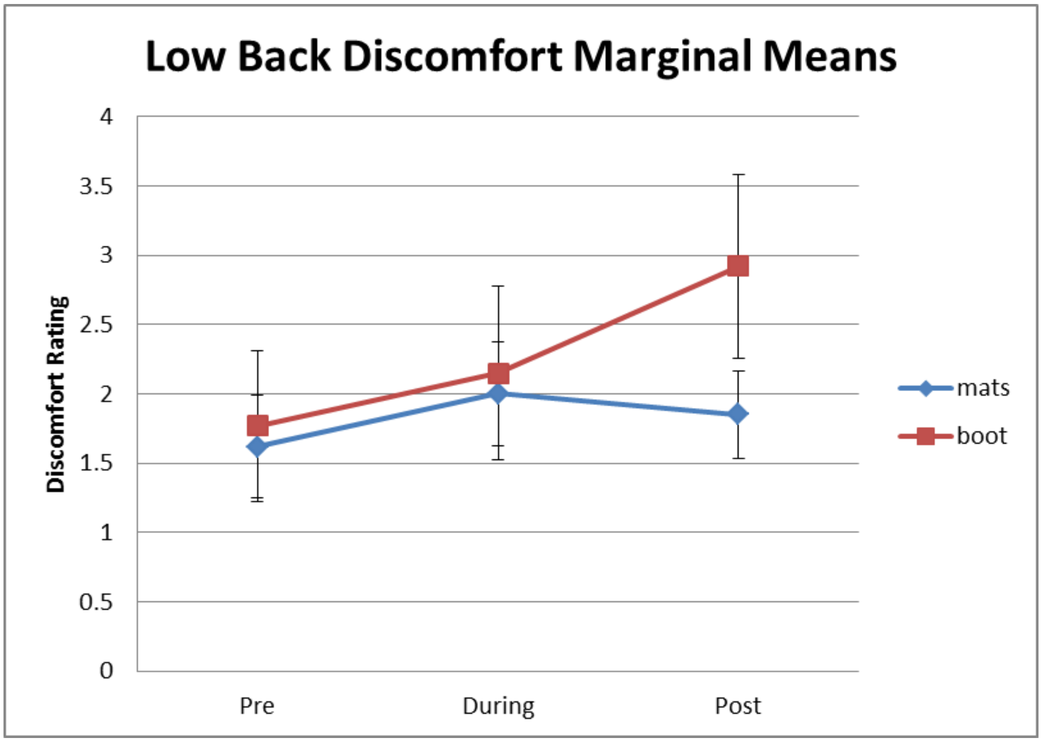


Figure 9: Low back discomfort means with standard error

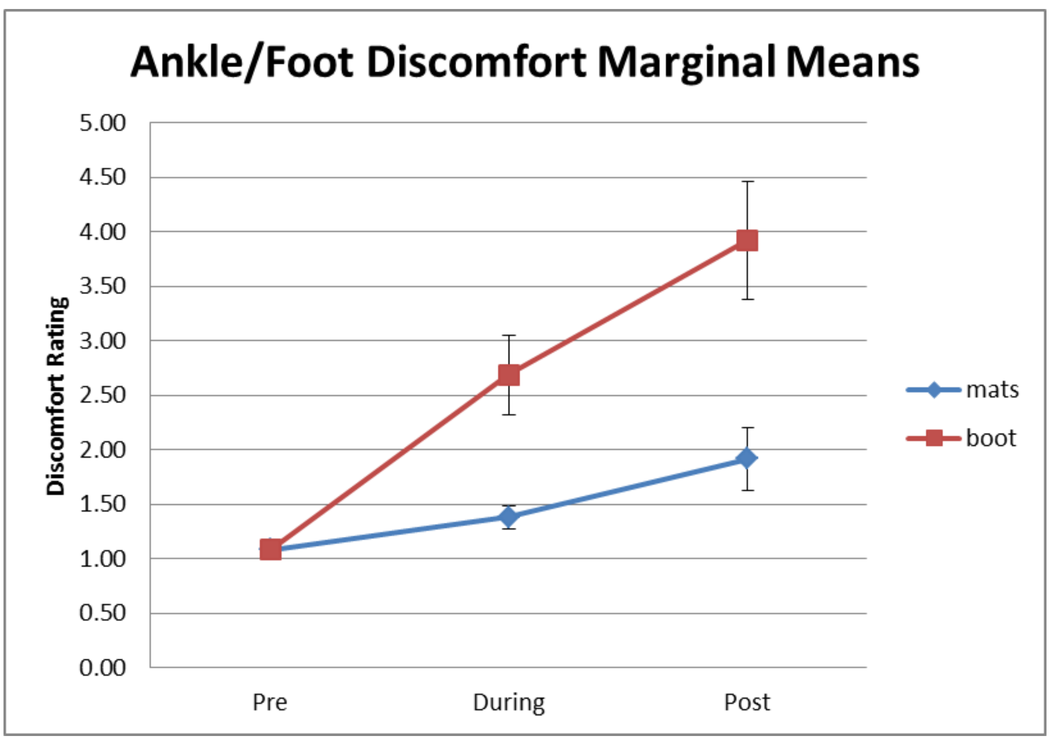


Figure 10: Ankle/Foot discomfort means with standard error

Chapter 4

4 Summary

The objective of this thesis was to determine the differences in gait while walking with portable anti-fatigue mats and walking with work boots only. Research suggests that prolonged standing and walking can result in the development of low back pain (Callaghan et al., 1999; Callaghan & McGill, 2001; Cromwell et al., 1989; Gregory & Callaghan, 2008; Hansen et al., 1998; Shabat et al., 2005; Whittle, 1999), plantar fasciitis and heel spurs (Lutter, 1997), orthopedic changes in the foot(Cham & Redfern, 2001; Leber & Evanski, 1986), restricted blood flow (Hansen et al., 1998), swelling of the feet and legs (Hansen et al., 1998), and increased risk of developing arthritis in the knees and hips (Coggon et al., 2000; Rossignol et al., 2005). The portable anti-fatigue mats were developed to provide the same relief as anti-fatigue mats to the mobile worker. Anti-fatigue mats have been found to successfully alleviate pressure, stimulate blood circulation, decrease impact shock, and dramatically reduce stress to the lower back, leg joints, and major muscle groups (Cham & Redfern, 2001; Hansen et al., 1998; Whittle, 1999). Therefore, understanding how the portable anti-fatigue mats provide relief would have some benefit. In order to understand the effect of the portable mats, kinematic and kinetic testing was completed, along with a discomfort survey observing the low back, hips, knees, and ankle/foot discomfort.

It was hypothesized that low back discomfort would decrease while wearing the portable mats as compared to work boots. Lower limb and foot discomfort while wearing the portable mats would also decrease as compared to work boots. During gait, joint angles and moments at the hip, knee and ankle would change with portable mats as compared to work boots. Medial-lateral centre of pressure and anterior-posterior centre of pressure displacement would decrease while wearing the mat-type outsole. And that the GRF and joint loading rate would decrease while wearing the portable anti-fatigue mats. The hypothesis that joint angle and moment, COP differences, and GRF and joint loading would significantly change was rejected, while the hypothesis for a decrease in low back and foot/ankle discomfort was supported.

When observing the kinetic data, results showed that there were small changes in GRF loading rate and COP_{AL} and COP_{ML} differences when wearing the portable anti-fatigue mats, however none were statistically significant. There were also small changes in peak forces, joint loading rates and joint moments at the hip, knee, and ankle, however none of which were statistically significant. Kinematic data was also observed and results showed that while wearing the portable anti-fatigue mats, there were no changes in angle of the hip, knee and ankle between conditions or for condition and time interaction. Results for the perceived discomfort survey showed that there were significant changes between conditions for the knee ($p < 0.05$) and feet/ankles ($p < 0.05$) where subjects perceived having less discomfort while wearing the portable anti-fatigue mats compared to work boots. There was also a significant difference in time for the feet/ankles and the lower back where subject felt an increase in discomfort over time for both conditions. However in the lower back, subjects felt and increase in pain from pre to during exercise and a decrease in pain from during to post exercise while wearing the portable anti-fatigue mats, whereas for the boot only condition, subject felt a consistent increase in discomfort over time. It was also observed that the condition and time interaction for the feet/ankles and the low back were statistically significant, meaning that subjects felt less discomfort over time while wearing the portable anti-fatigue mats.

Subjective discomfort and pain ratings decreased in the feet/ankles and knees while wearing the portable anti-fatigue mats. Subjects also felt less discomfort overtime in the lower back and feet/ankles while wearing the portable anti-fatigue mats compared to wearing the work boot only. The question is: where did this difference come from? There were no significant differences in any kinetic and kinematic variables observed, meaning no visible changes in gait while wearing the portable anti-fatigue mats. After extrapolating the data overtime using a trend line, there were still no significant differences. Subjects felt more comfort while walking with the portable anti-fatigue mats. This can be attributed to the added cushioning of the outsole, however when the kinetic data does not show significant differences it is difficult to truly determine the causal effect of the increased comfort. Research shows that insoles have been referred to as mobile mats that are effective in reducing back, leg and foot pain (King, 2002). Pratt et al. (1986) examined five different types of insoles using force plate recordings and an accelerometer to record shock absorption. The viscoelastic materials were determined to be superior in shock attenuation. Windel et al. (1999) examined the difference between four different types of insoles in shock attenuation while military running and marching. Using pressure sensors in the boot beneath the insole, they found an insole that provided a 23% reduction in shock attenuation while marching and 27% reduction while running (Windle et al., 1999). This is not consistent with what this study found as there were no significant differences between the work boot and portable anti-fatigue mats in GRF loading rate although, this study did not compare differences while running. Running does create a significantly higher impact shock than walking (Chan et al., 2013) and there may be a reduction in impact shock when running while using the portable anti-fatigue mats. Using pressure sensors inside the boot may have also changed these results as the pressure is directly beneath the foot rather than beneath the outsole. This is the first study to measure portable anti-fatigue mats and it would be interesting to see how they differ from insoles. To truly understand this difference, more research comparing the two would have to be completed.

Physiological differences may be the reason for the significant changes in discomfort. Some researchers found differences in leg volume, temperature and muscle activation (EMG) while measuring discomfort and fatigue while standing (Cham & Redfern, 2001), though this was not observed in this study. There are many discrepancies when examining physiological changes on different flooring conditions, some agree with each other (Saggini, Bellomo, Iodice, & Lessiani, 2009)(Zander et al., 2004)(Madeleine et al., 1998), while some disagree (Kim et al., 1994; Madeleine et al., 1998). Further research examining the physiological effects of the portable anti-fatigue mats while walking would have to be completed in order to confirm these finding.

Low back discomfort has been shown to increase while walking. According to most studies, pain and discomfort generally appears to be greatest at the feet and progressively less as it travels up the kinetic chain affecting the knees, then hips, and then the lower back (Cham & Redfern, 2001; Hansen et al., 1998; Hansen et al., 1998; Redfern & Cham, 2000). This study has some similarities as the discomfort is greatest at the feet; however the discomfort seemed to skip the knees and hips, and again proceed with greater discomfort ratings in the low back thus contradicting the other studies. Gregory and Callaghan (2008) found that low back flexion increased over time which corresponded to the increase in low back discomfort over time. Although postural differences of the lower back were not measured in this study, low back posture difference may be the reason for increased low back pain in both conditions.

Limitations

Subjective ratings have high variability, making them sensitive only to very large differences in discomfort between the work boot and the portable anti-fatigue mats. As there was no significant difference in kinetic or kinematic data, without physiological measurements that can differentiate effects of different material stiffness (work boot vs. portable anti-fatigue mats), subjective ratings of discomfort represent the only measurement available.

While the 3 hours of standing/walking time in this study, as well as others (Cham & Redfern, 2001; Redfern & Cham, 2000; Wiggermann & Keyserling, 2013) have been shown to capture some significant differences, the time duration may not capture all of the effects that might otherwise be seen with repeated days of exposure to 8- to 12-hour work shifts as could be experienced in most industries.

There are methodological issues regarding this study that may have played a pertinent role to the results. The reliability of gait data has been shown to be generally good (Kadaba et al., 1990; Nester et al., 2003), but some variation between the two experimental conditions is to be expected (Nester et al., 2003). Another factor affecting the data is the use of skin mounted markers and their effect on kinematic and joint moment data (Kadaba et al., 1990). In this study, most of the markers were mounted on the skin, however to respect the privacy of subjects, some of the markers were mounted on skin tight clothing. Clothed and skin mounted markers are known to exaggerate joint angles (J. P. Holden et al., 1997; J. P. Holden et al., 1997), which may produce errors in the data. However, for the purpose of this study, although the absolute angles and kinetics may not be completely valid, as a relative measure they remain valuable.

In addition to the issues regarding gait data, our study has only evaluated the immediate effect of the portable anti-fatigue mats and although there are some immediate effects, the long term and possibly more beneficial effects may only be apparent after several weeks to months of wearing the portable anti-fatigue mats. It could also be argued that a more appropriate study design would involve all participants wearing the same footwear, in this case the same work boot. This would make a more controlled study design and would allow for a more exact representation for the effect of the portable anti-fatigue mats. Subjects were also instructed to maintain a similar walking speed for all test conditions. Alterations in walking speed have been shown to affect knee joint loading (Browning & Kram, 2007), although changes were not significant in this study. During the pilot study a metronome was used and the device created an apparent change in gait during the test trials. Therefore, subjects were instructed to walk at their normal walking speed and the metronome was not used in this study. Finally, due to the small group of subjects used in the study, having a larger group of subjects would have influenced the data adding more reliability and validity to the study.

Ergonomics

In many cases, workers who are on their feet for prolonged periods have sore feet and joints and turn to interventions such as anti-fatigue matting. The portable anti-fatigue mats claim to have the same properties as standard anti-fatigue mats, making matting available for the mobile worker. As the gait mechanics are unchanged with the use of these materials it could be noted that the portable anti-fatigue mats can be a good intervention to increase comfort. In this study, there was no significant difference in impact shock when comparing the portable anti-fatigue mats to work boots, however, a previous study by Gauvin et al. (2009) confirmed that there is a reduction in impact shock between the portable mats and the use of running shoes. However, we did find significant differences when examining the perceived comfort while wearing the portable anti-fatigue mats. Therefore, for ergonomic practitioners, the recommendation of this product should be given careful consideration in its application to specific industries. The portable anti-fatigue mats are for indoor use only as the materials would deteriorate very quickly with outdoor use.

In conclusion, the portable anti-fatigue mats did not produce significant changes in kinetic and kinematic variables but did produce significant differences in perceived discomfort ratings. This product could be advantageous to its users as it does not change the sole of the boot or shoe, and purely increases perceived comfort. Based on the results from this study, it seems to be warranted that further studies examining issues such as physiological differences, insole/orthotic use while wearing portable anti-fatigue mats, as well as understanding the effect of the portable anti-fatigue mats on the lower body over a longer period of time.

Appendices

Appendix 1: Consent Form

LaurentianUniversity
UniversitéLaurentienne

CONSENT FORM

Study Title: *Measuring the Effectiveness of Portable Anti-Fatigue Mats Before, During and After a Prolonged Walking Exercise*

Investigators: André Gauvin, BSc, MHK Candidate
Dr. Sylvain Grenier (Supervisor)

I am a Masters Student in the School of Human Kinetic Laurentian University studying the effect of Portable anti-fatigue mats, in kinetic and kinematic, and perceived discomfort. The study is intended to provide information to determine if portable anti-fatigue mats actually do reduce discomfort and improve gait kinetics and kinematics. You should know that prolonged walking may increase fatigue and lower limb muscle pain. The study will take approximately 4.5 hours of your time and will involve walking throughout the Ben Avery Building with and without Ergomates, walking on a force plate before, during, and after the long walk, and filling out a perceived discomfort questionnaire before, during and after the long walk.

Your participation in this study is strictly voluntary. You have the right to withdraw at any time without penalty.

If you have any questions or concerns about the study or about being a subject, you can call me at (705) 919-4813 or the Research Officer at (705) 675-1151, ext. 3213 for information.

Your identity will not be revealed at any time.

I ________________ agree to participate in this study, and I have received a copy of this consent form.

______________________________ ________________________
Subject's Signature Date

If you are interested in the results of the study please enter your e-mail and I will send you the results at the end of the project.
E-mail:______________________________

Appendix 2 : Discomfort Survey

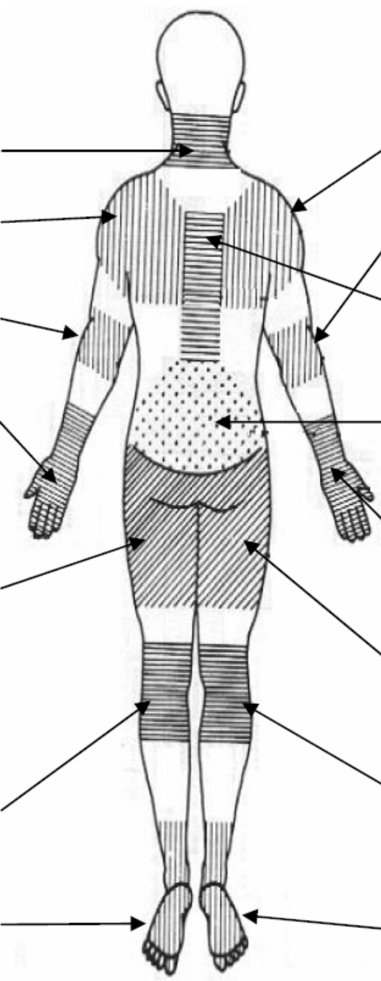
LaurentianUniversity
UniversitéLaurentienne

Discomfort Survey

Subject ID: ______________

Please rate the level of discomfort by checking off the appropriate box using the scale of 0 to 10, with 0 being no discomfort and 10 being the worst discomfort ever.

No Discomfort ↓ 0 1 2 3 4 5 6 7 8 9 10 Worst Discomfort Ever ↓	
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Neck
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Left Shoulder
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Left Elbow/ Forearm
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Left Wrist/ Hand
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Left Hip/ Thigh/ Buttock
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Left Knee
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Left Ankle/ Foot



	No Discomfort ↓ 0 1 2 3 4 5 6 7 8 9 10 Worst Discomfort Ever ↓
Right Shoulder	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Right Elbow/ Forearm	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Upper Back	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Lower Back	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Right Hand/ Wrist	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Right Hip/ Thigh/ Buttock	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Right Knee	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Right Ankle/ Foot	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Appendix 3: Kinetic and Kinematic

Kinetics

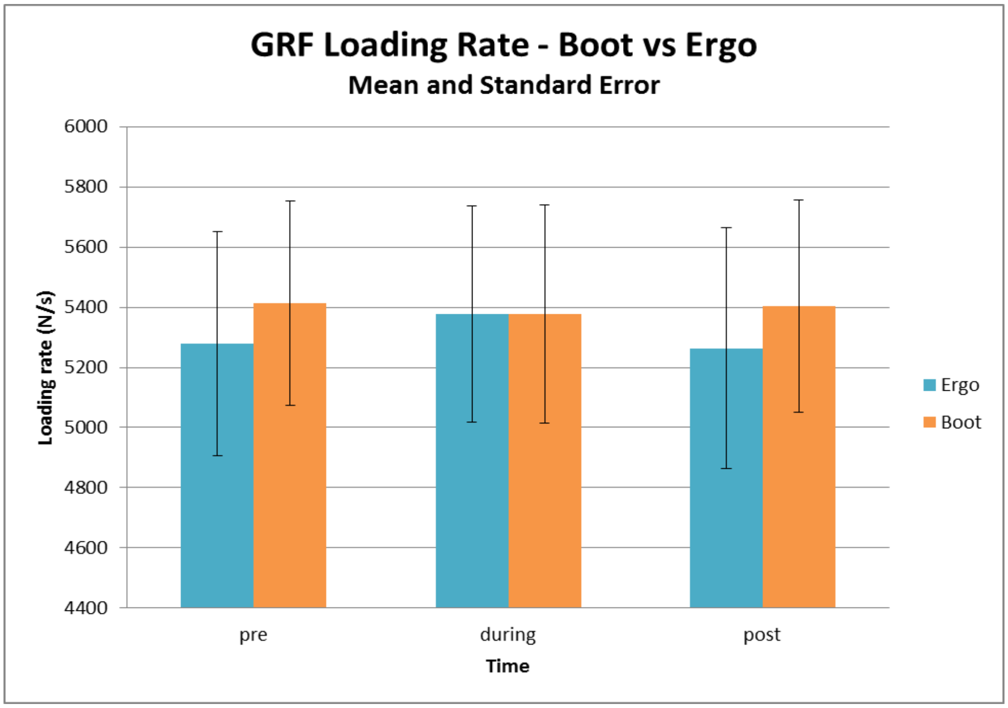


Figure 11: GRF loading rate data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats).

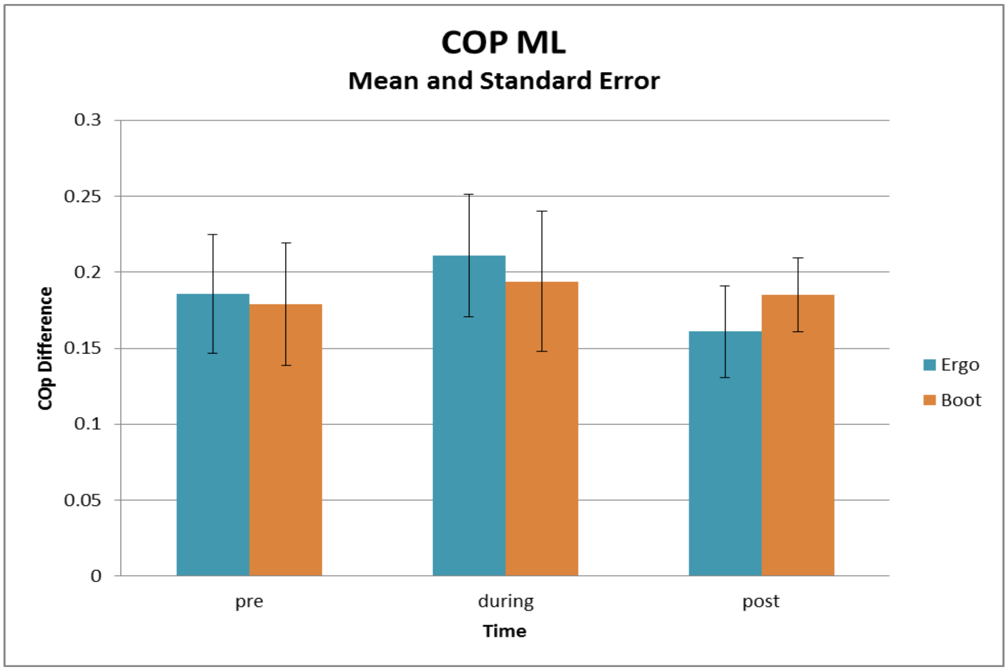


Figure 12: Medial-Lateral COP difference in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats).

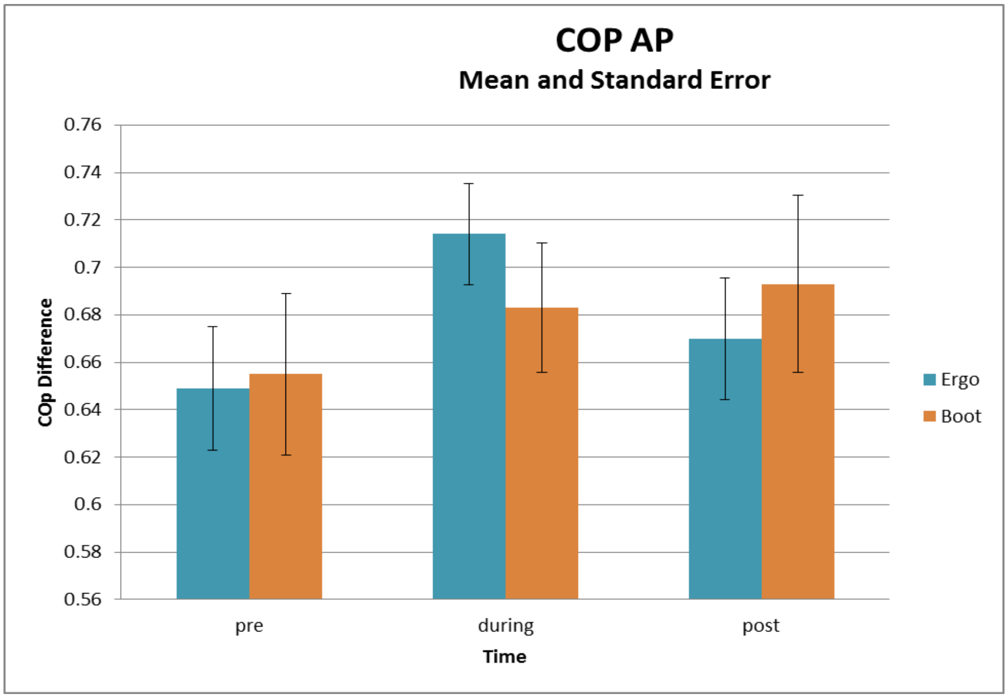


Figure 13: Anterior-Posterior COP difference in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats).

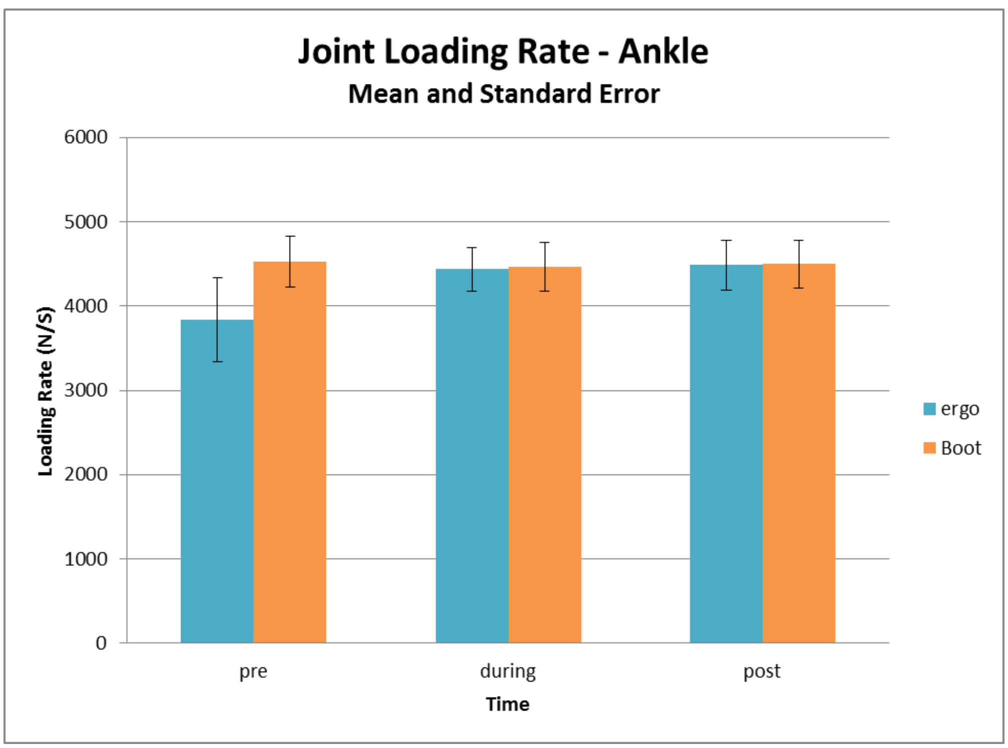


Figure 14: Ankle joint loading rate data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

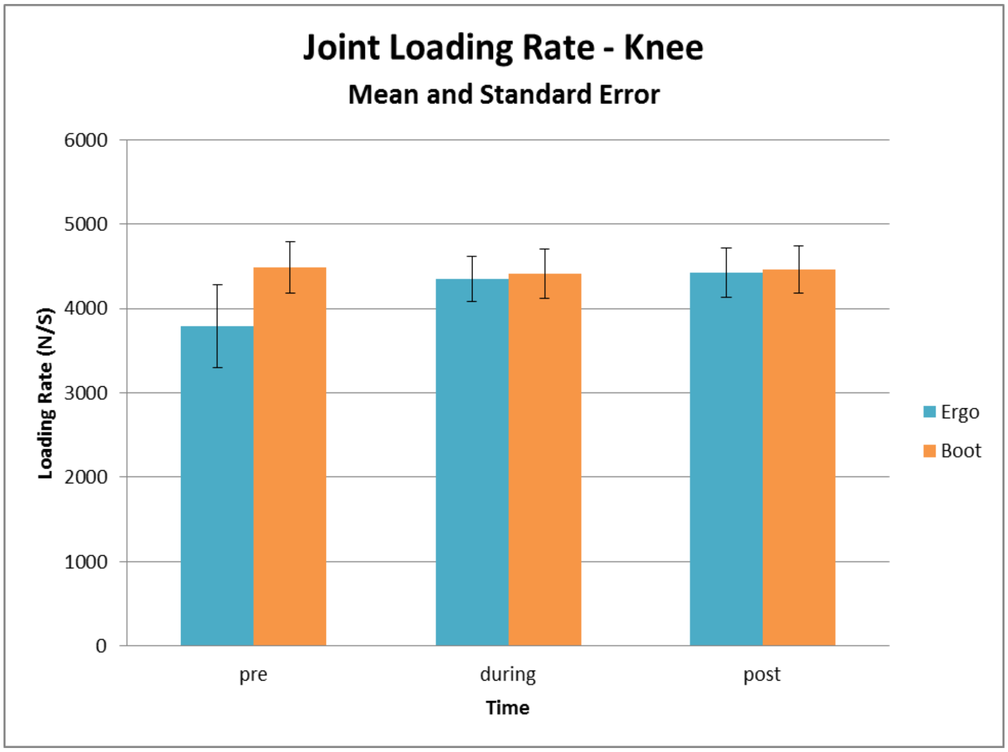


Figure 15: Knee joint loading rate data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

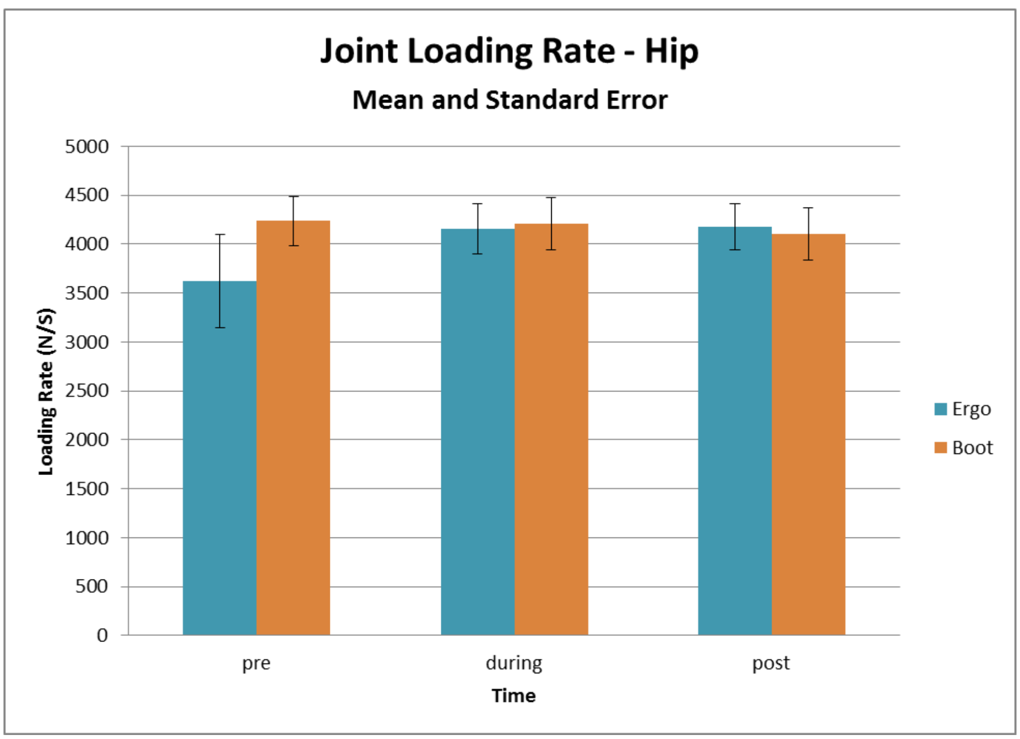


Figure 16: Hip joint loading rate data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

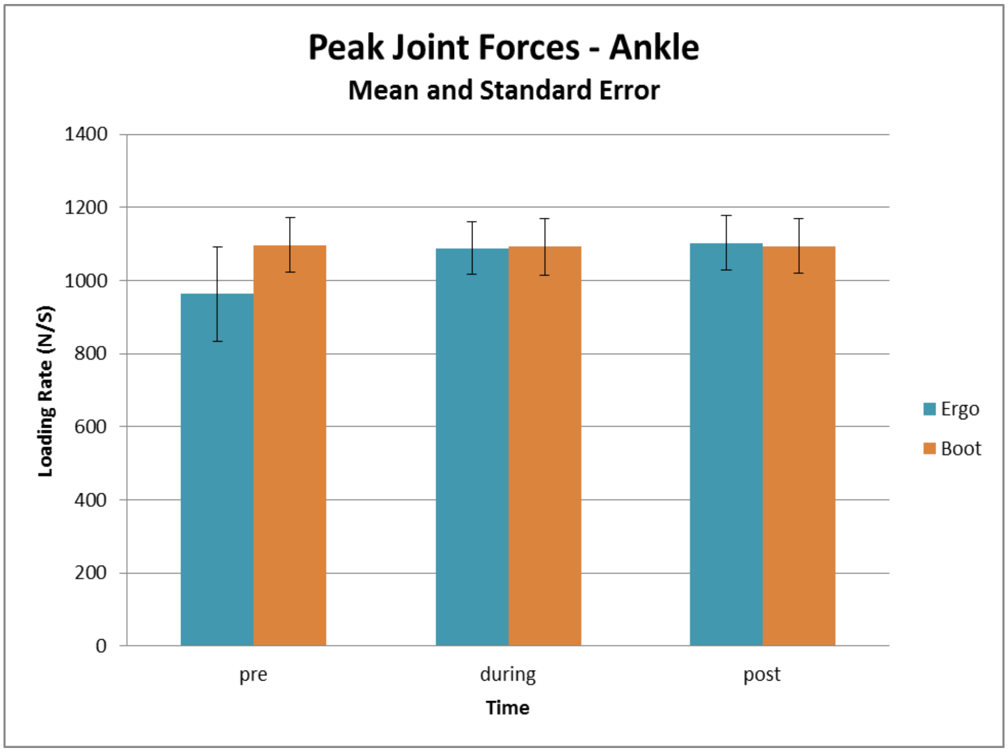


Figure 17: Peak ankle joint force data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

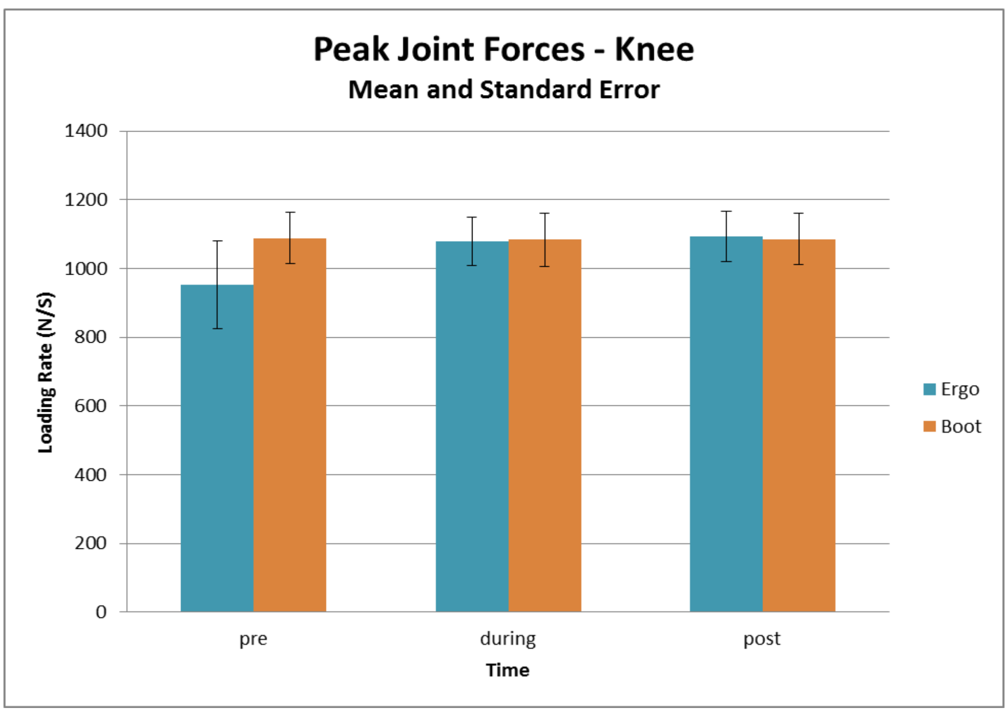


Figure 18: Peak knee joint force data for each subject in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

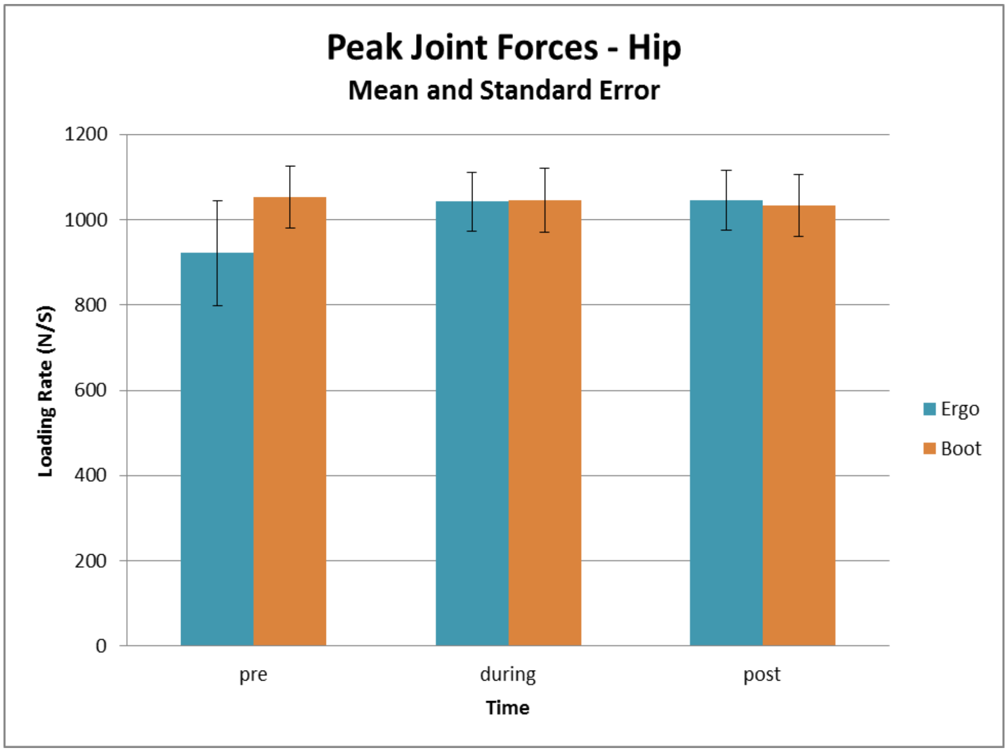


Figure 19: Peak Hip joint force data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

Kinematics

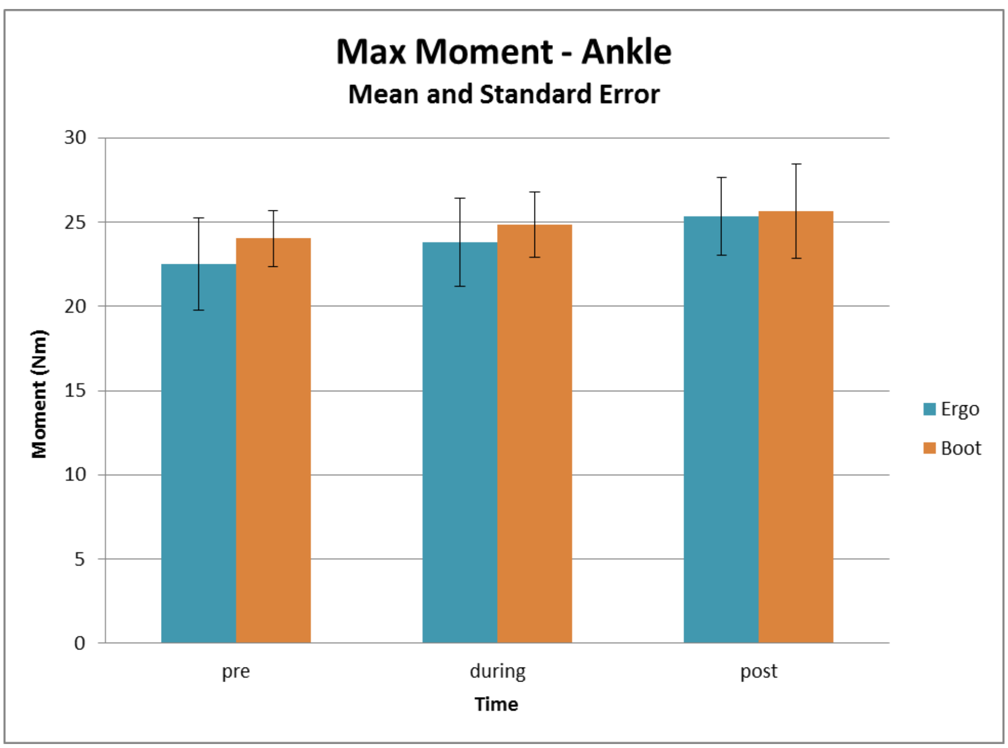


Figure 20: Max ankle moment data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

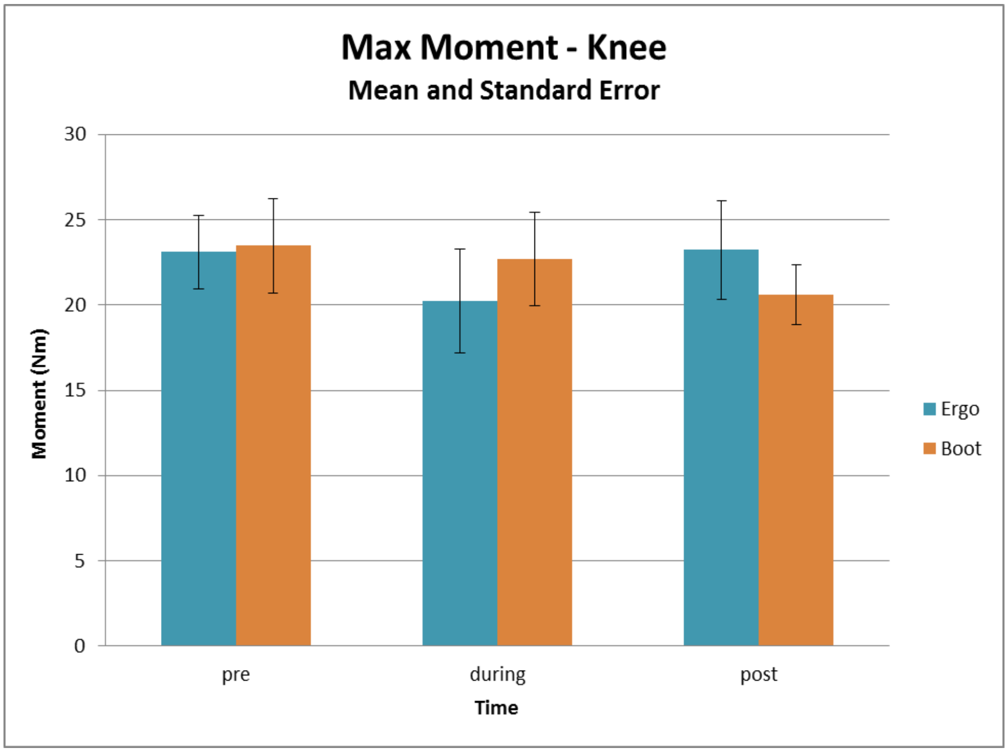


Figure 21: Max knee moment data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

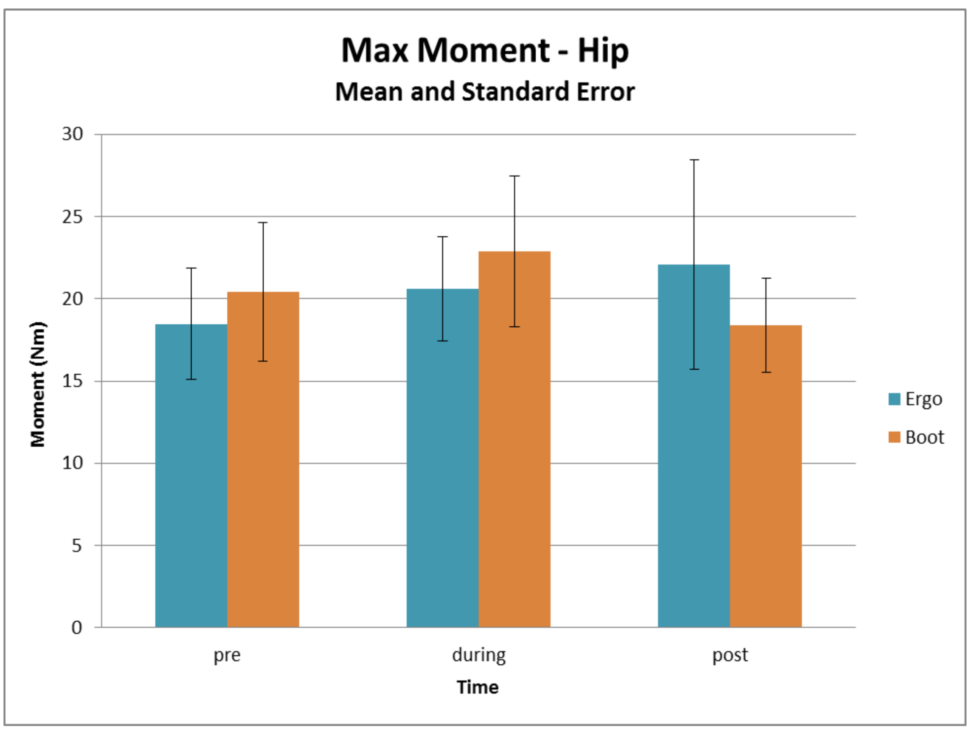


Figure 22: Max hip moment data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

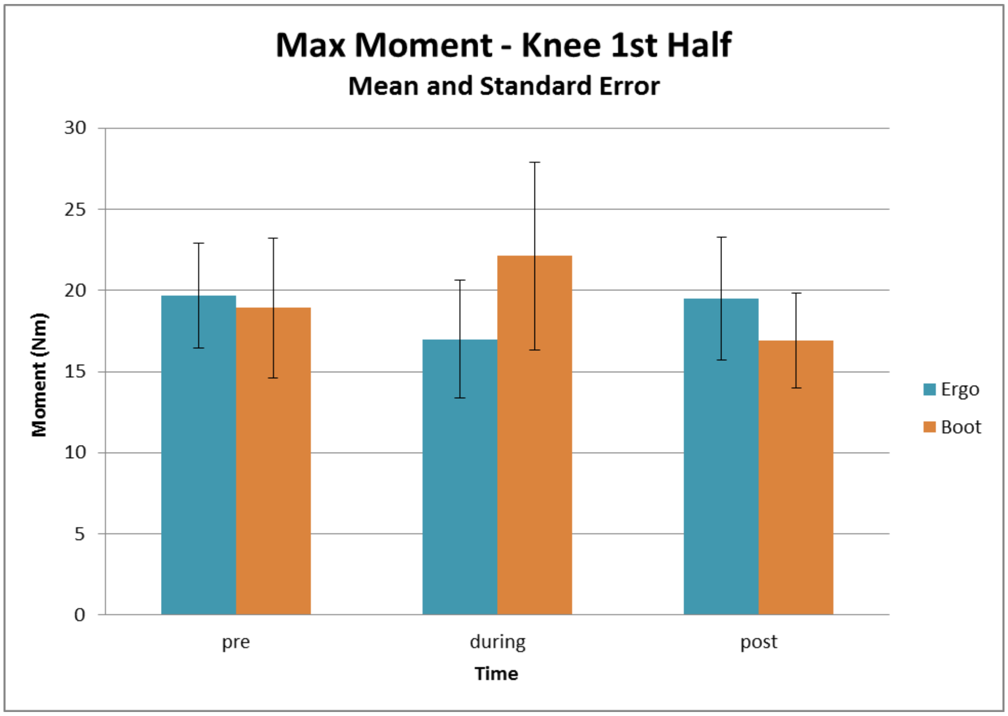


Figure 23: Max knee moment 1st half data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

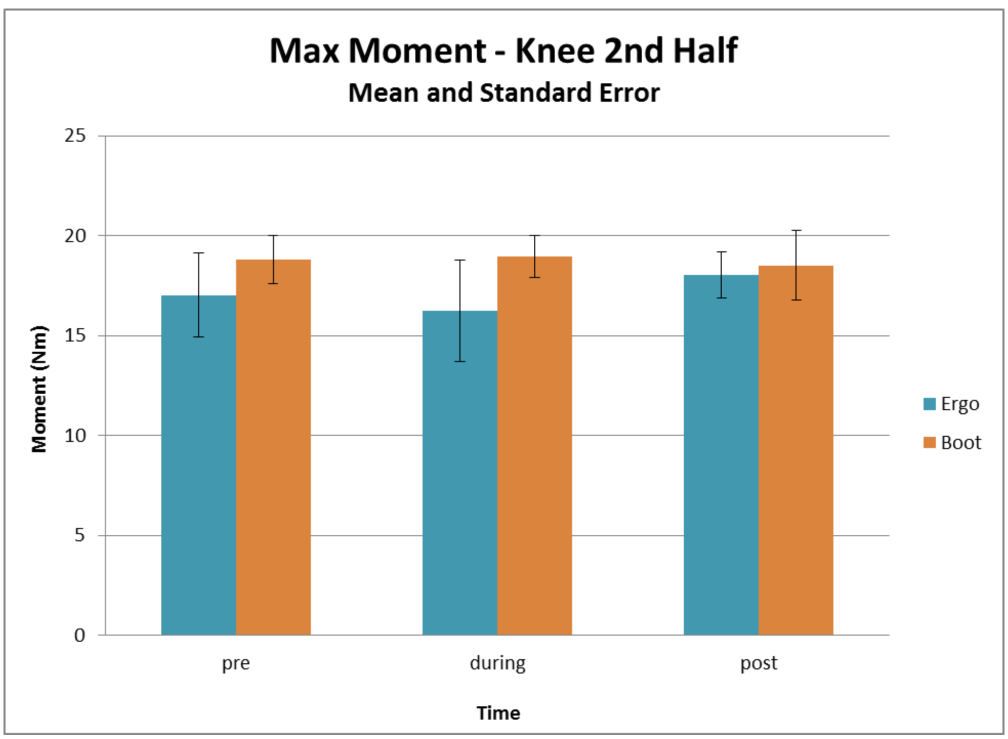


Figure 24: Max ankle moment data in pre, during and post exercise for each condition (work boot, portable anti-fatigue mats)

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