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The Effect Of Extended Durations Of Walking In Different Footwear On Measures Of Balance

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THE EFFECT OF EXTENDED DURATIONS OF WALKING IN DIFFERENT FOOTWEAR ON MEASURES OF BALANCE

by

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ABSTRACT

REBECCA LANE MACNEILL: The Effect of Extended Durations of Walking in Different Footwear on Measures of Balance
(Under the direction of John Garner)

The purpose of this study was to investigate the effects of extended walking durations on a hard firm surface in different types of industrial footwear on balance and postural control. Postural sway variables (RMS sway and sway velocity in the medio-lateral (ML) and anterior-posterior (AP) directions) were measured, based on center of pressure (COP) movement, with the NeuroCom Equitest Balance Master-Posture Platform Sensory Organization Test (SOT). Fourteen healthy adult males participated, and measures were taken at 30 minute time intervals over 4 hours of standing/walking. The eyes open (EO) condition of the SOT was utilized for this study. Each subject endured three testing conditions of footwear: the Steel-Toed Work Boots (WB), Tactical Boots (TB), and Low-Top Flat Sole Slip-Resistant Boots (LB). The postural sway measures taken are an indication of balance; increased postural sway is indicative of a decrease in balance, which may be a result of muscular fatigue. No significant results with regard to AP RMS sway, AP sway velocity, or ML sway velocity were obtained. However, ML RMS sway was shown to increase significantly across subjects over the 4 hour duration. It can be hypothesized that these increases in ML RMS sway resulted mainly from hip and knee muscular fatigue. The high boot shafts utilized in this study could be a cause for obligate hip strategy utilization and, thus, muscular fatigue at the hip

and knee. Because ML sway magnitude is strongly correlated with falls in general, the results of this study are relevant, especially as possible contributory factors to decreases in balance in industrial settings, in which falls are relatively prevalent.

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INTRODUCTION

Proper postural control and balance are essential in industrial settings in order to prevent falls and, thus, injuries. The vestibular, somatosensory, and visual systems in the human body provide inputs to the brain to provide cognitive recognition of the limits of stability in order to prevent falls (Yaggie and McGregor, 2002). Increases in postural sway, which often accompany fatigue, mark decreased stability. These increases in sway can be attributed to impairments of any of these systems (Lepers et al., 1997). As muscular fatigue occurs, postural sway increases, stability decreases, and the ability of the postural system to handle disturbances is inhibited (Yaggie and McGregor, 2002). The onset of muscular fatigue, thus, requires more exertion from the postural system in order to maintain correct posture (Corbeil et al., 2003). The existing literature has shown decrements in balance and postural control with progressive fatigue during walking and standing for extended durations.

In industrial occupational settings, workers are at constant risk of falling, so it is essential that industrial workers be able to maintain balance (Kincl et al., 2002). In any setting, falls are usually the result of trips or slips which may cause loss of postural control (Maki et al., 2008). Therefore, postural responses are of particular interest with this population (Kincl et al., 2002). Because the foot is essentially the base of support for human balance, its stability is essential in the preservation of postural control. Due to the relatively small size of this base of support, even the smallest biomechanical alterations could have profound effects on support (Cote et al., 2005). It becomes clear that footwear heavily influences balance and stability and can increase or decrease the risk of falls (Menant and Steele et al., 2008). Some contributing features of footwear may include but are not limited to midsole hardness, shoe elevation, shaft height, and shaft stiffness, all of which can affect stability and the onset of muscle fatigue (Cote et al., Menant, Bohm and Hosl, Menant and Steele et al.).

There seems to be a lack of literature describing the influences of boot type and duration on fatigue and, thus, postural control/balance. Cham and Redfern, upon completion of their study on the effects of flooring on fatigue and standing comfort, recommended that similar studies be performed with at least a four hour duration to determine with optimum accuracy the effects of long duration walking and standing on muscle fatigue and postural control. Additionally, this study found that weight shifts at the center of pressure, indicative of decrements in balance, accompanied fatigue (Cham and Redfern, 2001). It was concluded in this study that there was miniscule statistical significance in muscle fatigue until the third hour of standing, at the earliest (Cham and Redfern, 2001). In our study, we plan to implement this 4 hour duration recommendation in testing the effects of shoe type on fatigue and postural control.

The impact of type of footwear on balance and fatigue will be a central focus of this study. In previous studies, it has been shown that midsole hardness, shoe elevation, heel height, and boot shaft height and stiffness are shoe characteristics which typically impact muscular fatigue and balance (Cote et al., Menant, Bohm and Hosl, Menant and Steele et al.). Steel-toed work boots as used in occupational settings, as per the ANSI

Standard Z-41, typically are relatively heavy, have high boot shafts, have wide soles, but have lower-soled heels. These types of shoes are designed with the primary purpose of foot protection, but not necessarily balance maintenance. The characteristics of width and boot shaft height may aid in balance control because of the provision of ankle support. This support decreases the need for activation of additional ankle musculature and, thus, fatigue (Bohm and Hosl, 2010). Furthermore, the characteristic low heel may also aid in balance (Menant and Steele et al., 2008). Tactical boots typically have a smaller mass, lower boot shaft height, and smaller width than work boots, but generally have a higher heel. These may indicate that postural control will be less in tactical boots than work boots. However, other research suggests that this boot will allow for better balance because the structure of its inherent support is more similar to that of an athletic shoe. Also, its smaller mass may contribute to lesser muscular fatigue. Furthermore, we may expect low-top slip-resistant shoes to render even lower postural control due to their lower boot shafts and smaller widths, but the smaller mass of the low-top slip-resistant shoe may contribute to less fatigue and, thus, better balance.

Although there is a considerable amount of literature concerning the effects of footwear type on balance in general, there seems to be a lack of literature on the effects of specific types of footwear on balance and, furthermore, the effects of these types of footwear on muscular fatigue and, thus, balance for extended walking periods. Therefore, the purpose of this study is to analyze the effects of work boots, tactical boots, and low-top slip-resistant footwear on muscular fatigue and balance for extended periods of walking.

Definitions:

Balance: the maintenance of the center of gravity within the limits of the base of support, which is determined by foot position (Kincl et al., 2002); the ability to maintain the center of mass over the base of support in order to sustain equilibrium in a gravitational field (Horak, 1987).

Base of Support: the area including space inside the boundaries created by a hypothetical line between the tips of the toes, anteriorly and a hypothetical line between the tips of the heels, posteriorly as well as the inferior aspects of the feet (Levangie and Norkin, 2006).

Center of Gravity: a single point in a body where a force equal to the magnitude of the weight of the body can be applied in order to create exact balance with the rotational and translational effect of gravity on the body; also, the (unfixed) point in the body where the weight acts; often used synonymously with "center of mass," though there is a very small difference; depends on body position (Rodgers and Cavanagh, 1984); synonymous with "center of mass".

Center of Pressure: a point which is the center of pressure distribution; often considered the point at which a force is applied (Rodgers and Cavanagh, 1984).

Dynamic Posturography/Sensory Organization Test (Neurocom): a testing system which isolates inputs of the vestibular, visual, and somatosensory systems; isolates neuromuscular outputs; and isolates mechanisms of center integration used for postural control and balance (NeuroCom International, Inc. Clackamas, Oregon).

Equilibrium: the state in which a body or system is when the resultant forces and moment working on that body or system are equal to zero; the body is not necessarily at rest; the body does not necessarily have zero forces working on it (Rodgers and Cavanagh, 1984).

Fatigue: cognitive perception of tiredness (Cham and Redfern, 2001); a decline in the capacity to generate force (Corbeil et al., 2003).

Isokinetic Movement: refers to muscle action in which the rate of contraction or lengthening of a muscle is invariable; also refers to a constant load velocity of the working muscle or constant joint angle velocity (Rodgers and Cavanagh, 1984).

Postural Control/Postural Stability: the maintenance of one's center of mass vertical projection on a surface, which is the center of pressure; used synonymously with "balance" (Levangie and Norkin, 2006).

Proprioceptive System: the body system which promotes body position awareness and contributes to the maintenance of balance; includes input from the muscles, tendons, and joints; sensory receptors involved include those in muscle spindles, skeletal muscles, and Golgi tendon organs, which supply information on muscle length and tension, muscle force, and velocity (Sturnieks and Lord, 2008).

Somatosensory System: the body system which includes the tactile and proprioceptive systems; includes input from Meissner's corpuscles, Pacinian corpuscles, Merkel's disks, and Ruffini endings, which all are touch inputs to the central nervous system (Hijmans et al., 2007).

Vestibular System: the body system responsible for information including head position and motion relative to gravity, head posture, and body and eye movements; the structures of the vestibular system are in the inner ear (Sturnieks and Lord, 2008).

Visual System: the body system which provides environmental information via the eyes as well as input about movements and position of the body; very important in posture in balance in that information from this system is used to regulate postural sway (Sturnieks and Lord, 2008).

Hypotheses:

Balance:

H_{0A}: Individuals' balance will not be affected while exposed to extended durations of walking on a hard firm surface.

H_{1A}: Individuals' balance will be impaired while exposed to extended durations of walking on a hard firm surface.

The functioning of the vestibular, somatosensory, and visual systems is a direct determinant of the body's ability to maintain balance. According to previously performed research on balance, decrements in any of these systems decrease stability, and, thus, an increase in postural sway results. Furthermore, the research demonstrates that muscular fatigue of the postural muscles is accompanied by an increase in postural sway, as demonstrated by center of pressure weight shifts, indicating decreased stability. Additionally, the postural systems become less capable in compensating for disturbances as muscular fatigue augments, and, as muscles fatigue, more exertion is required from the postural system to sustain erect posture and maintain equilibrium. Other significant research asserts that progressive fatigue will occur with standing or walking duration. Therefore the alternative hypothesis is expected to be supported in this study, in that the exposure to extended durations of walking on a hard firm surface will increase the postural instability as measured in this study.

Footwear:

H_{0B}: There will be no differences between different footwear conditions in individuals' balance while exposed to extended durations of walking on a hard firm surface.

H_{1B}: There will be significant differences among different footwear conditions in individuals' balance while exposed to extended durations of walking on a hard firm surface.

The feet, as the body's base of support and important sense organs in center of pressure adjustment, are indispensable in the balance and postural system. Therefore, the stability of the foot is essential to balance maintenance. Furthermore, the type of footwear one wears is an important determinant of postural control because it provides the medium between the foot and support surface and affects somatosensory feedback mechanisms. According to the research, characteristics of footwear, such as midsole hardness, shoe elevation, heel elevation, boot shaft height, and boot shaft stiffness heavily impact postural control strategies and balance. Midsole hardness affects stability by center of mass fluctuations within the base of support and tactile sensory input transmission to sole receptors. Shoe and heel elevation also affect center of mass and pressure distribution. The boot shaft height and stiffness affect postural control by influencing ankle joint stability, range of motion, and fatigue. Because the different types of footwear utilized in this study (work boots, tactical boots, and slip-resistant shoes) have significantly different characteristics in these respects, the alternative hypothesis is expected to be supported in that there will be significant differences among the footwear conditions in individuals' balance during extended walking durations on a hard firm surface.

Chapter II

REVIEW OF LITERATURE

Balance and postural control can be defined in simplest terms as the maintenance of one's center of mass vertical projection on a surface, which is the center of pressure (COP) (Levangie and Norkin, 2006). The term postural stability (or postural control) more specifically considers the neuromotor processes which are involved in movement and the maintenance of this center of mass within the base of support (Levangie and Norkin, 2006). It is also relevant that the ground reaction force is applied at the center of pressure (Enoka, 2002) and that on the foot there is a point where body weight is distributed equally medial-laterally and anterior-posteriorly called the center of balance (Cote et al., 2005). In order to maintain balance in bilateral or unilateral stance, the center of gravity must be kept within the limits of the base of support, which is determined by foot position (Kincl et al., 2002). The boundaries of the base of support are also referred to as the limits of stability and cognitive recognition of this to prevent falling is obtained through inputs of the vestibular, somatosensory, and visual systems (Yaggie and McGregor, 2002).

Postural control and balance can be quantified and measured via forceplate and/or accelerometer (Adlerton and Moritz, 2003). In quiet standing, foreceplates can be used to evaluate the center of mass projection. The movement of the center of pressure, as a representative of movement of the entire body, can be used to calculate and evaluate postural stability (Caron, 2003). Postural control and balance can also be measured in an assessment of the excursions of center of pressure time-to-boundary. Such measures evaluate an estimate of the time which may be required for the center of pressure to arrive at the limit of the base of support if it continued in its directional speed, as in Hertel's study involving the measure of postural sway in quiet single leg standing of 24 young women with force plates (Hertel et al., 2006). Mean velocity of center of pressure has been shown to be the most reliable measure of postural sway among modern and classic measures of sway, including RMS distance, median power frequency, and sway area. Lin's study of center of pressure-based measures in 32 healthy individuals during quiet upright stance showed this to be true, in alignment with previously performed studies (Lin et al., 2008). An increase is postural sway indicates a decrease is stability and can be attributed to decrements in any or all of the systems which contribute to the maintenance of postural stability and balance: the visual, vestibular, and proprioceptive systems (Lepers et al., 1997). It is these three systems which identify the limits of the base of support to prevent falls (Yaggie and McGregor, 2002). Conflicting inputs from these systems has been used expansively to assess balance, posture, and response to disturbances in these inputs (Lepers et al., 1997).

Additionally, fatigue increases postural sway and, thus, decreases stability, as shown in Yaggie's and McGregor's study of plantarflexor and dorsiflexor fatigue (induced by isokinetic contractions) effects in the ankle on sway using 24 men (Yaggie and McGregor, 2002). Measurements for muscular fatigue are calculated using the co-contraction index, which is determined through integration of the ratio of EMG activity of the agonist to antagonist muscles in each pair (Chambers and Cham, 2007). The ability of the postural system to cope with small disturbances is further inhibited as a fatiguing activity advances (Yaggie and McGregor, 2002). In Corbeil's study on postural control and muscle fatigue, subjects' postural sway increased with augmenting muscle fatigue. The subjects demonstrated a great median frequency, mean, and velocity in terms of center of pressure (Corbeil et al., 2003). As compared with the control, the range of oscillations and the oscillation around the mean location of the center of pressure variability were not affected by conditions of fatigue. However, mean velocity increases in the oscillations resulted in the fatigue conditions, which demonstrates that postural control was changed by fatigue (Corbeil et al., 2003). Furthermore, this implies that muscle fatigue increases the rate of occurrence of postural actions needed to moderate erect posture by requiring more exertion from the postural system (Corbeil et al., 2003).

There are several possible explanations for the adaptations which usually accompany long-term muscular fatigue (Corbeil et al., 2003). Activating the antagonist muscles, creating a "stiffening strategy," could be used to minimize deviations in center of pressure (Corbeil et al., 2003). The decrease in the rate of force development from the fatigued muscles could require an increase in the frequency of the postural corrections in order to avoid greater displacement of the center of pressure (Corbeil et al., 2003).

In Cham and Redfern's study on the effects of flooring on fatigue and standing comfort, the results demonstrated that center of pressure weight shifts accompanied fatigue (2001). In conclusion of this study, it was recommended that similar studies be performed with a minimum four hour duration in order to determine more accurately the effects of long duration standing/walking on muscle fatigue and postural control (Cham and Redfern, 2001). This is because there was little to no significance, statistically, in the measurements of muscular fatigue until at least the third hour of standing (Cham and Redfern, 2001). The literature, in summation, seems to conclude that with standing or walking duration, there will be progressive fatigue. This fatigue is associated with a decrease in postural control and balance.

The postural system has the following responsibilities: maintenance of the center of mass within the base of support in accordance with gravity, generation of motor responses in anticipation of decisive goal movements, and adaptation (Kandel et al., 2000). Equilibrium, with regard to postural stability, is maintained through proprioceptive information from the vestibular, somatosensory, and visual sensory sources. The information obtained through these afferent sources is integrated in the cerebellum and brainstem, which then produce appropriate motor commands (Lepers et al., 1997). These systems are continuously imparting corrections in order to maintain balance (Yaggie and McGregor, 2002). Damage or impedance of any of these systems will change the postural system itself (Lepers et al., 1997). These sensory systems allot learning in the central nervous system (Levangie and Norkin, 2006). The somatosensory system involves both the tactile and proprioceptive systems. Meissner's corpuscles, Pacinian corpuscles, Merkel's disks, and Ruffini endings all convey the sense of touch to the central nervous systems as a part of the tactile system (Hijmans et al., 2007). Furthermore, cutaneous mechanoreceptors in foot soles provide pressure distribution information to the central nervous systems. Information regarding joint angles and changes therein are provided by the proprioceptive system to the central nervous system, having been distinguished by Golgi tendon organs, muscles spindles, and joint afferents;

however, it is currently unclear the role of feet and ankle proprioception in control of balance (Hijmans et al., 2007).

The visual system contributes to balance through providing continuous information from the body's environment and supplies a feedback mechanism in body position and movement (Sturnieks and Lord, 2008). The visual system is integral during gait to foot placement and identification of surrounding hazards (Sturnieks and Lord, 2008). The maintenance of balance is dependent upon spatial perception as recognized by the visual system (Sturnieks and Lord, 2008). The vestibular system consists of structures in the inner ear which sense motion and position of the head in reference to gravity (Sturnieks and Lord, 2008). This aspect of the postural system also aids in posture and head, eye, and body movement coordination (Sturnieks and Lord, 2008). Recent studies have suggested that the vestibular system heavily influences fall risk (Sturnieks and Lord, 2008).

The responses elicited from inputs are based on past cognitive and reactive experiences as well as the intention of the produced response. Reactive, or compensatory, responses are based on displacement of the center of mass. Proactive, or anticipatory, responses are based off of the anticipation of potential destabilizing external forces (Levangie and Norkin, 2006). Experiments are often performed involving the interference and conflict among the three systems to evaluate postural sway (Lepers et al., 1997).

The parameters of postural response are particularly applicable in an industrial occupational setting in which workers are constantly subject to support and falling issues.

It is essential for workers in these types of settings to be able to maintain balance for the sake of safety (Kincl et al., 2002). According to the Bureau of Labor Statistics, nonfatal injuries in the workplace decreased from 2008 to 2009, but the rate of occurrence of occupational injury in fire protection engineering and civil and heavy engineering construction from 2008 to 2009 has increased. The increased chances of falls and slips render postural instability extremely dangerous (Kincl et al., 2002). Thus, the postural muscles are in a constant effort to maintain stability (Kincl et al., 2002). Medio-lateral sway magnitude is strongly correlated with falls in general (Hijmans et al., 2007). An increase in postural sway is indicative of impaired postural control and, thus, a decrease in stability (Yaggie and McGregor, 2002). Falls in any setting usually result from a slip or trip which stimulates a temporary loss of postural control (Maki et al., 2008). Failure of the balance recovery mechanism results in a fall (Maki et. al., 2008). The control of body sway and, thus, prevention of falls, can be obtained by a number of mechanisms including the ankle strategy and the hip strategy. In a given situation, if ankle motions accommodated by a stiff segmented upper body occur to make corrections, the ankle strategy is being utilized (Adlerton and Moritz, 2003). This concept is similar to that of an inverted pendulum. Using the hip strategy to control body sway involves using the hip as a hinge for the rest of the body. This strategy is normally a second resort to the ankle strategy (Adlerton and Moritz, 2003).

The feet are essential in the upholding of balance and posture, as they act as sense organs in adjustment of the center of pressure and tactile receptors in assisting with fluid movement (Hosoda et al., 1998). Because the foot provides the base of support upon which balance depends, its stability in itself is important in the maintenance of postural control. Because this base of support is relatively small, postural control strategies may be heavily influenced by even the slightest biomechanical alterations in the support surface. This includes, especially, the type of footwear providing the base of support and interface between the foot and surface (Cote et al., 2005). Being essentially the support of the foot, footwear heavily influences stability and balance and, thus, the risk of trips and slips associated with falls. The type of shoe one wears influences balance by affecting somatosensory feedback mechanisms from the base of support (the foot) and establishing the conditions at the point of contact between the foot and the walking surface (Menant and Steele et al., 2008). Particularly midsole hardness in a shoe has a profound effect, in response to gait termination, on impeding balance control during movement. Soft midsoles prove to be more restrictive through reducing the maximum difference in the center of mass and center of pressure. Essentially, the range of the center of mass over the base of support is constrained. With a softer interface between the foot and the standing/walking surface, less mechanical support is provided to create counteractive reactive forces for the range of center of mass movement. Furthermore, differences in midsole material can impair dynamic postural control, as shown in Perry's study on dynamic balance and control with different midsole hardness during unanticipated gait termination involving 12 healthy young females (Perry et al., 2007). The results from this study indicate that midsole hardness is an impediment to balance control. The movement of the center of mass in the medial-lateral range decreased within the base of support, which demonstrates constraint of the balance control system (Perry et al., 2007). The maximum difference in the center of pressure and center of mass was reduced, which could demonstrate that softer midsole material provides restriction in this respect (Perry et al., 2007). Soft soles decrease balance, whereas hard soles improve balance. Hard soles are thought to aid in tactile sensory input transmission to sole receptors, which better allows the central nervous system to respond in balance control (Menant and Steele et al., 2008). Also, elevated shoes increase postural sway and are detrimental to the maintenance of balance because this type of heel shifts the center of mass anteriorly, changing pressure distribution, as shown in the results of Menant's study on footwear, balance, and stepping in older people. Also, higher heels may cause instability laterally because a small critical tipping angle is presented with these types of shoes (Menant and Steele et al., 2008). This finding is consistent with other studies which have found that elevated heels on shoes are disadvantageous to gait and stability in older adults (Menant and Steele et al., 2008). The height and stiffness of the boot shaft also have a significant impact on muscular fatigue and, thus, postural control, as shown in Bohm and Hosl's study on the effects of boot shaft thickness on joint stability and muscular fatigue. In general, the function of the boot shaft is to prevent ankle inversion that could cause injuries. High boot shafts are meant to provide ankle joint stability (Bohm and Hosl, 2010). They allow for less range of motion and, thus, affect the propulsion power at that joint (Bohm and Hosl, 2010). Because they restrict ankle range of motion, high boot shafts force an individual to utilize the hip strategy more, which requires bigger muscle groups and is, thus, more powerful than the ankle strategy. Additionally, high shafts with a soft collar may increase ankle tactile feedback which increase balance control. Also, stiff boot shafts limit ankle range of motion and increase co-contraction (Bohm and Hosl, 2010). Bohm and Hosl's results showed that eccentric energy and co-contraction were both increased at the knee joint with a stiff boot shaft, which could cause a decrease in gait efficiency. This, in turn, could cause premature knee muscle fatigue while walking (Bohm and Hosl, 2010).

Furthermore, shoes with elevated heels present a reduced posterior center of mass-base of support margin. These types of shoes are believed to require more efficient control medio-laterally, thus requiring more time in double support (Menant and Steele et al., 2008). Again, in this study, soft sole shoes proved to lead to a larger lateral center of mass-base of support margin when compared with that of standard shoes, suggesting that the subjects did not consciously adjust foot placement to sustain stability in the frontal plane but rather the subjects consciously restricted center of mass medio-lateral digression (Menant and Steele et al., 2008).

Additionally, walking surface has profound effects on balance and postural control. Uneven surfaces increase the tendency of the center of mass to approach the boundary of the base of support, thus presenting a challenge of balance control, as shown in the results of Menant's investigation of the effects of certain shoe features on perceptions of stability and comfort and dynamic control of balance in young and older people (Menant and Steele et al., 2008). Also, walking on uneven surfaces changes lower-limb kinematics which possibly causes reductions in breaking and loading rates. It is believed that walking on uneven surfaces causes a person to react by flattening the foot at contact in order to optimize stability (Menant and Steel et al., 2008).

Because extended duration walking evidently causes an increase in muscle fatigue, particularly at the ankle musculature, it can be hypothesized that walking for extended durations, results in a decrease in balance, as indicated by an increase in center of pressure movement. In summation, the resulting increased muscular fatigue results in an impedance to the postural system and a decrease in the maintenance of equilibrium. Balance maintenance is essential in an industrial setting, in which specific types of footwear are utilized. Because the feet, as the base of support, are crucial in postural control, footwear type is highly relevant to balance in occupational and industrial settings.

Chapter III

METHODS

The purpose of this study was to analyze the effects that walking on a hard firm surface in three different common types of industrial footwear have on balance and postural control. In particular, the effects of exposure to a hard firm surface for extended time periods were analyzed.

Participants

The participants in this study were fourteen healthy adult males who were recruited based on an anthropometric blocked assignment. As per the Institutional Review Board regulation, written informed consent was acquired. Participants were excluded based on the following criteria: cardiovascular, musculoskeletal, pulmonary, orthopedic, and neurological abnormalities, which include but are not limited to disease of the vestibular system and any present complications with walking or standing which may inhibit successful testing session completion and normal gait and/or postural control. Table 1 provides relevant participant demographics.

Table 1

Participant Demographics	Mean ± SD
Age (years)	23.6 ± 1.2
Weight (kg)	89.2 ± 14.6
Height (cm)	181 ± 5.3

Instrumentation

The NeuroCom Equitest Balance Master-Posture Platform (NeuroCom International, Inc. Clackamas, Oregon) was used to assess standing balance in the Applied Biomechanics Laboratory (ABL) within the University of Mississippi's Department of Health, Exercise Science and Recreation. The NeuroCom system encompasses an 18" by 18" dynamic dual force plate which has the capabilities of rotation and transition and a transitional visual scene; both of which have sway-referencing capabilities. The specific balance assessment tool was the Sensory Organization Test (SOT). The SOT has the capabilities to administer six different experimental conditions while utilizing the platform's sway-referencing capabilities and the visual scene. However, only one condition was analyzed for this study: standing with eyes open with no sway-referenced support nor visual surround (EO). Sway analyses were made based upon foot forces which estimated center of pressure. In order to prevent injury from falling during balance testing, a harness system was provided to participants.

Experimental Conditions

The participants were tested in three different conditions of footwear: the Steel-Toed Work Boots (WB), Tactical Boots (TB), and Low-Top Flat Sole Slip-Resistant Boots (LB). The WB are equipped with steel toes or metatarsal guards which protect the toe from compression and impact injuries, oil-resistant soles, and an elevated boot shaft which extends beyond the ankle joint with distinctive heels. These boots meet ANSI-Z41-1991 standards as per regulations of the OSHA for footwear safety and protection (Occupational Safety and Health Administration, U.S. Department of Labor). Various populations for which the ANSI does not have a prescribed footwear standard to meet typically wear the LB and TB. Size 11 was the average footwear size used for participants in this study. This size's footwear characteristics are described in Table 2.

Table 2

Footwear Characteristics

Shoe	LB	TB	WB
Mass (kg)	0.4	0.5	0.9
Boot Shaft Height (cm)	9.5	16.5	18.5
Heel Sole Width (cm)	8.5	8.8	9.6
Forefoot Sole Width (cm)	10.5	11.0	12.0
Heel Height (cm)	4.1	4.1	2.8

Experimental Testing Procedures

The testing procedures were performed in the University of Mississippi's Applied Biomechanics Laboratory (ABL). The testing procedures involved for each subject included a study design with repeated measures, with duration of exposure to a hard firm surface as a nine level independent variable: pre-test, 30, 60, 90, 120, 150, 180, 210, and 240 minute time intervals of exposure in wearing each of the three footwear types. Each participant read and completed the informed consent form and then completed a preliminary medical questionnaire. The testing protocol entailed assessment of each participant in the eyes open with fixed support and no visual sway-referencing (EO) condition of the SOT on the NeuroCom Equitest Balance Master. Each subject's first session was utilized for acclimatization purposes, in which each participant was subjected to the SOT. The first footwear condition protocol was administered in the subject's second session. Randomized assignment of one of the three types of footwear occurred. The pre-test measure (Pre), before the walking portion of the test began, included assessment on the NeuroCom. After walking began, the subjects were then assessed every 30 minutes for a duration of 4 hours (240 minutes). The time intervals for testing for each of the three footwear types were Pre, 30 min, 60 min, 90 min, 120 min, 150 min, 180 min, 210 min, and 240 min. The precise same testing procedures were administered for each of the subjects' following two succeeding sessions with each of the two other footwear types, each being randomly assigned. For the testing protocol, each participant was directed to walk at a self-selected pace and self-selected course for 30 minute intervals on the hard firm surface for each balance testing session. During each walking period, each participant was given the option to stop walking briefly and intermittently to relax, but was prohibited from leaving the hard firm surface and sitting down until the duration of the assigned exposure was concluded. A minimum of 72 hours rest from testing was required for each subject in between testing conditions. Each type of footwear and socks were provided to participants before each testing session for control purposes.

Data Processing

Center of Pressure (CoP) movement was the determinant of dependent sway variable values. The NeuroCom Equitest Balance Master provided the raw data from which these variables were calculated. Postural sway was characterized by the calculated CoP average sway velocity (VEL) and root-mean-square (RMS) sway in the medio-lateral (ML) and anterior-posterior (AP) directions during each of the 3, 20 second testing periods for the EO condition of the SOT test. Velocity is calculated by dividing displacement by time; furthermore, sway velocity is measured by the CoP's peak-to-peak change per unit time. The RMS sway is a rectifying measure which estimates sway amplitude as well as the general movement of the CoP. VEL and RMS were used to label the outcome variables in the AP direction (APVEL and APRMS) and the VEL and RMS in the ML direction (MLVEL and MLRMS). Postural sway occurs because and is indicative of postural muscles' activation and constant adjustments as a mechanism to try to keep the CoP within the base of support (BoS). VEL indicates the rate of this muscular compensation, and RMS sway illustrates the amount of compensation utilized to maintain the CoP within the BoS in order to successfully maintain balance. Higher VEL and RMS sway values demonstrate decreased balance and postural stability by the implication of greater angular changes in CoP location. The following equations were used to calculate the Sway VEL and RMS, respectively:

Equation 1 $$\text{SWAY VEL} = \left(\frac{1}{t}\right)\sum_{i=0}^{n}|COP_i - COP_{i-1}|$$

Equation 2 $$\text{SWAY RMS} = \sqrt{\left(\frac{1}{n}\right)\sum_{i=0}^{n}(COP_i - COP_{avg})^2}$$

Statistical Analysis

In order to establish if any differences in postural stability measures over time between each of the three different types of footwear (WB, TB, and LB) existed, a repeated measures analyses of variance (RMANOVA) was completed. In order to determine any differences within the exposure time and/or the shoe types, postural stability dependent variables were evaluated using a 3 x 9 (Boot [WB v. TB v. LB]) x (Extended duration of walking intervals [Pre, 30, 60, 90, 120, 150, 180, 210, and 240]. A Bonferroni post-hoc analysis was performed if significance was found in order to locate the significance found. If the Mauchly's test of sphericity was violated, a Greenhouse-Geisser correction was utilized to determine significance. Significance was set at an alpha level of p=.1 for all analyses performed; the SPSS 17 statistical software package was used to run all statistical analyses.

Chapter IV

RESULTS

Anterior-Posterior Sway RMS (APRMS)

No statistically significant differences among the time points for the Eyes Open (EO) condition of the SOT with a main effect of Time and no Time-Shoe Interaction differences were found, based on a repeated measures ANOVA with a Greenhouse-Geisser correction.

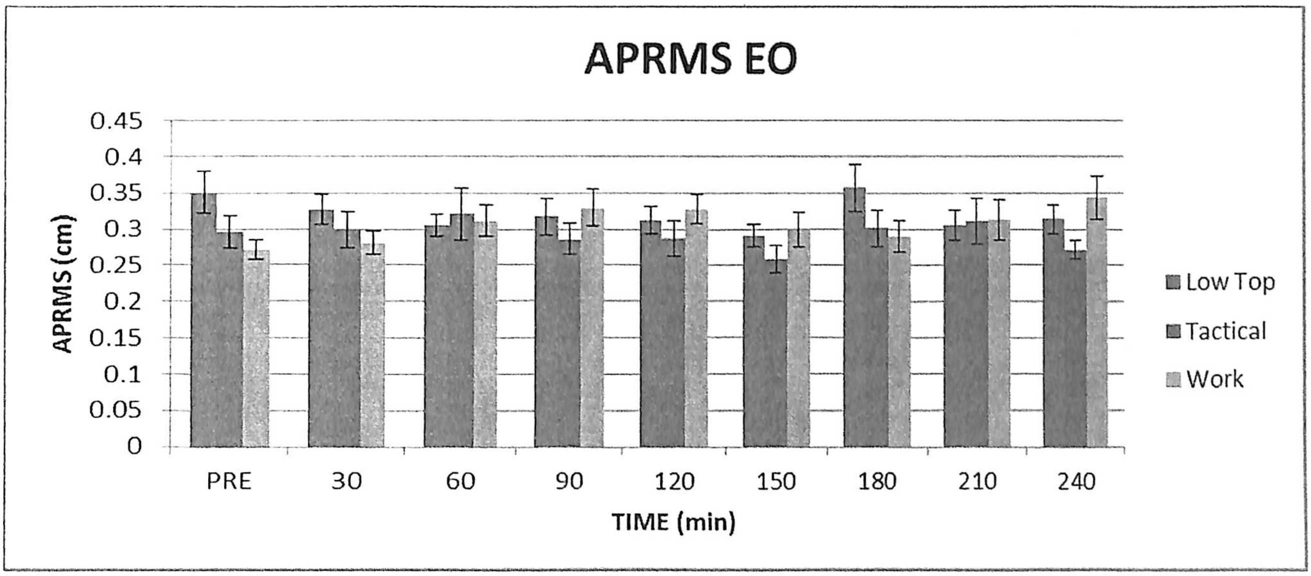

Figure 1: Anterior-Posterior direction Averaged Sway RMS measures for the EO condition testing postural stability. Bars indicate standard errors.

Anterior-Posterior Sway Velocity (APVEL)

No statistically significant differences among the time points for the Eyes Open (EO) condition of the SOT with a main effect of Time and no Time-Shoe Interaction differences were found, based on a repeated measures ANOVA with a Greenhouse-Geisser correction.

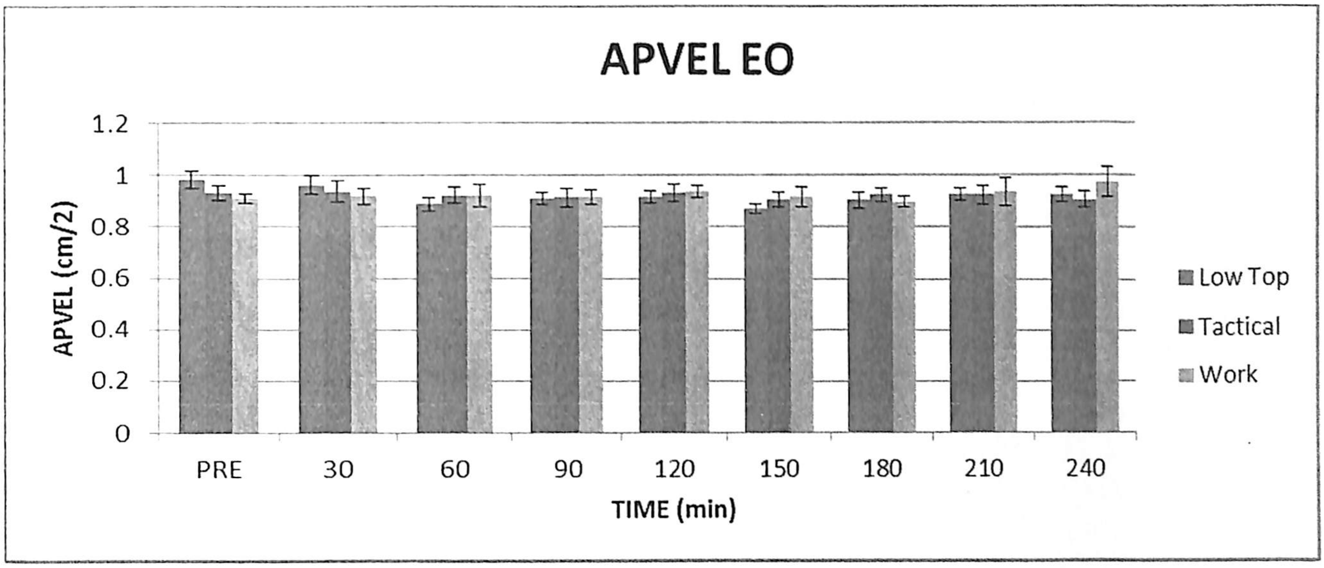

Figure 2: Anterior-Posterior direction Averaged Sway Velocity measures for the EO condition testing postural stability. Bars indicate standard errors.

Medio-Lateral Sway RMS (MLRMS)

Statistically significant differences were among the time points for the Eyes Open (P=0.025) (F(8,88)=2.347, P<0.05) condition of the SOT with a main effect of Time and no Time-Shoe Interaction differences, based on a repeated measures ANOVA with a Greenhouse-Geisser correction. There was no significance revealed among the different time points for the Eyes Open condition, as indicated by the Post-hoc test and no time-shoe interaction significant differences were found.

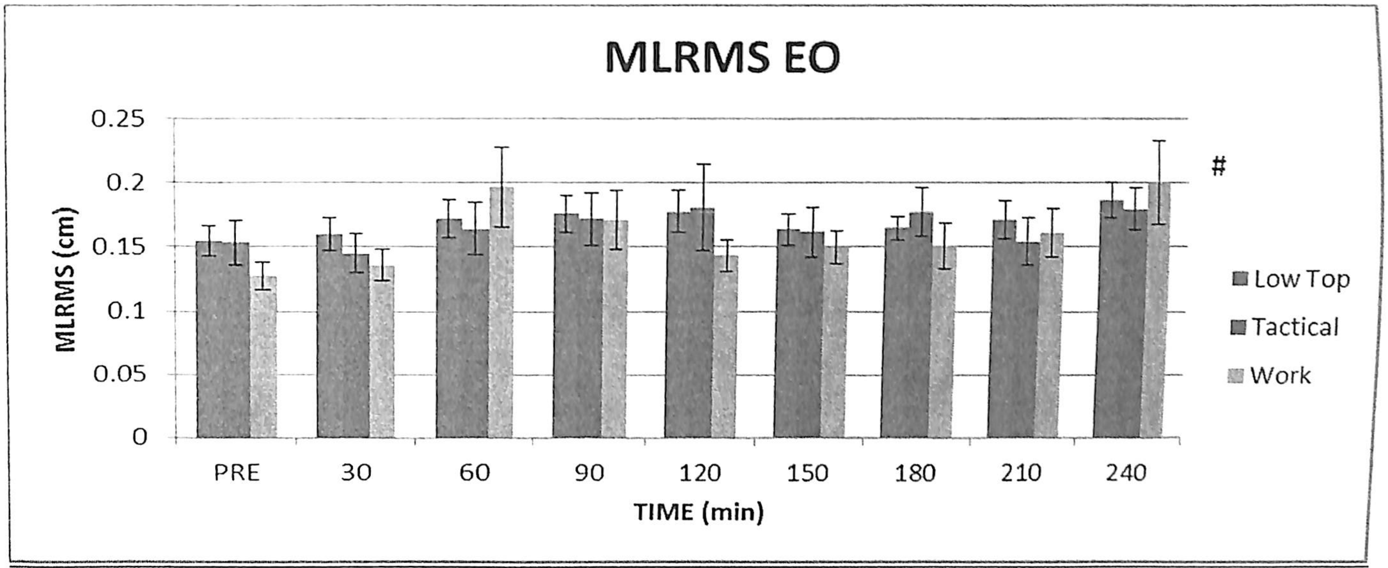

Figure 3: Medio-Lateral direction Averaged Sway RMS measures for the EO condition testing postural stability. # indicates a significant difference over time intervals and bars indicate standard errors.

Medio-Lateral Sway Velocity (MLVELO)

No statistically significant differences among the time points for the Eyes Open (EO) condition of the SOT with a main effect of Time and Shoe and no Time-Shoe Interaction differences were found, based on a repeated measures ANOVA with a Greenhouse-Geisser correction.

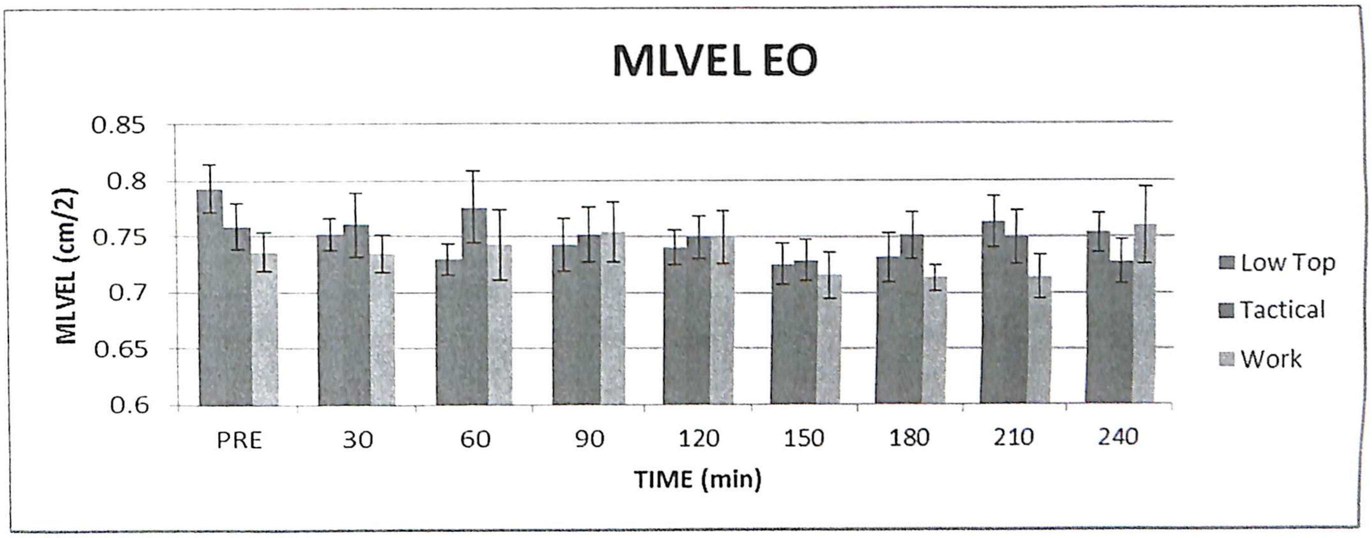

Figure 4: Medio-Lateral direction Averaged Sway Velocity measures for the EO condition testing postural stability. Bars indicate standard errors.

Chapter V

DISCUSSION

The purpose of this study was to investigate the effects of walking on a hard firm surface in three different types of commonly used industrial footwear on balance and postural control. Particularly, the effects of exposure to a hard firm surface for extended durations were analyzed. The results suggest that there is an effect of increased medio-lateral (ML) RMS postural sway over a four hour duration of standing/walking conditions on a hard, firm surface across all subjects and among the three different shoe types utilized in this study. These results support the hypothesis that time would affect postural sway and demonstrate consistency with those results of previous studies on the effects of long term standing/walking, particularly with the studies of Yaggie and McGregor, Gribble and Hertel, and Menant and Steele. No statistically significant differences were found among the three different shoe types or across time in AP (AP) RMS sway, AP sway velocity, or ML sway velocity, which does not support the hypothesis that effects would be shown within the dependent variables among the work boot, tactical boot, and low-top slip-resistant shoe conditions.

The current study was based on evidence that muscular fatigue results from extended duration walking and standing, which in turn incurs decrements on the balance system. This study was largely based on Cham and Redfern's study on the effect of flooring on standing comfort and fatigue, which found that there were no significant differences in center of pressure weight shifts for the first three hours of standing. Cham and Redfern concluded that duration of standing (or, walking in the current study), in fatigue investigations is important and that significant differences muscular fatigue may not occur until the third or fourth hour. This explains conflicting results of previous studies of two hour or less durations. Because of their findings, Cham and Redfern suggested conducting studies of minimum four hour duration to increase accuracy in results concerning fatigue and postural control. This recommendation was implemented in the current study by utilizing a four hour duration of standing/walking, resulting in the significant increase in ML RMS postural sway over the four hour duration, but not in the other three measurements of postural sway.

Yaggie and McGregor found that ankle musculature fatigue increases postural sway, which is indicative of decreased stability and that augmenting muscular fatigue results in the decreased ability of the postural system to cope with disturbances. The results of this study are also consistent with Corbeil's study of postural control and fatigue, which found that postural sway increased with fatigue, and with Lepers's study on the effects of exercise on postural control, which supported the notion that increased postural sway is indicative of decreased stability, resulting from decrements in the balance system. The results of these studies support the current study's finding that ML RMS sway increased over time, demonstrating a decrease in balance.

No significant results were shown among the different types of footwear for AP RMS sway and sway velocity or for ML RMS sway and sway velocity. This is inconsistent with studies which have shown that elevated heels on shoes, such as that in the work boots and tactical boots utilized in the current study, impair stability (Menant and Steele et al., 2008). It has been shown, such as in Menant and Steele's study on footwear features on balance, particularly in older people, that elevated shoes tend to increase postural sway because the center of mass (and, thus, the center of pressure) is shifted anteriorly. This, in turn, decreases balance. Furthermore, higher-heeled shoes may cause lateral instability because of the smaller tipping angle and, thus, require more efficient ML control, which was found to be directly related to heel height (Menant and Steele et. al., 2008). The results of increased ML RMS sway may actually be supportive of this notion because this increased sway is indicative of decreased lateral stability. It is possible that the elevated shoes utilized in this study were a cause of increased ML sway over time.

Previous studies, such as Bohm and Hosl's study on the effects of boot shaft thickness on joint stability and muscular fatigue, have also shown that boot shaft height and stiffness significantly affect muscular fatigue. Because high boot shafts, such as in the work boots and tactical boots in the current study, are intended to provide ankle joint stability by restricting ankle range of motion, a forced use of the hip strategy, which is a second resort to the ankle strategy in controlling body sway, may result. Also, Bohm and Hosl found that increased eccentric energy and co-contraction at the knee joint resulted from stiff boot shafts, which could cause muscle fatigue at the knee and decrements in balance over time. It would be expected from these findings that the high boots shafts of the tactical boot and work boot used in this study would result in a use of the hip strategy, muscular fatigue at the knee and hip, and, ultimately, a decrease in balance. Resulting RMS sway increase over time, with no respect to footwear, in the ML direction may indicate that the hip strategy was indeed utilized because of the restrictive nature of the work boots and tactical boots. The increase in RMS sway, essentially a measure of how far the center of pressure moves in time, and not sway velocity, indicates a use of hip strategy, which involves larger musculature and grosser movements, because it suggests a larger sway amplitude, as emphasized in Gribble and Hertel's study on lower-extremity muscle fatigue and postural control. Musculature at the ankle is more able to produce fine compensatory movements, compared to the gross movements of the hip strategy. Because the ankle strategy is utilized for small perturbations, sway velocity may be more highly related, and compensatory reactions at the hip and knee may result in larger center of pressure displacements. The high boot shaft highly limits use of the ankle strategy, and so changes in sway velocity may not have resulted.

The results of Gribble and Hertel's study, furthermore, support the current study's results. Gribble and Hertel's results suggest that proximal muscle fatigue, which might occur from use of the hip strategy, substantially affects ML postural control more than that of distal (ankle) musculature. Previous studies have correlated muscular fatigue with increased postural sway (Cham and Redfern, Yaggie and McGregor, Corbeil, Lepers, and Nardone). Based on the results of this study, it may be possible to attribute the increased sway to fatigue of the musculature. Furthermore, it can be hypothesized that fatigue at the hip and knee resulted in significant ML sway changes, but the same did not occur for fatigue at the ankle. This finding is consistent with the current study's finding of increased RMS sway in the ML direction. These findings coincide with those of previous studies, which found that proximal muscle fatigue in the lower extremity demonstrate greater influence on postural control, compared with that of ankle musculature. Gribble and Hertel also postulate that the postural system may more heavily rely on ankle musculature when proximal musculature becomes fatigued. When this occurs, because the ankle joint has great proprioceptive capabilities, compensatory contractions and center of pressure changes result from continued postural corrections. A major conclusion of Gribble and Hertel's study was that there is an apparent relationship between decreased postural control and muscular fatigue at the hip and knee, which corresponds to the current study's result of increased ML RMS sway resulting from fatigued hip musculature due to boot-type enforced hip strategy.

Conclusions

Extended duration walking/standing resulted in significant balance decrements in the ML direction, as indicated by an increase in RMS sway. However, no significant results regarding balance were found in RMS sway and sway velocity in the AP direction or in sway velocity in the ML direction. It can be postulated that this increase in ML sway resulted from muscular fatigue, particularly at the hip and knee. Furthermore, this could be a result of a forced hip strategy induced by the high boot shafts utilized in this study. It has been found that falls in general are strongly correlated with ML sway magnitude (Hijmans et al., 2007). The results of this study may help explain causative factors of balance decrements in industrial and occupational settings where workers are more susceptible to falls.

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