THE ACUTE INFLUENCE OF OCCUPATIONAL FOOTWEAR ON BALANCE

by
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ABSTRACT

There is a great number of potential risks for falls and injuries because of problems in the workplace. In 2010, there were almost 3.1 million nonfatal and 646 fatal illnesses and injuries disclosed in the workplace (BLS, 2010). Fatal and nonfatal occupational injuries have decreased in the recent years but there is still much room to improve. Inappropriate footwear has been attributed to 45% of all falls (Menant et al. 2008). Past studies have shown that industrial footwear can have a detrimental effect on balance (Menant et al. 2008, Chander, Garner & Wade 2013). Occupational footwear have not been designed based on foot biomechanics but based solely on physical safety. The purpose of this study was to examine the effect different types of occupational footwear have on dynamic balance for acute bouts of time. Thirty-one healthy adult males (aged 21.2 ± 1.4 years; weight 82.6 ± 15.4 kg; height 179 ± 9.4 cm) with no musculoskeletal, orthopedic, neurological, cardiovascular, and vestibular abnormalities were examined. The participants were expected to come to two visit days. The first was a familiarization and lasted about ten minutes, while the second was the actual test and lasted about an hour. Dynamic balance was measured on the NeuroCom Equitest MCT (BWM, BWL, FWM, FWL). Latencies values were found to determine reaction times to the perturbations. Individuals were randomly assigned the three different types of footwear: work boot (WB) (mass 0.39±0.06 kg), tactical boot (TB) (mass 0.53±0.08 kg), and low-top slip-resistant shoe (LT) (mass 0.89±0.05 kg). 1 x 4 [Testing Session x Footwear Condition (BF v. LT v. TB v. WB)] RMANOVA was used to evaluate balance dependent variables. Post-hoc pairwise comparisons identified differences between footwear conditions. Significant differences were found in FWM and FWL translations, but post-hoc comparisons found no differences between

footwear. Significant differences were also found in the BWL translations between the barefoot condition and TB and between the barefoot condition and WB. Both the TB and WB had a higher boot shaft height as well as increased latency values. Higher latency values mean a longer time to respond to perturbations, which could result in a fall or injury. These results would suggest that based solely on latency values that the LT is the better footwear. If these findings were combined with findings on EMG, chronic responses, and SOT, one footwear could be deemed best.

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CHAPTER I

INTRODUCTION

Adequate balance and postural stability are essential to prevent injuries or falls in occupational settings. Industrial workers have a consistent risk of falling, so their maintenance of balance is of great importance (Kincl et al. 2002). Postural control is described as a skill in which the central nervous system learns information from sensory systems, the muscles, and passive biomechanical elements (Winter 1995). The body's center of mass (COM) must be maintained over the base of support (BOS) to attain postural control in the standing position (Winter 1995). To maintain normal posture and balance, an unimpaired neuromuscular system and high cognitive neural function is essential (Levangie, P.K. and Norkin, C.C. 2006). The central nervous system consists of the visual system, somatosensory system, and vestibular system. These systems aid in preserving balance and detecting changes that may result in a fall. Postural control also relies on information from the Golgi tendon organ, muscle spindles, joint receptors, proprioceptors, and sensory receptors on the foot sole (Levangie, P.K. and Norkin, C.C. 2006).

Footwear plays a key role in the maintenance of balance and postural control because the foot is fundamentally the body's base of support (Menant et al. 2008). Around 45% of all falls are due to unsuitable footwear (Menant et al. 2008). Increases in latencies are often accompanied with a decrease in responses to external perturbations, resulting in decreased balance. Different types of footwear, such as the work boot (WB), tactical boot

(TB), and low-top slip-resistant footwear (LT), can affect these latencies. There are different features associated with each footwear condition, which include boot shaft height, footwear mass, heel height, and mid-sole stiffness (Böhm, Hösl 2010, Menant et al. 2008, Menant et al. 2009). The LT is designed for comfort, while the WB and TB are primarily intended to aid in protection and safety.

Dynamic balance is the maintenance of the center of gravity (COG) within the BOS under perturbed conditions (Hosoda et al. 1997). The motor control test is used during dynamic balance studies and is used in this particular study. The three strategies that are used as correction mechanisms in dynamic balance are the ankle strategy, hip strategy, and stepping strategy (Winter 1995).

There is a great amount of past research on balance and postural control in chronic settings (Chander, Garner & Wade 2013, Corbeil et al. 2003, Winter 1995, Hosoda et al. 1998). Research is lacking in the acute settings and their outcomes. There is also a deficiency in the testing of these particular footwear types. One study used the same footwear conditions, however, focusing on fatigue in a chronic setting (Chander, Garner & Wade 2013). That study allowed information to be gathered about the footwear for long durations of time but did not focus on reaction times and latencies. There is also a small amount of research on dynamic balance. Static balance is more predominantly studied, but the study on balance over long periods of time also focuses on dynamic balance (Chander, Garner & Wade 2013).

The impact of the type of footwear on balance and latency values in an acute setting will be the main focus of this paper. This study continued on with EMG values, but this was not included in the research and results of this paper.

Purpose:

The purpose of this study was to analyze the effect barefoot, work boots, tactical boots, and low-top slip-resistant footwear have on dynamic balance in an acute setting.

Hypotheses:

Footwear:

H_{01}: There will not be a difference in latency reaction times between different footwear conditions while exposed to external perturbations.

H_{A1}: There will be a difference in latency reaction times between different footwear conditions while exposed to external perturbations.

Definitions:

Balance: the ability to maintain the center of gravity within the limits of the base of support to strengthen equilibrium (Horak 1987); is also controlled by the foot position (Kincl et al. 2002).

Base of Support: the area bounded by the tips of the toes anteriorly and the tips of the heels posteriorly for a human BOS; is significantly smaller for a human species than the quadruped species (Levangie, P.K. and Norkin, C.C. 2006).

Center of Gravity (COG): the single point at which the magnitude or weight of the body will be applied to create balance in relation to translational and rotational gravitational effects that act on the components of the system; used synonymously with center of mass but there is a minute difference between the two (Rodgers, Cavanagh 1984).

Center of Mass (COM): the point on a body that would move similarly to the movement of a individual's external force; the meeting place of the three mid-cardinal planes of the body; it is not always located in the body (Rodgers, Cavanagh 1984).

Center of Pressure (COP): the position at which the center of pressure distribution is located; frequently deemed the place or area at which a force is applied (Rodgers, Cavanagh 1984).

Dynamic Posturography/Sensory Organization Test (NeuroCom): a testing system that distinguishes between the visual, somatosensory, and vestibular system inputs; also isolates outputs of the neuromuscular system, as well as balance and postural control mechanisms for center integration (NeuroCom International, Inc. Clackamas, Oregon).

Electromechanical Delay: the delay of a muscle's neural stimulation and the formation of tension in that muscle (Blanpied, Oksendahl 2006).

Equilibrium: the circumstance at which the moment acting on a body and the resultant force are equal to zero; does not mean that there are no forces acting on the system or the system is at rest (Rodgers, Cavanagh 1984).

Golgi Tendon Organ: detect changes in muscle tension or force and are located in tendons; are arranged in an in-series pattern (Hosoda et al. 1997).

Isokinetic Movement: the constant rate at which the muscle action is shortening or lengthening; usually applied to a constant load velocity or joint angular velocity (Rodgers, Cavanagh 1984).

Latency: the time in milliseconds from when the platform begins to move until the individual initiates the adaptation of his or her posture; used synonymously with reaction time; has an inverse relationship with balance maintenance; how well you can correct yourself when a perturbation is present; measures where the COP is located (Hosoda et al. 1998).

Muscle Spindle: an afferent sensory receptor that is embedded in the intrafusal muscle fibers; is capable of detecting changes in the muscle fiber length (Hosoda et al. 1997).

Myotatic Reflex: reflexes in response to a stretch; used synonymously with stretch reflex (Blanpied, Oksendahl 2006).

Perturbation: a variation of a system or process from its routine state of path; produced by an outside source (Winter 1995).

Postural Control/Postural Stability: the ability to sustain equilibrium by keeping the center of mass within the base of support in a gravitational field; used synonymously with balance (Horak 1987).

Proprioceptive System: the body system that assists in balance maintenance and stimulates awareness of the body position; consists of input from skeletal muscles, Golgi tendon organs, and muscles spindles, which contribute muscle length, tension or force, and velocity information (Sturnieks, Daina L. and Stephen R. Lord 2008).

Reaction time: the time it takes for a subject to initiate a response to a perturbation or stimulus; used synonymously with latency (Hosoda et al. 1998).

Somatosensory System: the body system that involves tactile receptors and proprioception; consists of input from Ruffini endings, Merkel's disks, Pacinian corpuscles, and Meissner's corpuscles that are all central nervous system touch receptors (Sturnieks, Daina L. and Stephen R. Lord 2008).

Stimulus: a thing or event, which elicits a functional response of an organ or tissue (Winter 1995).

Stretch reflex: a muscle contracting through a reflex to a pull of an attached tendon; important for the maintenance of balance and postural stability; consists of the muscle spindle and Golgi tendon organ (Blanpied, Oksendahl 2006).

Vestibular System: the body system that includes information about motion relative to body and eye movements, head posture, and gravity; also contains information about head position; structures are within the inner ear (Sturnieks, Daina L. and Stephen R. Lord 2008).

Visual System: the body system involved in gaining information from the environment, as well as the position and movement of the body, through the eyes; information utilized in the regulation of postural sway (Sturnieks, Daina L. and Stephen R. Lord 2008).

CHAPTER II

REVIEW OF LITERATURE

Balance

Balance is crucial to prevent falling through body posture and dynamics (Winter 1995). Humans are naturally unstable beings unless a control system is constantly at work. This is because two-thirds of a person's body mass is stationed two-thirds of that person's body height above the ground (Winter 1995). One of the most prevalent causes of unexpected injuries is falls (You et al. 2001). Falls are a common occurrence in certain occupational settings. The human body is also a tall structure with a high center of gravity and a small base, making it a relatively unstable complex (Guskiewicz, Perrin 1996). It is crucial for workers to maintain postural balance, allowing them to carry out specific assignments and occupational safety (Kincl et al. 2002). Falls have one of the third highest incidence rates, accounting for fourteen percent of injury and illness occurrences in a hazardous waste cleanup company (Akbar-Khanzadeh, Rejent 1999).

Balance is an intricate system that involves correlation of many motor, sensory, and biomechanical parts. An individual is able to sense the location of his or her body in relation to the environment and gravity using three different systems (Nashner 1993). The three central nervous system complexes that are responsible for maintaining balance are visual, vestibular, and somatosensory or proprioceptors. Vision is our primary system in balance that takes in afferent information. The visual system supplies continual information from the environment and provides a feedback mechanism for the position and movement of the body (Sturnieks, Daina L. and Stephen R. Lord 2008). The vestibular system contains structures of the inner ear and senses the position of the head and motion in relation to gravity (Sturnieks, Daina L. and Stephen R. Lord 2008). This system senses accelerations linearly and angularly, while correcting it. Much research exhibits that fall risk is greatly influenced by this system. The somatosensory system senses the body's position and velocity, the body's contact with outward objects, and the position of gravity (Winter 1995). This system consists of both the proprioceptive and tactile systems (Sturnieks, Daina L. and Stephen R. Lord 2008). Neuromusculoskeletal diseases cause degradation and damage in the balance control systems, which result in a decrement to balance performance (Winter 1995). These systems sense changes in perturbations. Small perturbation stimuli require a small correction response, while large perturbation stimuli require a larger correction.

Proprioception is the perception of the movement of the limbs, body, and head. Two types of sensory receptors that play a role in preventing the body from further injury and in controlling the posture of the nervous system are muscle spindles and Golgi tendon organs. The muscle spindle is an afferent sensory receptor that is embedded in the intrafusal muscle fibers and is capable of detecting changes in the muscle fiber length. Hence, whenever a stretch is being applied on the extrafusal muscle fibers by means of a perturbation, the spindle senses this stretch and excites the agonist muscle to contract and prevent the individual from losing balance. Golgi tendon organs detect changes in muscle tension or force and are located in tendons. They are arranged in an in-series pattern (Levangie, P.K. and Norkin, C.C. 2006).

Balance can be defined as the maintenance of the body's center of gravity within the base of support (Winter 1995). The center of gravity (COG) is the vertical projection of the center of mass (COM) (Winter 1995). The base of support (BOS) is the total amount of area that the body is in contact with the ground when in an erect bipedal stance in the anatomical position (Rodgers, Cavanagh 1984). If the COG moves out of the parameter of the BOS, the individual has surpassed the limits of stability. This could result in a step or stumble to regain the COG within the BOS or supplemental external support is needed to prevent a fall (Nashner 1993). The center of mass (COM) is a fixed anatomical location, a point corresponding with the total body mass, and where the three body planes cross one another (Rodgers, Cavanagh 1984). However, the center of mass can move out of the BOS. Another important component of balance is the center of pressure. The center of pressure (COP) is the area of pressure distribution found from a force platform (Rodgers, Cavanagh 1984). The COP is maintained within the BOS, because the foot makes contact with the floor. It is simply a measure of balance. There are limits of stability (LOS), which increase with the BOS. The LOS is the BOS's perimeter in the anterio-posterior and medio-lateral positions. The body is constantly working the postural muscles to keep the COG within the BOS with limited postural sway (Kincl et al. 2002).

In standing, only humans' feet touch the ground directly. Bipedalism also sets humans apart (Hosoda et al. 1998). Conclusively, feet play a vital role in preserving postural stability. Feet function as sense organs to carry the body and adapt the center of pressure to prevent falling. Feet also function as receptors by gathering information through the skin and producing smooth adaptations in posture (Hosoda et al. 1998). The sole of the foot is one of the most sensitive places on the human body because it is hairless.

There are many mechanoreceptors located here, and these are nerve endings that are aware of dynamic changes of receptors or other cells near the receptors (Hosoda et al. 1998). The soles of the feet are also defined as primary "antennas" for sensory input (Hosoda et al. 1997).

Static balance is the maintenance of the COG within the BOS under unperturbed conditions with minimal postural sway. It is simply standing balance (Winter 1995). To quantify static stability, COP can be evaluated during quiet bipedal posture (Federolf, Roos & Nigg 2012). Postural sway is the corrective mechanism placed on the body as a reaction to external perturbations. The body is described as an inverted pendulum model to understand postural sway, because it pivots about the ankle joint as an axis anterio-posteriorly and medio-laterally (Winter 1995). When the COG is anterior to the COP, the body will encounter a forward sway and must activate the plantarflexor muscles to counteract this movement. This then causes the COG to be posterior to the COP, resulting in a backward sway. To correct this movement, the dorsiflexor muscles are then activated. This anterio-posterior direction sequencing of events continues and is also seen in the medio-lateral direction (Winter 1995).

Dynamic balance is the maintenance of the COG within the BOS under perturbed conditions, and it is seen as a predominant function in locomotion (Hosoda et al. 1997). The test to measure static balance is the sensory organization test (SOT). The SOT disrupts the visual and/or somatosensory processes in relation to the body's COG and measures the maintenance of balance (Nashner 1997). The test to measure dynamic balance is the motor control test (MCT), which was the test used in this experiment. The MCT can measure perturbations with the stimulus in forward and backward motions (Hosoda et al. 1998).

There are three strategies that are used as correction mechanisms in dynamic balance. The ankle strategy is when the ankle plantarflexors or dorsiflexors are the only thing to move from small perturbations in the inverted pendulum (Winter 1995). The hip strategy acts to flex or extend the hip when the ankle strategy is not sufficient enough to maintain balance due to larger perturbations (Winter 1995). The stepping strategy is the act of stepping outside of the base of support to prevent falling (Winter 1995). In this strategy, the BOS increases and the COM decreases, which results in an increase in balance.

NeuroCom was founded as the leader in evaluating and restoring of balance. The Equitest system is one of the products of NeuroCom that can be used to objectively measure standing dynamic balance. It is used to mirror the challenges of daily living. The EquiTest measures and determines the results of the SOT and the MCT (Hosoda et al. 1997). It provides information applying to somatic sensation and visual sensation through double or single-leg stances with eyes open or eyes closed. Assessment is provided through either a stable/unstable support platform or stable/dynamic visual setting. There is a pressure sensor inside the force plate to detect center of pressure and body equilibrium, which transfers information to a computer for analysis. Force platforms assess symmetry, steadiness, dynamic stability, and dynamic balance (Guskiewicz, Perrin 1996). The force plate can move forward and backward, causing external perturbations. Through the computer analysis, the researcher can determine how quickly and how precisely the participant will respond to the perturbations.

A few of the most commonly reported balance measurements include the following, Equitest system, root-mean-square (RMS) sway, and sway velocity. The Equitest system can be used to determine postural stability for dynamic balance. RMS sway and sway velocity are possible measures for static balance. RMS sway is the amplitude approximation from movement of the COP. Sway velocity is the change in the COP peak to peak. Movements in RMS sway and sway velocity occur in anteroposterior (A/P) and mediolateral (M/L) directions (Winter 1995). Latency is one component that can be studied using the Equitest system to measure dynamic balance in which the perturbation is the stimulus measured. Latency is the time in milliseconds from when the platform begins to move until the participant initiates the adaptation of his or her posture, or reaction time. Latency has an inverse relationship with balance maintenance. It is how well you can correct yourself when a perturbation is present and measures where the COP is located (Hosoda et al. 1998). Latency is important because the longer it takes a person to respond to a perturbation, or reaction time, the lesser the balance performance will be. It is also important to measure different footwear in relation to the shoe masses and heights, which will be discussed later. Latency issues cause risks of falling and build up over periods of time causing chronic issues. Perception-action coupling is the connection between information and movement. It is measured by the sensory organization and muscle activation (Levangie, P.K. and Norkin, C.C. 2006).

Electromyography (EMG) analysis can be used alongside the Equitest to study the recovery of balance. EMG measures muscle activation (Qu, Hu & Lew 2012). EMG analysis has been used to identify the causes of insufficient physiological responses and the subsequent falls and the differences between failed and successful balance recovery (Qu, Hu & Lew 2012). EMG is used to determine which muscles are active in an activity or a fall and for how long they are active.

Footwear

The initial point of contact between the environment and the body is the human foot. Footwear has a great effect on balance control and the chance of undergoing falls in normal walking (Menant et al. 2009). Workers that wear different forms of protective equipment demonstrate a variation in postural stability (Kincl et al. 2002). Unsuitable footwear has been associated with 45% of falls (Menant et al. 2008). A direct evaluation of the existence of falls in elderly showed definitive evidence that footwear had a significant effect on their risk of falls (Federolf, Roos & Nigg 2012). There is an elevated risk of falling associated with walking barefoot as well. Also, individuals wearing slippers rather than regular shoes have shown an independent involvement in greater possibility of injuries and falls (Menant et al. 2008). Slippers have shown to slow responses to perturbations and had harmful effects on postural responses (Hosoda et al. 1997). Material in footwear soles and footwear fixation of the ankle joints has hindered afferent information from being sent, which results in decreased reaction strength and speed (Hosoda et al. 1997).

Shoe features, such as heel height, sole hardness, heel and midsole geometry, and heel-collar height, have noticeable effects on gait and walking. It is evident that shoes affect the way that we walk (Soames 1985). In one study, young and old people walked in soft sole shoes and standard sole shoes. Both groups of people exhibited a larger lateral center of mass-base of support margin when walking in the soft sole shoes rather than the standard. This displayed the harmful effect diminishing the hardness of shoe sole had on stability. This study also showed that a tread sole and greater sole hardness did not improve walking stability. These findings conclude that a standard sole hardness is more influential (Menant et al. 2008). The influence of midsole hardness material hinders the dynamic balance control system (Federolf, Roos & Nigg 2012). According to one specific study, casual or athletic shoes were more stable than standing barefoot or in unstable shoes (Federolf, Roos & Nigg 2012). One contrasting find for shoe features was that there were no additional benefits in stability for the standard shoe versus the shoes with a tread sole, hard sole, flared sole, and beveled heel (Menant et al. 2009). Perry found that variations in and even the presence of midsole hardness are an obstacle for and impair feedback to gait termination for dynamic balance control (Perry, Radtke & Goodwin 2007).

While sole cushioning is an important characteristic in determining the best footwear to prevent falling, heel height is another feature that influences postural stability. One study showed that a greater shoe heel height resulted in a more cautious walking pattern and diminished medial-lateral balance control, resulting in impaired balance (Menant et al. 2008). This study also found that walking stability was not improved with increased collar height (Menant et al. 2008). In another study, it was found that with military boots compared to barefoot walking step and stride lengths, single support time, and swing phase increased. Along with these findings, cadence, double support time, and stance phase decreased in military boots in relation to barefoot walking. The military boots displayed about 5% step frequency reduction and 7% step and stride lengths increase in comparison to barefoot. This general added stability in the military boots could be a result of the greater weight, additional cushioning, snug fit, or low-heel component of the boots (Majumdar et al. 2006). In a recent study, athletic shoes were studied in comparison to standing barefoot and unstable shoes. The collar of the athletic shoes was thought to provide supplementary sensory information. This might prompt high-order postural control movement more beneficial to standing barefoot, and these movements contribute to the entire postural changes (Federolf, Roos & Nigg 2012).

Environmental features also determine the outcome of balance recovery and stability. In another footwear study, participants demonstrated notable decreases in shoe-floor angle at heel strike, walking velocity, and step length when walking on wet surfaces (Menant et al. 2009). In this study, participants showed a decline in walking velocity, step length, double-support time, greater step width, etc. when walking on unusual surfaces versus the control surface. Participants also displayed a decrease in step length, walking velocity, and shoe-floor angle at heel strike when walking on the wet surface versus the control surface (Menant et al. 2009).

There has been a great amount of previous research performed on the balance and footwear conditions mentioned. The purpose of this study was to determine the effect occupational footwear has on balance with varying degrees of perturbations. There are three different types of footwear used to study this dynamic balance control. These are the Steel-toed work boot (WB), the Tactical boot (TB), and the Low-top flat sole slip-resistant boot (LB) with the control group being barefoot. These shoes can be characterized and distinguished by mass and height. The WB met the Occupational Safety and Health Administration (OSHA) regulations for the ANSI Z41-1991 standards for protective footwear. "OSHA requires the use of personal protective equipment (PPE) to reduce employee exposure to hazards when engineering and administrative controls are not feasible or effective in reducing these exposures to acceptable levels" (Occupational Safety and Health Administration, Laws and Regulations, 1970). The characteristics for the WB include steel toes for toe protection against compression or impact injuries, elevated boot shaft height that expands superior to the ankle joint, a large mass, and oil resistant soles (Occupational Safety and Health Administration, Laws and Regulations, 1970). The TB has a lower heel height, a lesser mass than the WB, an athletic sole, and a shaft height lower than the WB but still superior to the ankle joint. The LB has a lower heel, a lesser mass, a flat slip resistant sole, and a lower shaft height than the WB and the TB. The LB is designed more for comfort, while the WB and TB serve for protection and safety. The masses of these footwear also play a role in balance performance and stability. An increased mass can result in an increase in energy expenditure and diminish balance performance (Garner et al. 2013).

The WB and TB can be grouped together because they both have heightened boot shaft. The TB and LB can be compared in their similarly light masses. Heightened boot shaft has also shown to support better balance performance, which is seen in the WB and TB (Chander, Garner & Wade 2013). The lower the mass of the boot, the lesser the workload and fatigue, resulting in better balance (Garner et al. 2013). Greater mass added on the distal end of the lever spends more energy than a lesser mass of footwear (Chander, Garner & Wade 2013). In this study, chronic conditions of balance performance were studied over prolonged periods of time during static balance (SOT) using WB, TB, and LB (Garner et al. 2013, Chander, Garner & Wade 2013). Through this study, one can see the effect acute bouts at the start of each experiment have on chronic conditions in the prolonged periods of time. The purpose of the present study was to draw conclusions concerning acute conditions of perturbations and the results it has on balance performance during dynamic balance (MCT) using the same occupational footwear. If the acute risks are decreased, this will improve postural stability and decrease the risks of falls.

CHAPTER III

METHODS

Purpose

The purpose of this study was to analyze postural stability changes in dynamic balance with four different footwear conditions. This study will determine the effect three common types of occupational footwear have on balance with varying degrees of perturbations. Suggestions for effective footwear and explanations for strategies in dynamic balance can be found from these conclusions. This could also lead to assumptions and recommendations to prevent falls and fall-related injuries in industrial settings. Determining adjustments in balance measures, such as dynamic balance recuperation and muscle activity of the lower extremity, was the long-term goal of this proposed study and research. The present study can be used to draw conclusions concerning acute conditions of perturbations and the results it has on balance performance during dynamic balance using the MCT. Postural stability increases and the risks of falls decreases as a result of the acute risks diminishing.

Participants

The participants in this study were thirty-one healthy male adults between the age of 19 and 35 years old. Written informed consent was obtained through the Institutional Review Board (IRB). Participants were eliminated if they had a history of cardiovascular, musculoskeletal, orthopedic, neurological, and vestibular abnormalities. These consist of but are not restricted to vestibular system diseases and walking or standing complications, which could interfere with effective completion of testing and ordinary postural control and/or gait. Table 1 includes applicable demographics of participants.

Table 1

Participant Demographics	Mean ± SD
Age (years)	21.2 ± 1.4
Mass (kg)	82.6 ± 15.4
Height (cm)	179 ± 9.4

Instrumentation

The NeuroCom Equitest Posture Platform was used to assess dynamic balance at the Applied Biomechanics Laboratory in the Turner Center (Division of Exercise Science) at the University of Mississippi. The system uses an 18” x 18” dynamic dual force plate, which has translation capabilities of forward and backward. This plate measures the vertical forces that the participant’s feet apply as well as the latency time period between the movement of the plate and the postural recovery reaction. The forces exerted by the feet are recorded to calculate the center of pressure for sway analysis. Analysis of the reaction times are given through the latency measures. Two conditions were used to utilize translation capabilities, which include forward translations [medium (FWM)/large (FWL)] and backward translations [medium (BWM)/large (BWL)]. To prevent injury during dynamic balance testing, participants were provided with a harness system.

Experimental Conditions

Participants were tested under four different conditions of footwear: the Steel-Toed

Work Boots (WB), the Tactical Boots (TB), the Low-Top Flat Sole Slip-Resistant Shoes (LT), and the barefoot control group. The WB is provided with oil-resistant soles, an elevated boot shaft with distinctive heels, and metatarsal guards or steel toes to preserve the toe from impact and compression injuries. The WB meets the footwear safety and protection ANSI-Z41-1991 standards of the OSHA regulations (Occupational Safety and Health Administration, U.S. Department of Labor). Many occupational settings usually wear the TB or LB when they do not have an ANSA footwear requirement. Table 2 displays the footwear characteristics for each condition.

Table 2

Footwear Characteristics

Shoe	LT	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 experimental testing procedures were performed in the University of Mississippi's Applied Biomechanics Laboratory. Upon arrival of a suitable participant, a member of the research team described the complete goal of the study and explained the importance of having a completely natural behavior throughout the experiment. The testing procedures included two visits in all. The first visit consisted of gaining informed consent and was a familiarization session, lasting about 10 minutes. The second visit was separated from the first by at least 48 hours. It was considered the testing session and lasted about 60 minutes. Participants would be given new socks and footwear that they would not keep. The order of the footwear was randomly selected, and dynamic balance was tested for four conditions. Participants were directed to stand on the NeuroCom as still as possible for balance testing. Following the completion of each footwear condition, participants were to be seated with footwear removed for a 10-minute washout period. This was repeated for each footwear condition, which were the three footwear explained earlier with barefoot as a control group.

Data Processing

The NeuroCom Equitest supplied the raw data for dynamic balance measures. Balance analysis consisted of latency measures. Latency is defined as the time in milliseconds between the beginning of the translation and the launch of the participant's active reaction. It was used as the balance dependent variable in this study. A greater latency means a greater reaction time, which results in a decrease in postural stability and balance.

Statistical Analysis

Latency values were assessed from the MCT using a 1 x 4 [Testing Session x Footwear Condition (BF v. LT v. TB v. WB)] repeated measures analyses of variance (RMANOVA). Latencies were evaluated independently for the medium and large backward and forward translations. Post hoc pairwise comparisons determined the differences between footwear conditions with Bonferroni corrections, while significance was set at an alpha level of p=0.05. A Greenhouse-Geisser correction was used to determine significance if the Mauchly's Test of Sphericity was disregarded for having a significance value greater than 0.05. SPSS 21 statistical software was used to obtain all statistical analyses.

CHAPTER IV

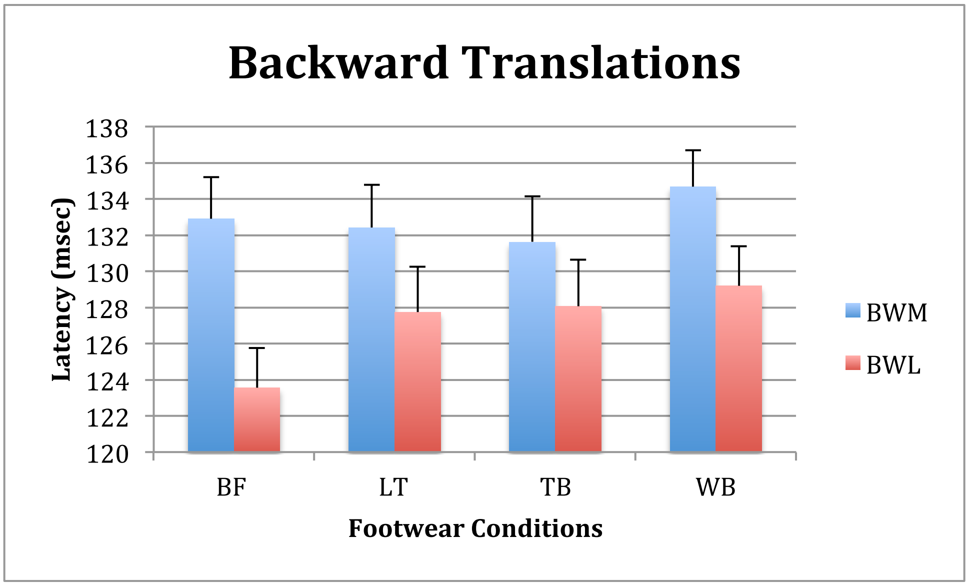
RESULTS

Backward Translations

A repeated measures ANOVA was done to find out any existing differences in the four footwear conditions between medium and large forward and backward perturbations. Significance was set at an alpha level of $p=0.05$ and post-hoc comparisons were used to determine differences between footwear conditions. Mauchly's Test of Sphericity was used to determine significance unless it was disregarded for having a significance value greater than 0.05, during which a Greenhouse-Geisser correction was used.

No statistically significant differences were found for the backwards-medium (BWM) perturbation for all footwear conditions based on repeated measures ANOVA. Statistically significant differences were found for the backwards-large (BWL) perturbation ($p=0.002$) based on repeated measures ANOVA. Multiple post-hoc comparisons revealed differences among footwear conditions were found between the barefoot condition and the tactical boot ($p=0.046$), as well as between the barefoot condition and the work boot ($p=0.003$). Barefoot condition had lower latencies than the tactical boot and the work boot. There was not a significant difference between the barefoot condition and the low-top slip-resistant footwear.

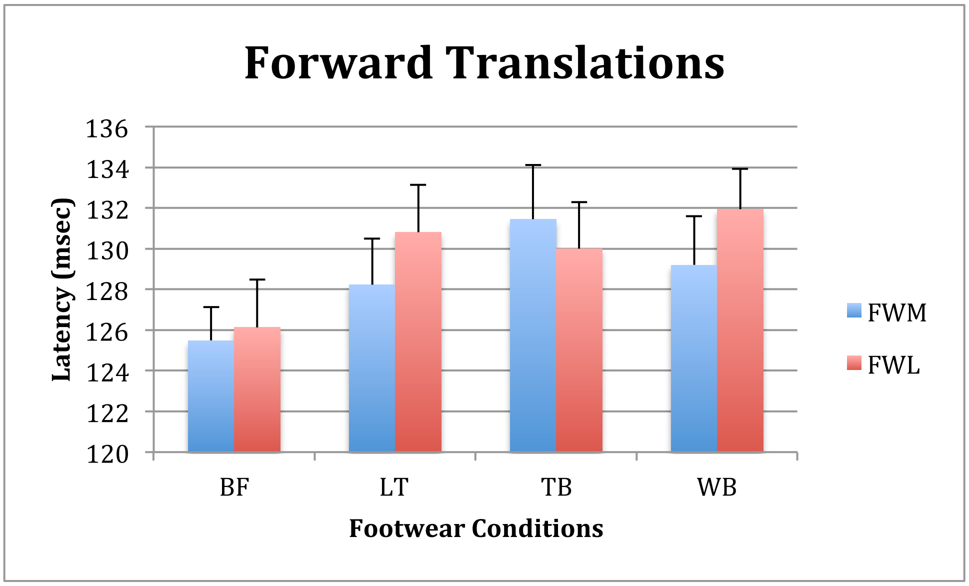
*Figure:



Forward Translations

Statistically significant differences were found for the forwards-medium (FWM) perturbation (*p*=0.036) based on repeated measures ANOVA. No post-hoc significant differences were revealed among the different footwear conditions. Statistically significant differences were found for the forwards-large (FWL) perturbation (*p*=0.033) based on repeated measures ANOVA. No post-hoc significant differences were revealed among the different footwear conditions.

*Figure:


Forward Translations
136
134
132
130
128
126
124
122
120
Latency (msec)
BF
LT
TB
WB
Footwear Conditions
FWM
FWL

CHAPTER V

DISCUSSION

This study evaluated the differences in balance reaction times between thirty-one healthy male adults under three occupational footwear and a barefoot condition while exposed to external perturbations. Latency values were determined through the NeuroCom Equitest in an acute setting. These values were examined in the medium and large, forward and backward perturbations to determine which footwear had lower latency, resulting in faster reaction times, indicative of better balance when exposed to external perturbations. When looking at latency values, we expected for the low-top slip-resistant shoe to have the greatest postural stability and balance because of its low boot shaft height and lighter weight. The results showed significant differences between the tactical boot and barefoot condition as well as between the work boot and barefoot condition for the backward large perturbation, which means the WB and TB had higher latency values and decreased balance performance in comparison to the LT.

Balance performance between footwear types:

This study compared three footwear conditions, which were work boot (WB), tactical boot (TB), and low-top slip-resistant shoe (LT). These footwear conditions were compared and contrasted in their shoe mass and boot shaft height. These were the constraints analyzed to determine which footwear condition had the lower latency, influencing postural control and stability. Footwear is essential for human balance and postural control. It is the only thing between the foot and the standing surface. Footwear productiveness is responsible for a successful transformation of the mechanical power output, which is produced by the musculoskeletal system (Cikajlo, Matjačić 2007).

The results demonstrated that there were significant differences in reaction time between the different footwear conditions. The results exhibited that both the medium and large perturbations for the forward translations had a significant difference, while only the large perturbation for the backward translations had a significant difference between the footwear condition. However, only the backward large perturbation condition displayed post-hoc significant differences between footwear. This could be the result of not enough variance in the sample size. If more participants had been studied, there may have been a greater variance and effect size that would result in additional post-hoc significant differences.

Performance was also an important factor, with safety and protection being the primary feature in occupational footwear. Footwear developed with safety features, crucial for an industrial setting, were used in this study. The WB met ANSI-Z41-1991 standards for footwear in safety and protection as per the OSHA regulations (Occupational Safety and Health Administration, U.S. Department of Labor). By focusing on the safety features, this occupational footwear may not meet the needs for normal gait and balance. The TB and LT can be used in populations where a prescribed OSHA regulation is not required (OSHA, Laws and Regulations, 1970).

Boot shaft height as a predictor of balance performance:

Boot shaft height plays an important role in balance maintenance. The greatest boot shaft height was in the work boot with a height of 18.5 cm. The tactical boot was next with a shaft height of 16.5 cm. Lastly, the low-top slip-resistant shoe had a height of 9.5 cm. The results of this study displayed that the TB and the WB had greater latencies than the barefoot condition. The TB and WB were also similar in that they both had a greater ankle shaft height. Results of this study suggest that the barefoot condition had a quicker reaction time than the TB and WB. The barefoot condition has lower latency responses because of the proprioceptive system that has sensory receptors on the bottom of the foot. Feet function as receptors, and the sole of the foot is one of the most sensitive places on the human body. There are mechanoreceptors and nerve endings located here that are aware of dynamic changes in the receptors (Hosoda et al. 1998). The soles of the feet are defined as “antennas” for sensory input (Hosoda et al. 1997). The barefoot condition and the LT shoe had similar latency values. However, the barefoot condition is the control because it is not contained by footwear.

It can be hypothesized from previous research that a greater ankle height in footwear might hinder the ankle strategy in response to a perturbation. This may result in decreased postural stability or possibly a fall. Also, the greater shaft height results in a lower possible range of motion for the ankle. This is expected to hinder the muscle spindles from sensing a change in muscle fiber length. Decreased speed and reaction strength has been shown with footwear fixation of the ankle joints, hindering afferent information from being sent (Hosoda et al. 1997).

However, other previous research has contrasted these findings. A large amount of literature supports the idea that an elevated boot shaft height above the ankle joint increases ankle support, provides greater postural stability, and provides compression around the ankle (Cikajlo, Matjačić 2007, Böhm, Hösl 2010). A significant boot shaft thickness functions to hinder inversion, which would protect the ankle from the common lateral collateral ligament sprain (Böhm, Hösl 2010). An elevated boot shaft restricts the ankle's range of motion (Cikajlo, Matjačić 2007). In one chronic study, the same footwear conditions were used as the present study. These footwear used in the occupational industry were compared while standing and walking on a firm surface for an extended period of time. The elevated boot shaft height exhibited additional balance in the WB and TB compared to the LT in this study (Chander, Garner & Wade 2013). Differences in findings for the elevated boot shaft height between these similar footwear could be due to differences in chronic and acute studies.

Mass of the footwear as a predictor of balance:

An increased mass can result in an increase in energy expenditure and diminish balance performance. The lower the mass of the boot, the lesser the workload and fatigue, resulting in increased balance (Chander, Garner & Wade 2013). Greater mass added on the distal end of the lever spends more energy than a lesser mass of footwear (Garner et al. 2013, Chander, Garner & Wade 2013).

It has also been shown to add stability with the military work boots. One study compared military boots to barefoot walking and found that step and stride lengths, single support time, and swing phase increased with the increased mass of the work boots. Cadence, double support time, and stance phase decreased as well with the military boots in relation to barefoot walking (Majumdar et al. 2006). This added stability is possible to be the result of the greater mass in the military boot.

Heel height as a predictor of balance performance:

Shoe heel height is another contributing factor in balance control. This study showed the LB and TB to have a heel height of 4.1 cm and the WB to have a heel height of 2.8 cm. A greater shoe heel height results in a more cautious walking pattern and diminishes medial-lateral balance control, which leads to an impaired balance. It also revealed a reduction in walking velocity (Menant et al. 2008).

Mid-sole stiffness as a predictor of balance:

Mid-sole hardness was not measured in the current study, but it is an important feature in balance maintenance in relation to footwear. The LT shoe had a softer mid-sole stiffness in comparison to the WB and TB. The influence of mid-sole hardness material has been shown to hinder the dynamical balance control system (Federolf, Roos & Nigg 2012). Another study compared young and older people walking in soft sole shoes to standard sole shoes. When walking in the soft sole shoes, both groups displayed a larger lateral center of mass-base of support margin. The result was that the soft sole shoes had a harmful effect on stability. However, a tread sole and greater sole hardness did not improve walking stability. A standard sole hardness was shown to be more influential in postural control (Menant et al. 2008).

Conclusion:

This study revealed significant differences in backward large translations as well as forward medium and large translations in relation to latencies. Forward translations have a greater significant difference between footwear than backward translations. Larger translations also initiate a quicker response than smaller translations. Chronic conditions of balance performance have been studied over prolonged periods of time during static balance (SOT) using the same footwear conditions as the present study (Chander, Garner & Wade 2013). Through the current study, one can see the effect acute bouts, at the start of each experiment, have on chronic conditions for prolonged periods of time. These results can help determine appropriate footwear for workers in the industrial and occupational settings, as well in designing new occupational footwear to improve postural stability.

Future research:

Further research can be done through connecting the results through EMG with the results through the force plate. This would indicate and compare differences between the sensory response times to the latency reaction times. This would associate the muscle's sensory changes with the response to changes. This is important because of the information known about the electromechanical delay. When muscles are tense, it takes them less time to respond to a stimulus. However, when the muscles are relaxed, it takes a greater time to respond to a stimulus. In an acute setting, only looking at latency values, the LT is the most beneficial footwear.

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