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BIOMECHANICS OF SLIPS IN ALTERNATIVE FOOTWEAR

A Dissertation

presented in partial fulfillment of requirements for the degree of

Doctor of Philosophy

in the Department of Health, Exercise Science and Recreation Management

The University of Mississippi

by

HARISH CHANDER

August 2014

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ABSTRACT

Injuries in the workplace pose a significant burden to the health of human beings as well as financial or economic losses to occupational organizations. Slips, trips and an induced loss of balance have been identified as the major causative factor for workplace injuries involving falls (Courtney et al, 2001; Redfern et al, 2001). The Bureau of Labor Statistics reported 15% of a total of 4,693 workplace fatalities and a total of 299,090 cases of non-fatal workplace injuries that were due to slips, trips and falls (BLS, 2011). The purpose of the study was to analyze the biomechanics of human locomotion under normal dry flooring conditions and under slippery flooring conditions with three commonly used alternative casual footwear [thong style flip-flops (FF), crocs with clogs (CC) and slip resistant low-top shoe (LT)]. The study will follow a within-subjects repeated measures design with each participant exposed to all three footwear using a counter balanced design. Eighteen healthy male participants with no orthopedic, cardiovascular or neurological abnormalities completed the study. Participants were required to come in for three testing sessions separated by at least 24 hours of rest interval and an initial familirization day. On each testing day, participants were provided with an alternative footwear based on a counterbalanced selection and were tested for maximal voluntary contraction for lower extremity muscles and were exposed to a series of walking trails that included a Normal Dry Surface Non Slip Gait Trial (NS); Unexpected Slip (US), Alert Slip (AS) and Expected Slip (ES). A 3 X 4 [3 (FF, CC, LT) X 4 (NS, US, AS, ES)] within-subjects repeated measures ANOVA was used to analyze the dependent slip parameters (heel slip distance and mean heel slip velocity), kinematic and kinetic gait variables (mean and peak vertical ground reaction forces and lower extremity

joint angles) and muscle activity (mean, peak and % maximal voluntary contraction in lower extremity muscles). Significant interactions between the footwear and gait trials were found for the slip parameters, gait parameters and muscle activity variables ($p<0.05$). Significant interactions were followed up with post-hoc multiple comparisons using a sidak bonferroni correction. Based on the results from the study the alternative footwear (CC & FF) had greater slip parameters, reduced ground reaction forces and a plantar flexed foot position at heel strike compared to the LT. The US and AS had greater incidence of slips than NG and ES and moreover with the a priori knowledge of the slippery flooring conditions (ES), the individuals were able to modify the gait kinematic and kinetic parameters rather than lower extremity muscle activity to reduce the potential for a slip. Overall, the most hazardous slips were seen with alternative footwear and during the unexpected slips followed by the alert slips. The LT had lower incidence of slips and maintained a normal gait pattern during all gait trial conditions and demonstrates to be the choice of footwear for maneuvering slippery flooring conditions that exist in both occupational and public places.

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

Injuries in the workplace pose a significant burden to the health of human beings as well as financial or economic losses to occupational organizations. Slips, trips and an induced loss of balance have been identified as the major causative factor for workplace injuries involving falls (Courtney et al, 2001; Redfern et al, 2001). The Bureau of Labor Statistics reported 15% of a total of 4,693 workplace fatalities and a total of 299,090 cases of non-fatal workplace injuries that were due to slips, trips and falls (BLS, 2011). The annual cost of workplace injuries due to slips, trips and falls in the United States was estimated to be over 6 billion US dollars with an expected cost of $43.8 billion by 2020 (Courtney et al, 2001).

Falls in the workplace are not always from an elevation. While 64% of work related falls were attributable to slips, trips and an induced loss of balance, 43% of the same level falls were found to be triggered by slips (Courtney et al, 2001). Pedestrian accidents in the walkway have been identified as the second largest generator of unintentional workplace fatalities (Leamon & Murphy, 1995). Proper postural control and balance in both static and dynamic conditions are essential in workplace settings and pedestrian walkway settings in order to prevent falls and, thus, injuries. Increased probability of falls have been related to decrements in balance control and these falls are often a primary causative factor for injuries and disabilities in the general population as well as in the contemporary industrial population where postural stability is challenged with unfavorable and unfamiliar environment (Lin, Seol, Nussbaum & Madigan, 2008).In an occupational setting, postural instability can be hazardous due to an increased risk of falls, slips, trips and other accidents (Kincl et al, 2002). In addition to acute fall related injuries, overexertion injuries have very high incidences for slip induced falls and makes the effort of recovering from an induced slip very demanding (Courtney & Webster, 2001).

Slips, trips and falls occur as a result of failure of normal locomotion and failure of attempts at equilibrium recovery following an induced imbalance (Davis, 1983; Gauchard, 2001). These slips, trips and falls can be induced by environmental factors or external factors or by failure of the human factors or internal factors. Among the environmental or external factors are the physical characteristics of the floor or ground surface such as the type, smoothness or roughness of the surface, compliance of the surface and the presence and absence of contaminants or obstacles (Redfern et al, 2001). The human factors or the internal factors constitute the human postural control system which is a complex sensorimotor function with afferent information from the visual, somatosensory and vestibular system along with central integration of these afferent stimulus and specific motor responses (Gauchard, 2001; Redfern et al, 2001; Hanson, Redfern & Mazumdar, 1999).

Preventing and reducing slip and fall accidents have been an important aspect of ergonomics research and have focused on slip-resistant properties of the floor-shoe interface. The focus of ergonomics research in slip, trip and falls has grown from a tribological perspective which deals with the interactions between the physical properties such as the friction, lubrication, viscoelasticity of the floor and the shoe to a more recent biomechanical perspective that includes the human factors associated with a fall. The biomechanical perspective includes analysis of gait parameters and ground reaction forces during walking and slipping under varying environmental conditions, which provides a greater insight to the human factors involved in the event of slip and a fall. Research has also focused on balance recovery from perturbations and slips which includes analysis of anatomical anthropometric factors, physiological factors and motor control factors (Redfern et al, 2001).

The outcome of recovering from a slip is invariably dependent upon the external environmental factors and the internal human factors. The type of the footwear and the type of flooring conditions and the interaction between them by means of the footwear-floor interface constitutes the external factors in determining the outcome of a slip. The internal human factors constituting the postural control system is affected by aging, fatigue, anthropometric features and with any abnormalities or degradation caused by disorders and diseases of the human postural control system and musculoskeletal system.

Thus, a number of influential parameters due to extrinsic and intrinsic factors contribute to slip propensity and also the outcome of a slip with either a recovery or failure to recover from the slip and ultimately leading to a fall. Future research on the biomechanics and physiology of slips is recommended including different extrinsic and intrinsic factors with the inclusion of tribology of material science. A very simple modification in an attempt to prevent slips is to modify the footwear in occupational and pedestrian environments. Although, there is considerable amount of literature discussing slips in occupational mandated footwear, the impact of alternative and casual footwear such as flip-flops and crocs which are commonly used among pedestrians and few of the occupational environments such as a hospital setting have not been analyzed yet. Specific occupations such as doctors and nursing staff in the hospitals wear these alternative footwear throughout the work day, stressing the importance of this research. Furthermore, usage of flip-flops and crocs in and around the workplace as an alternative footwear has grown in the recent years, further emphasizing the need to address the effect of these footwear on slip events.

An important distinguishing factor that might predict the outcome of a slip event is the design feature of these alternative footwear. These alternative footwear do not secure themselves completely over the entire foot, and the heel almost always, is not attached to the footwear. The primary point of contact or the link between the footwear and the foot, and subsequently the primary area of somatosensory feedback, comes from the forefoot segment. Previous gait kinematics studies suing different footwear make an assumption that the foot and the footwear as one rigid body and make interpretations of gait analysis based on the movement of that rigid segment. However, the same assumption could not be made about the use of these alternative footwear, in which the hind-foot is detached from the footwear. This is crucially important in biomechanics of slip studies, since the heel movement is analyzed to identify the type and the severity of the slip. Hence, with the increased use of these alternative footwear in occupational and non-occupational environments, the need for understanding its effect on human gait and slips is extremely important in the prevention of fall and fall related injuries.

Purpose of the Study

Balance and gait mechanisms during normal locomotion and under slippery conditions have been studied extensively (Winter, 1991; Winter, 1995; Redfern et al, 2001) and consequently, there have been several studies that focus on the biomechanics of slips, trips and falls which are the primary causative factors for fall and fall related injuries in pedestrian population and especially in occupational environments, where there is a greater incidence of slips due to the environmental occupational hazards (Redfern et al, 2001; McGorry et al, 2010; Cham & Redfern, 2002a; Cham and Redfern, 2002b; Hanson et al, 1999; Perkins, 1978; Standberg & Lanshammar, 1981). The effect of different footwear, different flooring conditions and the footwear-floor interactions on the biomechanics of gait and balance have also been identified (Li, Wu and Lin, 2006; Shroyer& Weimer, 2010; Perry, Radtke & Goodwin, 2007, Menant, Perry, Steele, Menz, Munro & Lord, 2008, Divert, Mornieux, Baur, Mayer & Belli, 2005, Bohm & Hosl, 2010).

While extensive literature exists on biomechanics of balance, gait and slips and the influence of footwear on these, there is still dearth of literature on the effect of much commonly used alternative footwear on the biomechanics of gait and slips. Hence, the purpose of the study was to analyze the effects of alternative footwear [thong style flip-flops (FF), crocs with clogs (CC) and slip resistant low-top shoe (LT)] on the biomechanics of gait and slips. Specifically, the slip parameters, the kinematic and kinetic variables and muscle activity during gait under normal dry and slippery floor conditions will be analyzed with these alternative footwear. By addressing these findings, the strategies involved during slip events may be explained and recommendations for effective footwear design can be made. These inferences and recommendations may further help limit fall and fall related injuries in an occupational and recreational setting. The long-term goal of this proposed research would be to determine and understand how commonly used alternative footwear behave under slippery conditions.

<u>Hypotheses</u>

Slip Hypothesis - Specific Aim 1:

To investigate the effect of alternative footwear (FF, CC & LT) on slip parameters during an unexpected slip, alert slip and an expected slip in comparison to normal dry surface gait.

H_{01}: Individual's slip parameters will not be altered when exposed to an unexpected, alert and an expected slip while wearing alternative footwear.

H_{A1}: Individual's slip parameters will be altered while be altered when exposed to an unexpected, alert and an expected slip while wearing alternative footwear.

Different types of footwear affect gait and posture kinematics adversely. Footwear characteristics such as the boot shaft height, mass, mid-sole hardness and thickness, elevated heels, type of material of the footwear and especially the tread sole pattern influence gait and ultimately the slip propensity when exposed to slippery conditions. The differences in the coefficient of friction between the footwear type and surface type have been reported as a prime factor in slip and trip induced falls. Slip characteristics have been shown to be altered based on the perception of the slipperiness of the floor of an unexpected slip in comparison to an alert or expected slip. Proactive strategies are implemented with a priori knowledge of an impending slip. Hence, the null hypothesis that the slip parameters will be not be altered when exposed to different slip events while walking with different alternative footwear is expected to be rejected.

Gait Kinematics and Kinetics Hypothesis - Specific Aim 2:

To investigate the effect of alternative footwear (FF, CC & LT) on kinematic and kinetic gait variables during normal dry and slippery flooring conditions.

H_{02}: Individual's kinematic and kinetic gait variables will not be altered when exposed to normal dry and slippery flooring conditions while wearing alternative footwear.

H_{A2}: Individual's kinematic and kinetic gait variables will be altered when exposed to normal dry and slippery flooring conditions while wearing alternative footwear.

Unlike other shod conditions, these alternative footwear do not secure the hind foot, heel and the ankle joint of the lower extremity. The movement of the entire foot and the footwear as one rigid segment seen in close fitting athletic shod conditions is not present in alternative footwear. As a result the interlinked point of contact of these alternative footwear and foot is accomplished only by the toes for flip flops and the forefoot for crocs. Hence, gait kinematics are negatively affected by these modifications in the footwear-foot interface. A reduced gait speed, decreased step and stride length, lowered double support time and over all reduced stance phase was seen in flip-flops compared to close fitting athletic shoes. Hence, the null hypothesis that the kinematic and kinetic gait variables will not be altered when exposed to normal dry and slippery conditions while walking with different alternative footwear is expected to be rejected.

Muscle Activity Hypothesis - Specific Aim 3:

To investigate the effect of alternative footwear (FF, CC & LT) on lower extremity muscle activity during normal dry and slippery flooring conditions.

> **H_{03}:** Individual's lower extremity muscle activity will not be altered when exposed to normal dry and slippery flooring conditions while wearing alternative footwear.
>
> **H_{A3}:** Individual's lower extremity muscle activity will be altered when exposed to normal dry and slippery flooring conditions while wearing alternative footwear.

Lower extremity muscular activity under go either a reactive or proactive strategy in the event of an unexpected slip and expected slip respectively, creating corrective moments to prevent from falling down. The muscles of the knee have been shown to produce the majority of the corrective responses through flexion-extension moments, while the musculature at the hip are predominantly utilized for stabilization of the body during a slip. Knowledge or perception of the slippery surface has been to shown to produce greater activation and co-contraction of the agonist / antagonist pairs of lower extremity musculature in an attempt to reduce the probability of slip events. Moreover, it is hypothesized that the alternative footwear, because of its design feature which does not attach to the entire foot, would increase the ankle musculature activation in an attempt to secure these footwear. Hence, the null hypothesis that the lower extremity muscle activity will not be altered when exposed to normal dry and slippery flooring conditions while walking with different alternative footwear is expected to be rejected.

Operational Definitions

Posture:

Posture is essentially the relative position of the various parts of the body with respect to one another (the egocentric coordinate system) and to the environment (the exocentric coordinate system). A third frame of reference is that of the gravitational field (the geocentric coordinate system). The orientation of the body part can be described in terms of each of these frameworks (Kandel, Schwartz &Jessell, 2000).

Postural Equilibrium:

Regulation of posture with respect to gravity is important in maintaining postural equilibrium, which may be defined as the state in which all forces acting on the body are balanced so that the body rests in an intended position (static equilibrium) or is able to progress through an intended movement without losing balance (dynamic equilibrium) (Kandel, Schwartz &Jessell, 2000).

Balance:

The ability to maintain the vertical projection of the center of mass within the base of support can be defined as Balance. Balance and postural stability are often used synonymously. Postural stability depends on the intentional action, the choice of movement strategy and the under lying neuromotor process (Levangie&Norkin, 2006). 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).

Friction:

Friction is the force resisting the relative motion of objects against each other. Types include, dry friction, fluid friction, lubricated friction, skin friction and internal friction.

Coefficient of Friction:

The coefficient of friction (COF, μ) is a dimensionless scalar quantity which is the ratio of the force of friction between two objects and the normal force, which is perpendicular to the moving surface.

Tribology:

Tribology is the science and engineering of interacting surfaces in relative motion.

Electromyography (EMG):

Electromyography (EMG) is a clinical technique for evaluating and recording physiologic properties of the muscles at rest and while producing force. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An EMG represents the spatial and temporal summation of all motor unit action potentials in the proximity of the recording electrode. It is indicative of the level of muscle activity via the motor unit recruitment and rate coding (Basmaijan, 1985).

Center of Mass (COM):

COM is defined as the point on a body that moves in the same way that a particle subject to the same external forces would move. It is also the point where the 3 mid-cardinal planes of the body meet. The center of mass is not necessarily located in the body (Rodgers & Cavanagh, 1984).

Center of Gravity (COG):

COG is defined as the point at which a single force of magnitude mg (the weight of the body or system) should be applied to a rigid body or system to balance exactly the translational and rotational effects of gravitational forces acting on the components of the body or system. In other words, the point at which the weight of the body or system can be considered to act (Rodgers & Cavanagh, 1984).

The center of gravity and the center of mass are coincident, although in strict physical terms, there is an infinitesimal difference between the two. The center of gravity of the human body is not fixed at an anatomical location. Its location varies according to the position of the body segments (Rodgers & Cavanagh, 1984).

Line of Gravity (LOG):

LOG is defined as the perpendicular line towards the ground from the center of gravity (COG) of that particular body (Levangie&Norkin, 2006).

Base of Support (BOS):

The human species' base of support (BOS), is defined by the area bounded posteriorly by the tips of the heels and anteriorly by a line joining the tips of the toes, and is considerably smaller than the quadruped BOS (Levangie&Norkin, 2006).

Center of Pressure (COP):

COP is defined as a quantity, available from a force platform describing the centroid of the pressure distribution. It can be thought of as (and is sometimes called) the point of application of the force (Rodgers & Cavanagh, 1984).

Ground reaction Force (GRF):

The forces that act on the body as a result of interaction with the ground that is based on Newton's third law of motion, which implies that the GRFs are equal in magnitude and opposite in direction to the force that the body is applying to the ground (Rodgers & Cavanagh, 1984).

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)

CHAPTER II

REVIEW OF LITERATURE

The purpose of this investigation is to assess the effects of alternative footwear on gait and slip trials. This chapter will provide an insight to previous literature on the biomechanics of human gait under normal dry flooring conditions and under slippery conditions. This chapter is divided into five major sections as listed below. The first section titled biomechanics of human gait includes discussions about biomechanics behind normal walking, the systems involved, strategies implemented and assessment parameters. This is followed by the second section, which explains the biomechanics of human gait during slip events. The third and the fourth sections explain the extrinsic parameters including footwear characteristics and intrinsic parameters including the perception of slipperiness involved during a slip event. And finally, the fifth section comprises of a description of the alternative footwear and their comparison with other commonly used footwear during gait and slip events.

1. **BIOMECHANICS OF HUMAN GAIT**
    i. ***Kinematics of Human Gait***
    ii. ***Kinetics of Human Gait***
    iii. ***Muscle Activity of Human Gait***
2. **BIOMECHANICS OF SLIPS**
    i. ***Kinematics of Human Gait during Slips***
    ii. ***Kinetics of Human Gait during Slips***
    iii. ***Muscle Activity of Human Gait during Slips***
3. **EXTRINSIC FACTORS PREDICTING SLIP PROPENSITY**
    i. ***Footwear Characteristics in Prediction of Slip Propensity***
4. **INTRINSIC FACTORS PREDICTING SLIP PROPENSITY**
    i. ***Perception of Slipperiness***
5. **COMPARISON OF ALTERNATIVE FOOTWEAR TO SHOD CONDITIONS IN GAIT AND SLIP PARAMETERS**

BIOMECHANICS OF HUMAN GAIT

In order to analyze the biomechanics of slips, it is crucial to understand the biomechanics behind normal dry surface walking. Human bipedal walking is considered as a challenging neuromuscular task to the central nervous system, with coordinated repetitive sequence of limb movements to safely advance the human body with efficient energy expenditure (Winter, 1995). Human balance in static conditions is viewed as an inverted pendulum model where the center of gravity (COG) of the human body is required to be within the base of support (BOS)and human balance during dynamic conditions or steady state gait, is viewed as a series of controlled falling where the COG is always outside the BOS (Winter, 1995). The series of controlled falling is initiated with a voluntary forward acceleration of the body's COG outside the BOS (Winter, 1995) and implementing the stepping strategy to reestablish the BOS and thereby regaining balance. The coordinated repetition of this sequence gives rise to human bipedal gait.

i. Kinematics of Human Gait:

A gait cycle consists of two successive events of the same lower extremity, usually initial contact of one heel to the contact of the same heel again, and during a normal walking, is divided into a stance phase consisting of 60% of the gait cycle and swing phase consisting 40% of the gait cycle (Levangie & Norkin, 2006; Lamoreaux, 1971; Enoka, 2008). The Rancho Los Amigos (RLA) terminology classifies the stance phase into heel strike, loading response, midstance, terminal stance and preswing, and the swing phase into initial swing, mid swing and terminal swing (Levangie & Norkin, 2006). The temporal and spatial parameters of the gait cycle provide a kinematic description of the human locomotion. The temporal parameters include stance time, single-limb time and double support time, swing time, stride and step time, cadence and speed of walking. The spatial parameters include stride length, step length and width, and degree of toe-out (Levangie & Norkin, 2006). Stance time is the time spent by one extremity during the stance phase, while swing time is during swing phase. Single support time is time during the gait cycle where only one extremity is in contact with the ground, while double support time is when both extremity are in contact with the ground. Stride length is the linear distance between two successive events of the gait cycle, while step length is the linear distance between two successive points of contact of the opposite extremities (Levangie & Norkin, 2006; Enoka, 2008). Cadence is the number of steps per minute and walking velocity is the rate of linear forward motion of the body, which is derived from the product of the cadence and step length (Levangie & Norkin, 2006; Enoka, 2008). While all the above mentioned gait parameters are measured in the sagittal place, step width or the width of walking base and degree of toe out or the angle of foot placement in relation to the line of progression are measured in the frontal plane (Levangie & Norkin, 2006).

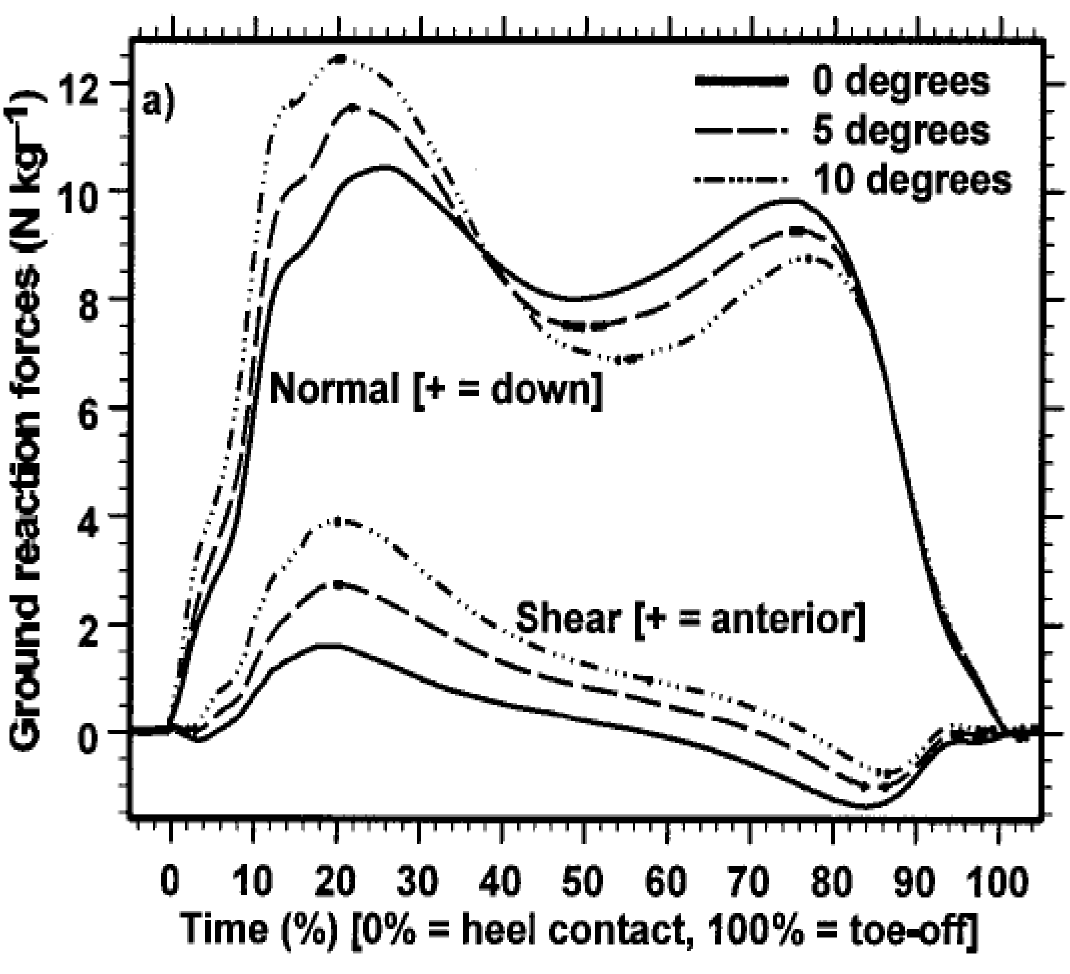
The movement of the heel during the initial period of the heel strike phase during normal dry surface gait has a characteristic pattern, where the heel rapidly negatively accelerates just prior to heel strike following which the heel moves slightly forward (Perkins, 1978; Strandberg & Lanshammar, 1981; Redfern et al, 2001, Cham & Redfern, 2001a). At heel strike, the heel has been shown to have an instantaneous velocity in the forward direction (Perkins, 1978; Strandberg & Lanshammar, 1981) and some instances in a rearward direction (Cham & Redfern, 2001a), after which the heel reaches a minimum velocity and comes to a stop, over which the rest of the foot rolls over completing the midstance.

Joint angles from the ankle, knee and the hip joints are assessed to determine the required amount of the range of motion (ROM) during normal dry surface locomotion (Winter, 1995; Cham and Redfern, 2001a; Redfern & DiPasquale, 1997). The ankle is maintained at slight dorsiflexion during heel strike and immediately rolls to peak plantar flexion at about 10% of stance phase. There is a forward rotation of the lower leg brought about by knee flexion at 30% stance phase, that moves the ankle to dorsiflexion and finally back to plantar flexion with the beginning of the push off period at about 80% of stance phase (Redfern et al, 2001; Levangie & Norkin, 2006). Following the initial increase in knee flexion at 30% stance phase, knee flexion angle increases again at 80% stance during push off period and to prepare for the heel strike of the opposite lower extremity (Redfern et al, 2001; Levangie & Norkin, 2006). The hip remains in an extended position for most of the stance phase to accommodate for the continuous forward movement of the body, while moving to an increased flexion position to prepare for the swing phase of the gait cycle (Redfern, et al, 2001).

ii. Kinetics of Human Gait:

Ground reaction forces are the foot forces during gait derived from interactions between the shoe and the floor (Levangie & Norkin, 2006; Enoka, 2008) and considered as one of the most critical gait parameters for assessment of the slips and falls (Redfern et al, 2001). The footwear serves to spread the load of the body weight over a wide area of the plantar surface of the foot and also serves to increase the contact times during the stance phase of the gait (Soames et al, 1985). The vertical normal force during a gait cycle is typically characterized by two peaks. This first peak occurs at the end of the loading response (25% into stance phase of the gait cycle) and the second peak occurs during the end of the stance phase at the beginning of the toe-off phase (Perkins, 1978; Lanshammar and Strandberg, 1981; Redfern, 2001). The anterior-posterior shear force during a normal gait cycle also exhibit a symmetrical biphasic peaks, where the first peak in the forward direction is due to the loading response and the second rearward directed peak is due to the pushing back of the toes during the push off phase of the gait cycle (Perkins, 1978; Lanshammar and Strandberg, 1981; Redfern, 2001) (Figure 1). The single point on the surface of the foot at which the resultant surface pressure acts, called as the center of pressure (COP), (Enoka, 2008) has a distinct characteristic pattern during walking. The COP starts at the postero-lateral edge of the heel at heel strike, moving towards mid-foot yet lateral to the midline during midstance and finally towards the ball of the foot during toe-off phase of the gait cycle (Redfern, 2001; Levangie & Norkin, 2006; Enoka, 2008).

Figure.1: From Biomechanics of Slips, Redfern et al, 2001.



Moments about the ankle, knee and hip have been included in kinetic analysis during normal gait (Redfern et al, 2001; Winter, 1991; Redfern & DiPasquale, 1997). The net moments about the lower extremity are responsible for helping to maintenance of balance and for generating power during gait. The ankle moment is characterized by an increasing plantar flexion moment as the stance phase progresses and the knee moment is characterized by a biphasic flexion-extension moment. The hip joint predominantly has an extension moment through most of the stance phase with an initial flexion moment in early stance (Winter, 1991; Redfern & DiPasquale, 1997).

iii. Muscle Activity of Human Gait:

Along with the kinematic and kinetic analysis, electromyography (EMG) has been used to assess muscle activity during human locomotion. Two major contributions from the muscles during a gait cycle are to provide a stable support moment during the stance phase and provide a propulsion moment to generate energy to move during the end of the stance and throughout the swing phase (Levangie & Norkin, 2006). Muscle activity during a gait cycle is very precise and has in phase coordination of the lower extremity muscle actions, which progressively become primarily isometric or eccentric rather than concentric, with the progression of the gait cycle (Boakes & Rab, 2006). An extensor moment from the hip extensors and an eccentric muscle action of the tibialis anterior is seen during the initial period of the stance phase followed by an extensor moment from the knee extensors which help during the loading response phase of the gait cycle (Boakes & Rab, 2006; Levangie & Norkin, 2006; Winter, 1991). The gluteus medius also undergoes an isometric muscle action during the loading response phase to stabilize the pelvis. Following this, an eccentric muscle action of the soleus muscle allows the forefoot to be pressed against the floor and the knee extended without the activity of the knee extensors

(Boakes & Rab, 2006). The hip and the knee move towards flexion during late stance with the ankle plantar flexors starting to produce a concentric muscle action that accelerates the body forward during push off (Boakes & Rab, 2006; Levangie & Norkin, 2006; Winter, 1991).

The pre-swing and the initial swing is characterized with concentric muscle actions from the hip flexors and the knee extensors followed by the passive pendulum action of the lower leg during mid-swing that further advances the body during gait. And, finally the eccentric action of knee flexors especially the hamstrings serves to slow the hip flexion and knee extension as the knee extensors and ankle dorsi flexors act to prepare the lower leg to accept weight during heel strike (Boakes & Rab, 2006; Levangie & Norkin, 2006; Winter, 1991). Due to the increased variability in the phasic EMG data of individual muscles, it is suggested that an average of multiple gait trials need to be performed to obtain a characteristic representation of the muscle activity during human gait (Boakes & Rab, 2006). Thus, muscle activity during normal human locomotion consists predominantly of isometric or eccentric muscle action of the lower extremity muscles that allows efficient storage and transfer of energy between limb segments with brief periods of high energy concentric muscle actions that help in forward motion of the body (Boakes & Rab, 2006).

BIOMECHANICS OF SLIPS

Human gait is invariably affected by the coefficient of friction (COF) that exist with when two surfaces come in contact, such as the sole of the shoe and floor that is being walked on, especially with different levels of COFs (high, medium & low). For a proper gait without any events of slips or loss of balance, a medium coefficient of friction is necessary. A very low coefficient of friction will provide a very low resistance for the foot to move and will cause the foot to slide excessively and may predispose to fall. Whereas, a very high coefficient of friction will provide an increased resistance for the foot to move and may even hinder normal foot motion in gait, in which case it may still predispose to fall by means of a trip, rather than a slip. Hence, a medium or normal coefficient of friction is necessary to allow smooth transitions of the foot one over the other and accomplish gait with the least energy expenditure as possible, especially in work place settings. The utilized coefficient of friction under normal walking conditions and normal walking speeds ranged from 0.17 to 0.20 (Redfern et al, 2001; McGorry et al, 2010). And when the utilized coefficient of friction exceeds the available at the footwear-floor interface, the slip propensity increases (Cham and Redfern, 2002b; Hanson et al, 1999; McGorry et al, 2010). During walking at a greater speed than normal walking, the step / stride length is longer and the angle θ, at which the lower leg makes contact with the ground is also greater, thus increasing the required coefficient of friction (Figure 3).

The biomechanical analysis of slips helps in evaluation of both the interaction of the footwear-floor interface and the description of motion of the body segments during the event of a slip (Li, 1991). Different terminologies exist for the classification of slips based on the severity of the slip outcome, by means of slip distances and perception of the slipping. Microslips and macroslips have been used to differentiate slip severity using slip distance from the heel motion as a classifying parameter (Perkins, 1978). Slip perception and recovery was used as a classifying parameter to categorize slip-sticks into, mini-slips during which the subjects did not detect the slipping motion; midi-slip during which slips are recovered without major gait disturbances; and maxi-slip during which the slip recovery involves large corrective responses and that are close to a fall (Standberg & Lanshammar, 1981; Redfern et al 2001).

i. *Kinematics of Human Gait during Slips:*

Gait kinematics are influenced by the available coefficient of friction and the slipperiness of the floor. A few kinematic variables are very commonly used as outcome variables to interpret the slip research. The most commonly reported are the slip parameters such as the heel slip distance, heel velocity and the foot-floor angle; joint angles of the ankle and the knee joints along with temporal-spatial parameters of gait including stride/step lengths, width of walking base, stride/step time and cadence (Perkins, 1978; Strandberg & Lanshammar, 1981). In the case of very low coefficient of friction surfaces, the slip parameters are analyzed to determine if the slips are hazardous.

Step length has a direct relationship with the shear force, and with a greater step length, a greater shear force is exerted during the initial heel strike phase and the chances of a slip are increased (Redfern et al, 2001). The distance and velocity of the heel motion following heel strike in a gait cycle have been used to characterize slip types (Redfern et al, 2001). Micro-slips are characterized by heel slip distance of 1cm-3cm and are not perceived by the individuals and easily compensated for by the automatic postural system. Macro-slips are characterized by the slip distances between 3cm-10cm, which will result in a loss of balance may or not result in fall, while slip distances greater than 10cm are most likely to result a fall due to the failure of the automatic postural system (Perkins 1978, Stranberg and Lanshammar, 1981, Redfern et al, 2001; Redfern and Cham, 2001a).

The differences in the temporal-spatial kinematic parameters of gait include a decreased step/stride length, to minimize the center of gravity (COG) excursions outside of the base of support thereby creating a greater stability during walking (Cooper & Glassow, 1963; Steindler, 1977; Lockhart, 2007). By decreasing the step/stride length, the step/stride time is increased and hence, automatically the amount of time in stance phase is increased which decreases the swing phase time. The opposite could be true for an increased COF, where the step/stride length could be increased with an increased step/stride time thereby increase the swing phase of the gait and avoiding time spent on stance in an extremely rough surface that prevents normal walking motion. Because of these modifications, the cadence or the walking velocity will become less or decreased in slippery conditions with a low COF.

The movement of the heel during the initial period of the heel strike phase during normal dry surface gait has a characteristic pattern, where the heel rapidly decelerates just prior to heel strike following which the heel moves slightly forward (Perkins, 1978; Strandberg & Lanshammar, 1981; Redfern et al, 2001, Cham & Redfern, 2001a). At heel strike, the heel has been shown to have an instantaneous velocity in the forward direction (Perkins, 1978; Strandberg & Lanshammar, 1981) and some instances in a rearward direction (Cham & Redfern, 2001a), after which the heel reaches a minimum velocity and comes to a stop, over which the rest of the foot rolls over completing the midstance. The most hazardous slips often occur shortly after heel strike (<70-120ms) (Lockhart & Kim, 2006). Heel velocity of 0.5m/s or higher have been shown to have an increased potential for a slip (Redfern et al, 2001). The time period during heel strike and 25ms immediately post heel strike have been shown to be more crucial to development of an unrecoverable slip propensity rather than the conditions during heel strike (McGorry et al, 2010). The relationship between the heel slip distance and peak heel slip velocity was investigated by Moyer et al, and concluded that peak slip velocities less than 1.0m/s and slip distance less than 100mm were considered to be non-hazardous slips. Whereas, any other situations with a peak heel velocity of higher than 1.0m/s and slip distance greater than 100mm were considered to be hazardous in nature (Moyer et al, 2006). The first period of double support during a gait cycle is considered as a critical time for regaining stability following a slip, and movement of whole body center of mass relative to the base of support during the period has been shown to have smaller excursions and a faster velocity to help prevent slip induced falls (You et al, 2001).

ii. Kinetics of Human Gait during Slips:

The ground reaction forces occurring immediately post heel strike is vital in the prediction of the slips and falls. The first peak in the shear force which occurs at about 19% of the gait cycle (90-150ms post heel strike) is the crucial time period during which most slips occur (Redfern, 2001). The highest shear forces occur during the heel contact and push-off phases of the gait cycle and considered as the points during which the highest incidence for a slip exists (Redferen, 2001; Redfern & DiPasquale, 1997; Hanson et al, 1999).

Figure 2: Forces at foot while walking; From Lockhart, Master's Thesis, 1997

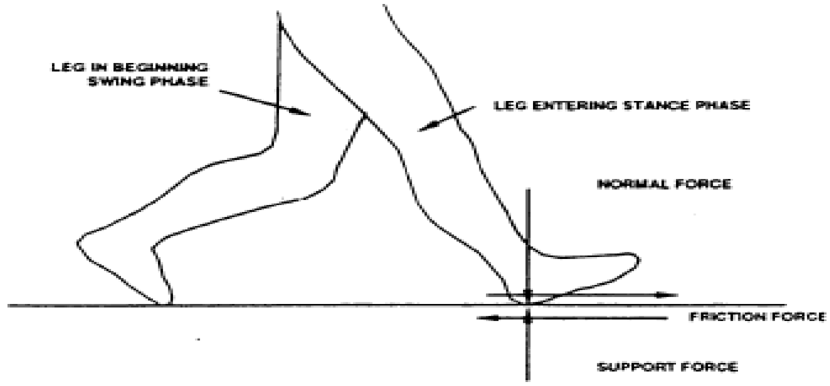
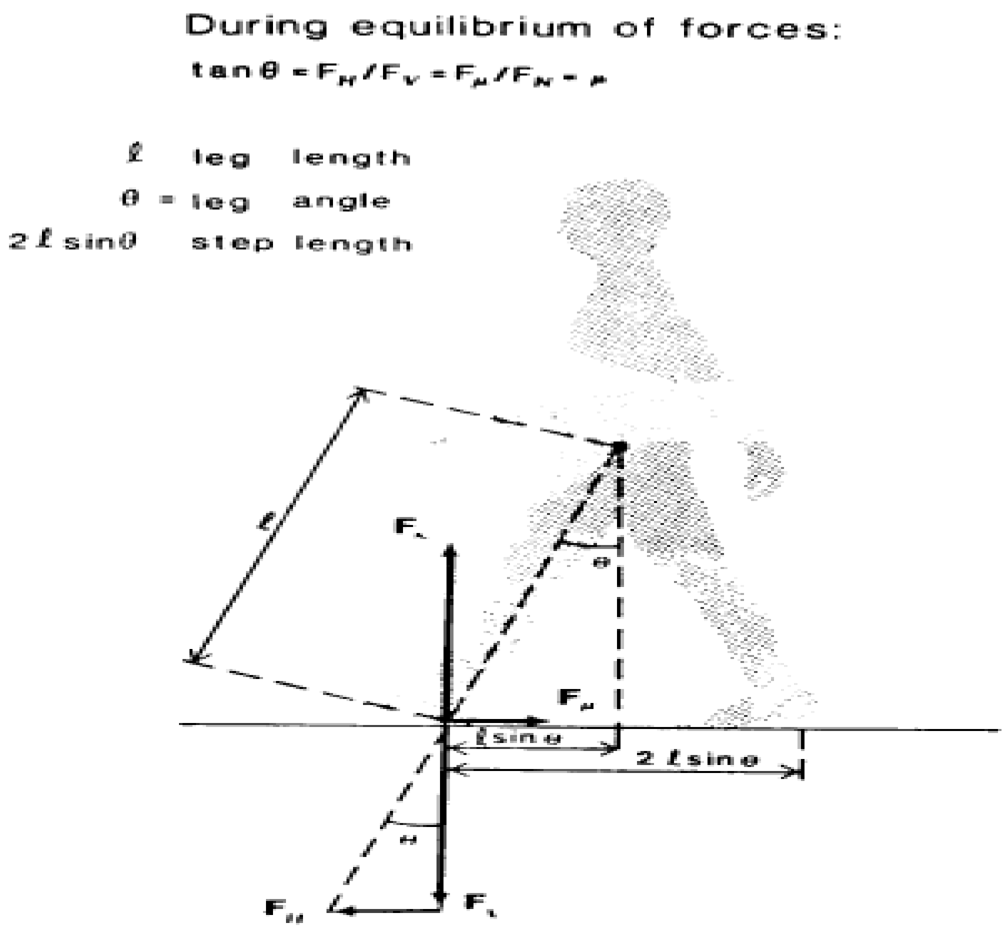


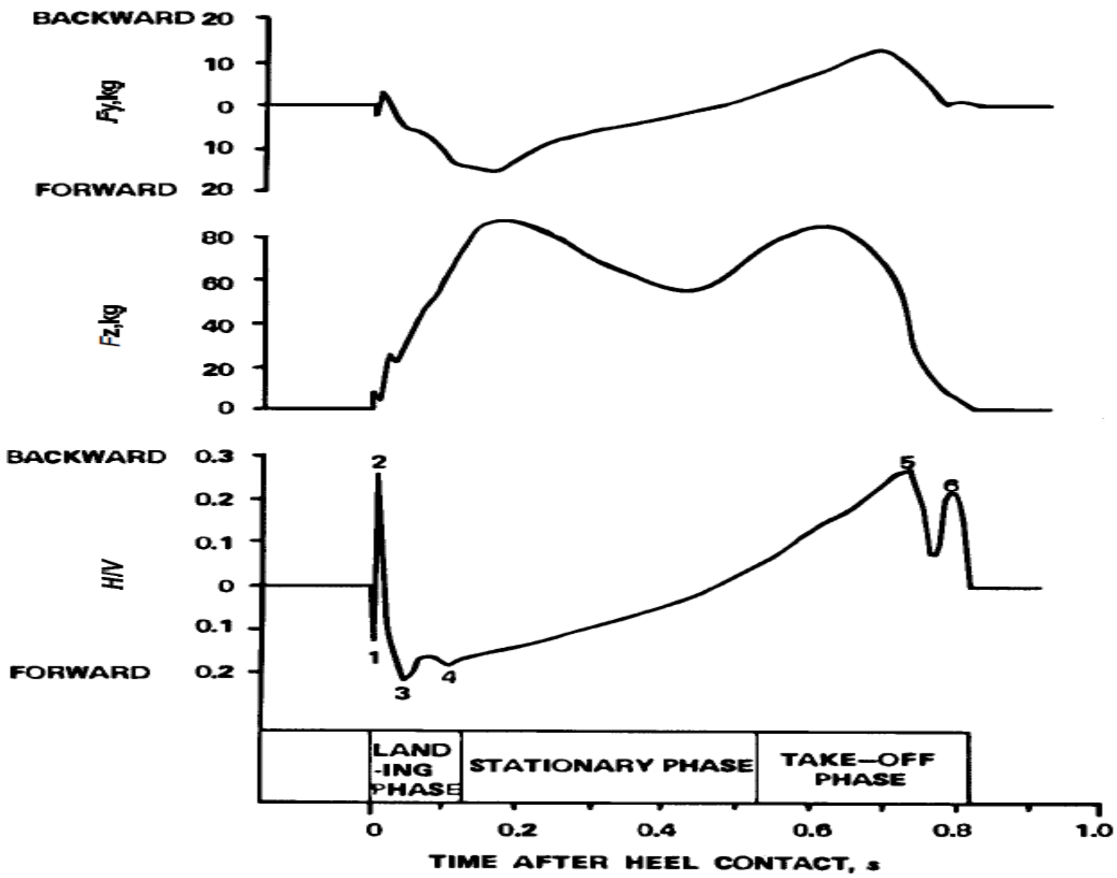
Figure 3: Distribution of Forces at heel, From Lockhart, Master's Thesis, 1997



The ratio of the shear force to the normal force during gait on dry surfaces is termed as the required coefficient of friction (RCOF) and during locomotion on slippery surfaces; the ratio of the shear force to the normal force that is available compared to the non-slippery surface is termed as the available coefficient of friction (ACOF). Hence, slip propensity in an occupational setting can be determined by comparing the RCOF and ACOF for a particular surface type and a particular footwear type. If the ACOF is greater than the RCOF, the individual should not slip, whereas, if the ACOF is lesser than the RCOF, the chances of a slip are increased (Redfern et al. 2001). Six peak forces are identified during a normal gait cycle under dry conditions using the ratio of the horizontal (F_H) to the vertical (F_V) ground reaction forces (Perkins, 1978; Lanshammar and Strandberg, 1981; Redfern, 2001) (Figure 4). The first peak is a forward force due to the impact of the heel while the second peak is a backward force exerted on the heel after contact during the early landing phase. The third and the fourth peaks are forward forces which retards the motion of the foot. And finally the fifth and the sixth peaks are in the backward direction due to the push-off phase of the gait cycle (Perkins, 1978, Redfern, 2001).

The third and the fourth peaks which are directed forwards (occurring during heel contact phase) and the fifth and sixth peaks which are directed backwards (occurring during the push-off phase) are usually assessed for slip propensity with the 3^{rd} and 4^{th} peaks considered more hazardous than the 5^{th} and 6^{th}, as the forward momentum of the body will continue to apply the body weight on the slipping foot (Lockhart, 1997; Redfern, 2001) (Figure 4).

Figure.4: From Biomechanics of Slips, Redfern et al, 2001.



Recovery from a slip will depend upon the moments generated from the lower extremity joints in an attempt to bring back the COG within the BOS and thereby prevent a slip induced fall. Redfern et al., describes that during this protective stepping strategy in response to a slip, the steady gait pattern is interrupted at the onset of a slip and the protective stepping strategy is left to attempt and regain balance and equilibrium. Due to this interruption in steady gait and the protective stepping strategy, large moment deviations are present in comparison to what is observed during normal dry gait (Redfern et al, 2001). The dominant response seen during a slip event is an increased knee flexion moment during 25-45% of the stance phase. While the hip generates an extension moment during the slip, the ankle acts as a passive joint with uncompleted transfer of body weight to the leading foot.

iii. Muscle Activity of Human Gait during Slips:

Reactive and proactive strategies are often described as the balance control mechanisms of an individual that are required during and for an impending slip event. The former is defined as the primary corrective response brought about by muscular forces and corrective moments to re-establish dynamic balance following a slip, while the latter is defined as the balance control mechanisms that occur prior to an impending slip (Chambers & Cham, 2007).

Muscle activity under slippery conditions have been reported for lower extremity muscles such as the quadriceps, hamstrings and gastrocnemius-soleus (Lockhart, 2007; Parijat & Lockhart, 2008; Chambers & Cham, 2007). A longer hamstring activity and a lower quadriceps activity during the stance phase and longer hamstring activity and decreased quadriceps mean activity during the swing phase was reported by Lockhart (Lockhart, 2007). Furthermore, lower mean and peak swing leg gastrocnemius activity was also reported during slippery conditions (Lockhart, 2007). Similar muscular responses were also seen under slip events when compared with young and old aged individuals, with a delayed latency from vastus lateralis activity in severe slips (Chamber & Cham, 2007). An increase in the frictional demand, heel contact velocity and a reduction in the transitional acceleration of the center of mass of the whole body has been reported under slippery conditions especially with induced fatigue of the lower extremity muscles (Parijat & Lockhart, 2008). The muscles of the knee joint are responsible for producing large moments to help recover from a slip, whereas the muscles of the hip joint play an important role in stabilization (Parijat & Lockhart, 2008) and during lower extremity fatigue trials a decreased peak knee moment was reported (Parijat & Lockhart, 2008). All these findings suggested that slip propensity could increase with fatiguing conditions of the lower extremity while affecting gait parameters.

Muscular activity during an alert or an expected slip resulted in a greater activation of the lower extremity musculature with the greatest increase in activity reported in the hamstrings and also with an early activation of the gastrocnemius muscle (Chambers & Cham, 2007). Greater muscle co-contraction analyzed with the co-contraction index (CCI) using the agonist / antagonist pairs of the ankle (tibialis anterior and medial gastrocnemius) and at the knee (vastus lateralis and medial hamstrings) were reported when anticipating a slippery surface and individuals who walked with a greater co-contraction were predisposed to experience less severe slips (Chambers & Cham, 2007).

EXTRINSIC FACTORS IN THE PREDICTION OF SLIP PROPENSITY

In the event of an impending slip, the gait parameters are adjusted in an attempt to avoid slipping. However, the extrinsic factors such as the environment, footwear and intrinsic factors like age, fatigue, obesity can affect the outcome of the slip. During a slip, there is an external perturbation from the extrinsic factors to the intrinsic postural control systems to recover and maintain equilibrium. Any failure of the intrinsic system to compensate for the perturbation from the extrinsic system may potentially lead to a fall. Extrinsic factors contributing to the slips and trips include a defective support surface which has been shown to cause more than 50% of these falls (Gauchard, 2001). The wear on the floor, the presence of an obstacle, the presence of a contaminant or extremes of natural causes such as excessive rain, snow or ice and artificial causes such as poor lighting, inadequate warning signs also include to the extrinsic factor list that contribute to falls. Such changes in the ground or the support surface can potentially destabilize the human postural system, potentially leading to a failure of the postural control system and ultimately to a fall.

Injuries from slips, trips and falls are the leading cause of absence from work in occupational settings. Hence, to prevent these injuries and protect their employees, the health and safety administration for occupational safety (OSHA) and American National Standards Institute (ANSI) has developed recommendations to provide slip resistant walking surface in the workplace. OHSA's general requirements for walking and working surfaces recommend a coefficient of friction of at least 0.5, to provide a reasonable slip resistance to walking, although certain activities, such as carrying items, pushing or pulling objects, or walking up on down-inclined surfaces may require a higher coefficient of friction. In order to achieve this COF irrespective of the type of footwear used, the OSHA suggests modifying the flooring material to change the COF rather than changing the material itself, especially in wet, oily or dirty work areas. This is accomplished by creating the slip resistant floors of the same material but with, serrated, punched or textured to add to its roughness which may increase the COF that is available in wet, oily slippery occupational working surfaces. There are many ways to test the slipperiness of the floor which is very commonly done in workplace settings and to make future recommendations for designing an occupationally safe environment and working surfaces. A few equipments that help us to do this are, the slip meter - a roller coaster type tribometer, Sigler pendulum tester, the tortus digital tribometer, the ASTM F609 horizontal pull slip meter and the ASTM F1678 portable inclinable articulated strut tribomter.

i. Footwear Characteristics in the Prediction of Slip Propensity:

Another vital extrinsic factor; the footwear which forms the interface between the foot and the ground have been studied extensively in occupational and recreational populations. The footwear modifications in occupational and alternative footwear have been shown to affect postural stability and balance (Chander et al, 2013). Different types of footwear affect gait and posture kinematics adversely. Improper alignment of the foot altered by different footwear leads to an increased metabolic cost, which in turn leads to a faster rate of development of muscular fatigue. Many literature and researches have analyzed gait and balance with different gait speeds, changing terrain, shoe types and in bare foot condition (Perry, Radtke& Goodwin, 2007, Menant et al, 2008, Divert et al, 2005, Bohm & Hosl, 2010).

Footwear characteristics such as the boot shaft height, mass, mid-sole hardness and thickness, elevated heels and type of material of the footwear influence balance and gait and ultimately the slip propensity in a slippery condition. Especially, the effect of the shoe sole tread patterns on slip propensity (Li, Wu and Lin, 2006; Li & Chen, 2005) and the effect of heel height on slip propensity have been studied previously (Blanchette, Braut & Powers, 2011). The differences in the coefficient of friction between the footwear type and surface type have been reported as a prime factor in slip and trip induced falls. Li, Wu and Lin found that the average coefficient of friction gain per tread groove depth increase in millimeter under slippery conditions ranged from 0.018 to 0.108 (Li, Wu and Lin, 2006). In addition to this, the same researchers in a subsequent paper reported that the orientation of the tread groove and its width also affect the COF significantly. Modifications on the occupational footwear even help prevent slips and trips in workplace settings by increasing the COF of friction between the sole of the occupational footwear and the working surface. As such, different materials of the sole of the footwear and different flooring types have their own advantages and disadvantages.

A majority of the soles of the footwear are made up of rubber to have a high COF safe enough to prevent slips and low enough to prevent trips. Even when the flooring type is the same, such as asphalt, it can differ in COF depending upon if the asphalt is dry or wet. Hence, with a common rubber sole of an occupational footwear, the dynamic or kinetic coefficient of friction decreases from 0.5-0.8 for dry asphalt to 0.25-0.75 for the same asphalt in wet conditions. Similar decrements in dynamic COF is seen in dry concrete (rubber on dry concrete = 0.6-0.85) to concrete floors when wet (rubber on wet concrete = 0.45-0.75). Rubber on vinyl floors are designed to have a minimum of 0.8 dynamic COF to have a safe working surface.

The tread patterns of the shoes affect friction especially under liquid contaminated surfaces. These new research based design in the tread groove depth, tread groove width and pattern help in prevention of fall in liquid collected walking surfaces. Li, Wu and Lin found that the average coefficient of friction gain per tread groove depth increase in millimeter under slippery conditions ranged from 0.018 to 0.108 (Li, Wu and Lin, 2006). In addition to this, the same researchers in a subsequent paper reported that the orientation of the tread groove and its width also affect the COF significantly. They reported that wider grooved footwear pads resulted in a higher COF and the footwear pads with tread grooves perpendicular to the friction measurement direction had higher COF (Li & Chen, 2005). High heeled shoes have been shown to use a greater utilized coefficient of friction thereby increasing the friction demand during walking which were related to an increase in the resultant shear force and a decrease in the vertical force and thereby increasing the probability of a slip (Blanchette, Braut & Powers, 2011).

Anti-slip footwear is recommended by OSHA and ANSI to prevent slips and falls in workplace settings, but it is not the sole of the footwear alone that play a role in helping prevent slips. The comfort and fit or the footwear, the mass of the footwear, other design features such as shaft height of the footwear and more importantly the relative age and wear of the footwear help prevent slips in occupational settings. Comparison of similar old versus new boots in fisherman who work in watery surfaces have been done, with the new boots offering a much better grip to the fishermen at work. This was performed as a means of promoting and making the fishermen aware to change their boots as soon as it is worn out.

INTRINSIC FACTORS IN THE PREDICTION OF SLIP PROPENSITY

Individual intrinsic factors such as dysfunctions or physiological deficits of the postural control systems, themselves can contribute to falls. Dysfunction in the visual, vestibular, somatosensory or the musculoskeletal system and any undue fatigue placed on these systems due to excessive workload in the occupational environment can potentially lead to falls. The risk of slips, trips and falls also increases with age, as there is physiological decline in function and performance of these postural control systems and the ability to walk safely with the center of mass (COM) within the base of support (BOS) decreases (Lockhart et al. 2005). While 32% of falls in the young adults were attributable to slips and trips, 67% of falls in the elderly have been reported due to slips (Lloyd and Stevenson, 1992). A decline in the muscular strength, vision, vestibular functions, diminished somatosensory and proprioceptive feedback which occurs with normal aging process and the added detrimental effect of diseases and disorders that affect these systems make the elderly population a vulnerable target not only for slips, trips and falls but also for the severity and recovery time of the injuries resulting from these falls. (Lockhart et al, 2002; Lockhart et al, 2008). The inability to control slipping responses may be the result of sensory degradation and muscle weakness that is attributable to aging (Lockhart, 2005) with an increased adaption time to slippery surfaces which was evident in the elderly population (Lockhart et al, 2007) and due to incorrect perceptions of floor slipperiness with uncompensated slip parameters (Lockhart et al, 2002).

Excessive body weight negatively affects balance, gait and slip parameters. Biomechanical and physiological rationale for this negative effect include, greater forward displacement of the center of pressure during dynamic standing activities and walking, an increased forward pelvis tilt and lumbar lordosis, reduced muscle strength with excessive adipose tissue and the inability to generate adequate muscle force to maintain stability during static and dynamic conditions (Capodaglio et al, 2012). The impaired ability to maintain balance during dynamic situations such as the initiation, detection and recovery in slip induced falls can be attributed to the increased risk of fall associated with obesity (Liu, 2011). On the contrary, few literatures have shown no differences in slip propensity of obese individuals compared to normal weight individuals (Pollack &Cheskin, 2007; Wu, Lockhart &Yeoh, 2011) with a greater step width in obese individual under slippery conditions (Wu, Lockhart &Yeoh, 2011).

Speed of walking and their effect on slip has been addressed previously (McGorry et al, 2010). McGorry found no significant differences in forward slip distance for walking speeds of 1.5 m/s (slow), 1.8m/s (medium) and 2.1m/s (fast) on marginally slippery floors with a COF ranging from 0.12 to 0.21 (McGorry et al, 2010). But, reported significant differences in instaneous forward horizontal heel velocity, 30ms after heel strike, with slow walking having less heel velocity than fast walking (McGorry et al, 2010). Decreased walking speed with increased stance phase and shorter step length was reported in the elderly under slippery conditions when compared to the young (Lockhart et al, 2007). Subsequently, decreased quadriceps activity was seen during slippery conditions in the elderly (Lockhart et al, 2007). The adaptation to slippery floor conditions was greater in the young population, where they were able to decrease the quadriceps mean muscle activity within one step, whereas, the older participant's activity remained the same for an entire gait cycle (Lockhart et al, 2007).

i. Perception of Slipperiness

Subjective perception of the floor slipperiness is based on visual perception and proprioceptive recognition of maintenance of balance during slip events. External factors like floor color, size, shape, texture gradient and individual internal factors like visual perception of the slip hazard, lighting,attentiveness and mental workload can influence the outcome of perceiving the slipperiness of surface (DiDomenico et al, 2007). Although small undetectable slips have been shown to occur regularly even during normal gait, the macro slips is usually perceivable to the individual (Hanson et al, 1999; Strandberg & Lanshammar, 1981). The perception and anticipation of a slip have been shown to reduce the possibility of a slip with biomechanical modifications to gait under slippery conditions (Chang et al, 2004; Cham & Redfern, 2002a). Thus the visual feedback from the visual system and the proprioceptive feedback from the somatosensory system are critical in determining the outcome of a slip. However, subjective slipperiness ratings alone may not be sufficient to identify slippery conditions. They have been used very cautiously as a measure of slipperiness, due to the underestimation of the surface slipperiness and the variability in the perception of the slips (DiDomenico et al, 2007). The inconsistencies in subjective responses could be due to the fact that each slip trial required different postural adjustments and gait patterns based on the sensory information available and used to accommodate for the slippery surface. Visual and auditory cues have been shown to override tactile proprioceptive sensations (Cohen and Cohen, 1994; DiDomenico et al, 2007). The changes in the gait variables in response to the perception of slippery hazardous conditions include a shorter step / stride length, thereby producing low heel velocities, smaller shear forces and lower required COF and lower GRFs during heel strike and push-off phases to reduce the likelihood of a slip.

Anticipation of slippery walking trials in comparison to dry normal walking, produced lower required coefficient of friction, reducing slip potential and failed to return to baseline normal dry walking values (Cham & Redfern, 2002a). This reduction in the peak RCOFs were brought about by postural changes and adaptations during the gait cycle, with decreased step length, low impact GRFs and with significant changes in joint moments (Cham & Redfern, 2002a; Cohen and Cohen, 1994; DiDomenico et al, 2007). Muscular activity during an alert or an expected slip resulted in a greater activation of the lower extremity musculature with the greatest increase in activity reported in the hamstrings and also with an early activation of the gastrocnemius muscle (Chambers & Cham, 2007). Greater muscle co-contraction analyzed with the co-contraction index (CCI) using the agonist / antagonist pairs of the ankle (tibialis anterior and medial gastrocnemius) and at the knee (vastus lateralis and medial hamstrings) were reported when anticipating a slippery surface and individuals who walked with a greater co-contraction were predisposed to experience less severe slips (Chambers & Cham, 2007).

COMPARISON OF ALTERNATIVE FOOTWEAR TO SHOD CONDITIONS IN GAIT AND SLIP PARAMETERS

The human foot is the first point of contact between the body and the environment or terrain which is vital in relaying the somatosenroy information to the CNS both during static and dynamic balance tasks. Furthermore, footwear serves as the interface between the human body and the supporting surface and can significantly affect the balance outcome measures (Menant et al. 2008). Efficient transformation of the mechanical power output produced by the musculoskeletal system through the footwear is responsible for a good performance in gait. Hence, the design and type of the footwear becomes important in gait and posture (Bohm&Hosl, 2010). Walking bare foot has also been related to an elevated risk of falls. The different features of the shoe design, such as the heel height, heel-collar height, sole hardness, heel and midsole geometry and slip resistance of the outer sole have been known to have on the influence on balance maintenance (Menant et al. 2008). Certain commonly worn footwear, such as slippers were found to be hazardous as they slowed down reactions to perturbations and also had adverse effects on posture reactions(Hosoda et al., 1997, Hosoda et al., 1998) even with barefoot walking shown to lead to an increased risk of falling (Menant et al. 2008).

Different types of footwear affect gait and posture kinematics adversely. Improper alignment of the foot altered by different footwear leads to an increased metabolic cost, which in turn leads to a faster rate of development of muscular fatigue. Many literature and researches have analyzed gait and balance with different gait speeds, changing terrain, shoe types and in bare foot condition (Perry, Radtke& Goodwin, 2007, Menant, Perry, Steele, Menz,Munro & Lord, 2008, Divert, Mornieux, Baur, Mayer & Belli, 2005, Bohm&Hosl, 2010).

The advent of flip-flops and crocs usage as alternative footwear has increased recently and can be attributed to its lightweight, comfort and convenience. However, the extrinsic factor such as the occupational hazardous environments and intrinsic factors such as age and obesity have negative impacts on gait biomechanics with usage of such alternative footwear. Specifically the response of these alternative footwear to slip propensity under slippery conditions have not been fully dealt with yet. Flip-flops and crocs are open type footwear including a relatively flat sole very loosely held on the foot by a "Y" shaped strap in the case of a flip flop and by an encased covering on the entire fore foot in the case of a croc. The crocs have a few advantages over the flip-flops, by having a base section that includes an upper and a sole. If the sole of these crocs are made of high coefficient of friction materials with tread patterns, it may offer a reduced risk for slips compared to flip flops which have flat and soft soles. The crocs also have the advantage of being water proof and breathable footwear allowing for ventilation.

Unlike other shod conditions, these alternative footwear do not secure the hind foot, heel and the ankle joint of the lower extremity. The movement of the entire foot and the footwear as one rigid segment seen in close fitting athletic shod conditions is not present in alternative footwear. As a result the interlinked point of contact of these alternative footwear and foot is accomplished only by the toes for flip flops and the forefoot for crocs. Hence, gait kinematics are negatively affected by these modifications in the footwear-foot interface. A reduced gait speed, decreased step and stride length, lowered double support time and over all reduced stance phase was seen in flip-flops compared to close fitting athletic shoes (McGinely et al, 2010). Although there is an increased use of these alternative footwear for its comfort and convenience, a decreased gait performance is evident when compared to close fitting shoes, and pose an increased threat and risk for slips and falls.

Temporal and spatial parameters of gait are quite commonly reported for alternative footwear in comparison with athletic shod conditions. A decreased stance phase-increase swing phase, decreased step-stride lengths and decreased period of double support are seen with alternative footwear (Shroyer& Weimer, 2010; Majumdar et al. 2006; McGinely et al. 2010). Differences in ground reaction forces for flip flops are still debatable, while Zhang et al showed no significant differences in ground reaction forces, Carl et al, showed increased forces compared to athletic shoes explaining the decreased shock attenuating capabilities of the alternative footwear, which could potentially lead to pathologic abnormalities in the foot (Zhang et al, 2012; Carl et al. 2008).

Extensive literature on kinematic gait analyses of barefoot and shod conditions during dry normal surface exists, which have focused on alternative open-toed footwear such as the flip-flops and slip-on footwear in comparison to close-toed shod conditions such as the athletic shoes or any shod condition that has a concealed foot with cushioning properties. Significant differences in gait kinematics in the alternative footwear included a shorter step-stride length (Shoryer et al. 2010a; Shoryer et al. 2010b; Carl et al. 2008; Majumdar et al. 2006) and a lesser dorsiflexion/ more plantar flexion angle at heel strike and during swing phase (Zhang et al. 2013; Menant et al. 2009). Flip flops and sandals have been shown to utilize a more flatter foot at contact when there is minimal cushioning (Zhang et al. 2013) and also during swing phase to hold the open-toed footwear in position during swing phase by gripping the footwear using the toes (Shroyer et al. 2010), while close-toed shod conditions have a longer step-stride lengths and greater dorsiflexion angles. Contrarily and more recently, increased dorsiflexion angle have been reported at heel contact, suggesting a mechanism to retain the thong flip flops during weight acceptance (Chard et al. 2013). Ground Reaction Forces (GRF) in alternative footwear such as flip-flops, open-toed shoes and other shod conditions have been debatable as well. Lower peak propulsive GRF and smaller loading rate of 1st peak vertical GRF were reported in shoes compared to barefoot, sandals and flip-flops (Zhang et al. 2013) and reduced peak vertical ground reaction force was reported in shoes compared to barefoot (Yan et al. 2012). Contrarily, in another study, flip flops were found to have the highest GRFs compared to barefoot walking (Shakoor et al. 2010). Subsequently, the muscle activity of the dorsi-flexors and intrinsic muscles of the foot can be expected to be increased during the swing and stance phases of the gait cycle. This increased muscle activity with alternative footwear can be detrimental especially in slippery conditions. Moreover, the somatosensory feedback mechanism might play an extremely important role in slip propensity. In the case of a shod condition which attaches to the entire foot, there is increased somatosensory information from the entire sole of the feet. However, in the case of a flip-flop, the only point of contact between the footwear and the foot is the 1st web space between the great toe and the 2nd digit. Thus, the unique foot angle in early stance, increased muscle activity, decreased stride lengths and the limited availability of somatosensory feedback from the feet may potentially influence slip propensity in alternative footwear.

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CHAPTER III

MANUSCRIPTS

MANUSCRIPT I

HEEL CONTACT DYNAMICS IN ALTERNATIVE FOOTWEAR DURING SLIP EVENTS

1. Introduction:

Injuries in and around the workplace pose a significant burden to the health of human beings as well as to the financial or economic losses to both the individual and the occupational organizations. Slips, trips and an induced loss of balance have been identified as the major causative factor for workplace injuries involving falls (Courtney et al, 2001a; Courtney et al. 2001b; Redfern et al, 2001) and pedestrian accidents in the walkway have been identified as the second largest generator of unintentional workplace fatalities (Leamon & Murphy, 1995). The Bureau of Labor Statistics reported 15% of a total of 4,693 workplace fatalities and a total of 299,090 cases of non-fatal workplace injuries that were due to slips, trips and falls (BLS, 2011). The annual cost of workplace injuries due to slips, trips and falls in the United States was estimated to be over 6 billion US dollars with an expected cost of $43.8 billion by 2020 (Courtney et al, 2001).

Slips, trips and falls occur as a result of failure of normal locomotion and failure of attempts at equilibrium recovery following an induced imbalance (Davis, 1983; Gauchard, 2001). These slips, trips and falls can be induced by extrinsic-environmental factors or by failure of the intrinsic-human factors. Included among the extrinsic-environmental factors are the physical characteristics of the floor or ground surface such as the type, smoothness or roughness of the surface, compliance of the surface and the presence and absence of contaminants or obstacles (Redfern et al, 2001; Gauchard 2001). Another vital extrinsic factor in the prediction of slips, is the type of footwear used and its interaction with the floor in the footwear-floor interface. Footwear design features that have been shown to enhance sensory input or mechanical stability of the foot and the ankle and thereby ultimately improving balance and gait mechanisms include a hard sole, elevated boot-shaft or a high-collar (Chander et al. 2014; Perry, Radtke &

Goodwin 2007). However, footwear design features that include soft soles and elevated heels have been shown to have lowered balance and gait performance (Menant et al. 2008; Divert et al. 2005; Bohm & Hosl, 2010). And, footwear with greater tread grooves have been shown to be slip-resistant and prevent slips and slip induced falls under slippery flooring conditions (Li & Chen 2005; Li, Wu & Lin 2006). The intrinsic or human factors constitute the human postural control system which is a complex sensorimotor function with afferent information from the visual, somatosensory and vestibular system along with central integration of these afferent stimulus and specific motor responses (Gauchard, 2001; Redfern et al, 2001; Hanson, Redfern & Mazumdar, 1999) which are also affected by aging, anthropometric features, gait speed, muscular fatigue and disorders of the musculoskeletal system. A crucial intrinsic factor in the prediction of slips, is the subjective perception and prior knowledge of the slippery flooring conditions. Anticipation of the slippery conditions, including attentiveness or alertness and mental workload can influence the outcome of slip events (DiDomenico et al, 2007). The perception and anticipation of a slip have been shown to reduce the possibility of slips and slip induced falls with biomechanical modifications to gait under slippery conditions (Chang et al, 2004; Cham & Redfern, 2002a).

Human gait is invariably affected by the coefficient of friction (COF) that exist when two surfaces come in contact, such as the sole of the footwear and floor at the footwear-floor interface. If the available COF at the footwear-floor interface is greater than the required COF for normal safe walking, the individual should not slip. However, if the available COF is lower than the required COF for normal safe walking, the slip propensity increases. The movement of the heel during the initial period of the heel strike phase has been analyzed and used as predictors of slip events. During normal dry surface gait, the heel movement has a characteristic pattern, where the heel rapidly decelerates just prior to heel strike following which the heel moves slightly forward (Perkins, 1978; Strandberg & Lanshammar, 1981; Redfern et al, 2001, Cham & Redfern, 2001a). At heel strike, the heel has been shown to have an instantaneous velocity in the forward direction (Perkins, 1978; Strandberg & Lanshammar, 1981) and some instances in a rearward direction (Cham & Redfern, 2001a), after which the heel reaches a minimum velocity and comes to a stop, over which the rest of the foot rolls over completing the midstance. The time period during heel strike and 25ms immediately post heel strike have been shown to be more crucial to development of an unrecoverable slip (McGorry et al, 2010) and the most hazardous slips often occur shortly after heel strike (<70-120ms) (Lockhart & Kim, 2006).

The heel slip distance and heel slip velocity of the heel motion following heel strike in a gait cycle have been used to characterize slip types (Redfern et al, 2001). Micro-slips are characterized by heel slip distance of 1cm-3cm and are not perceived by the individuals and easily compensated for by the automatic postural system. Macro-slips are characterized by the slip distances between 3cm-10cm, which will result in a loss of balance may or not result in fall, while slip distances greater than 10cm are most likely to result a fall due to the failure of the automatic postural system (Perkins 1978, Stranberg and Lanshammar, 1981, Redfern et al, 2001; Redfern and Cham, 2001a) and heel velocities of 0.5 m/s or higher have been shown to have an increased potential for a slip (Redfern et al, 2001). However, other research suggests that these values maybe too conservative (Brady et al. 2000), and only even greater slip distances and slip velocities are more likely to result in slip induced falls (Lockhart et al. 2006; Moyer et al. 2006). In other studies, Cham & Redfern demonstrated slip induced falls when the slip distances were equal or greater than 10 cm and when slip velocities were equal or greater than 0.8 m/s (Cham &

Redfern, 2002b) and Moyer et al. demonstrated slip induced falls with slip distances greater than 10 cm and slip velocities greater than 1 m/s (Moyer et al. 2006).

Preventing and reducing slips and slip induced fall accidents have been an important aspect of ergonomics research and have focused on slip-resistant properties of the footwear-floor interface. Footwear modifications including slip resistant soles have been mandated in occupational footwear by the Occupational Safety and Health Administration (OSHA) regulations and American National Standards Instruments (ANSI). However, the impact of alternative or casual footwear such as flip-flops and crocs which are commonly used among pedestrians and few of the occupational environments such as a hospital settings, under slippery conditions have not been analyzed yet. Furthermore, usage of flip-flops and crocs in and around the workplace as an alternative footwear due to its comfort and easy donning has grown in the recent years, further emphasizing the need to address the effect of these footwear on slip events.

Balance and gait mechanisms during normal locomotion and under slippery conditions have been studied extensively (Winter, 1991; Winter, 1995; Redfern et al, 2001) and consequently, there have been several studies that focus on the biomechanics of slips, trips and falls which are the primary causative factors for fall and fall related injuries in pedestrian population and especially in occupational environments, where there is a greater incidence of slips due to the environmental occupational hazards (Redfern et al, 2001; McGorry et al, 2010; Cham & Redfern, 2002a; Cham and Redfern, 2002b; Hanson et al, 1999; Perkins, 1978; Standberg & Lanshammar, 1981). The effect of different footwear, different flooring conditions and the footwear-floor interactions on the biomechanics of gait and balance have also been identified (Li, Wu and Lin, 2006; Shroyer & Weimer, 2010; Perry, Radtke & Goodwin, 2007, Menant, et al. 2008, Divert et al. 2005, Bohm & Hosl, 2010). While extensive literature exists on biomechanics of balance, gait and slips and the influence of footwear on these, there is still dearth of literature on the effect of much commonly used alternative footwear on the biomechanics of gait and slips. Hence, the purpose of the study is to analyze the effects of alternative footwear [crocs with clogs (CC), thong style flip-flops (FF) and slip resistant low-top shoe (LT)] on the slip parameters of heel slip distance and heel slip velocity during dry normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES). We hypothesized that the kinematic slip parameters will be greater in alternative footwear crocs and flip flops (CC & FF) compared to an industry standard low top slip resistant shoe (LT), leading to a greater potential for slips and slip induced falls. We also hypothesized that the slip parameters will be greater during an unexpected slip event compared to normal dry surface gait, alert and expected slip.

2. *Methodology:*

The purpose of the study was to examine the heel dynamics using kinematic measures during the stance phase of the gait cycle, more specifically during the first 120 ms following heel strike, which has been shown to be the time period during which the most hazardous slips occur. The heel contact dynamics was compared with three alternative footwear [Crocs with clogs (CC), Flip-Flops (FF) & Low Top Slip Resistant Shoe (LT)] under four gait conditions [(Normal Dry Gait (NG), Unexpected Slip (US), Alert Slip (AS) & Expected Slip (ES)] using a within subjects repeated measures design.

2.1. Participants:

Eighteen healthy male participants [Age: 22.28 ± 2.2 years; Height: 177.66 ± 6.9 cm; Mass: 79.27 ± 7.6 kg] completed the study. Participants who had any history of musculoskeletal injuries, cardio-vascular abnormalities, neurological disorders, vestibular disorders, under medications or any inability to walk and stand without support were excluded from the study. All participants were recruited through flyers approved by the University's Institutional Review Board (IRB). All participants read and signed the informed consent and also filled out the physical activity readiness questionnaire (PAR-Q) to rule out any of the above mentioned health complications and cleared for participation in the study.

2.2. Instrumentation:

2.2.1. 3D Motion Capture:

Vicon Nexus (Oxford, UK) 3D motion capture system with 12 infra-red T-series cameras was used to collect and analyze kinematic gait data. A lower body plug-in gait model from the Helen-Hayes marker system was used as for the participant configuration model. The motion capture system was calibrated every day prior to data collection and the kinematic data was sampled at 100Hz and collected using the Vicon Nexus software. Of the 12 infra-red cameras, eight were mounted on the walls to create a larger capture volume and the remaining four cameras were placed on tripods and positioned in close proximity to the walking pathway focusing on the lower extremity and foot segment.

2.2.2. Fall Arrest System:

A uni-track fall arrest system from Rigid Lines (Millington, TN); a lightweight horizontal rigid fall arrest track capable of supporting up to 900lb and installed with an inverted-U steel frame fixed to the laboratory floor was used as the safety fall arrest system to prevent any undesired falls. Participants were attached to the fall arrest track with the help of a back pack type harness system attaching to a moveable trolley inside the fall arrest track. The trolley was capable of locking itself without moving if there was greater than 50lb force imparted on the harness line. The fall arrest track and the harness along with the trolley were connected by a pulley system that allowed the investigators to move the trolley on top of the walking participant so that, the participants were not leading the trolley now was the trolley leading the participant. This was done to take away the closed kinematic chain between the participant and the fall arrest system and to minimize the impact of the harness and fall arrest system on the outcome of the slip events.

2.2.3. Slippery Agent or Contaminant:

Industrial vegetable based glycerol mixed with water in the ratio of 75% glycerol and 25% water was used as the slippery agent. The 75%-25% ratio was chosen for the study based on previous literature and with initial practice sessions in the laboratory prior to starting data collection. During the slip gait trials or slip events, glycerol was applied and evenly distributed on the Bertec force plate, on which the left leg of all participants, irrespective of their dominant extremity, would make contact during the gait trials. The application of the slippery agent was always performed by the primary investigator using the same measured and calibrated container to minimize the errors due to inter and intra rater reliability.

2.3. Experimental Procedures:

All participants visited the Applied Biomechanics Laboratory four times, separated by a minimum of 24 hours. A description of the experimental procedures for each visit is provided below.

2.3.1. Day 1:

The first visit was treated as a familiarization day, where all participants were exposed to the testing measures for gait trials and muscle activity. Informed consent was obtained from all participants following which they completed a physical activity readiness questionnaire (PAR-Q) and screened for any complications that might hinder them from completing the study. Anthropometric measurements such as height, weight, leg length, knee width, ankle width and foot/shoe size. Following this, participants were briefed on the walking gait conditions and were allowed to practice walking at their self-selected pace across the lab walkway. Participants were encouraged to walk at the same pace for every trial and their starting points were adjusted by the investigators to make sure there is clean contact with the dual force plates positioned in the middle of the walkway across the lab floor. Next the participants were positioned and strapped inside the harness connecting to the trolley and ultimately to the fall arrest track. Participants also performed the same practice gait trials with the harness while the investigators moved the trolley in-sequence along with the participant. A number of practice gait trials were performed until the subjects walked normally and with the same speed. Finally, the participants were assured of the fall arrest system catching them in the case of an undue fall, initiated by the slip. Participants were also asked to let go of their body weight and drop down on the harness system to further ensure that the fall arrest system would support their entire body weight and catch them preventing them hitting the floor, in the case of a slip. All participants were also asked to refrain from any physical workload especially to their lower extremities in terms of resistance or aerobic training and were also asked to avoid any pain medications until all their testing days were completed.

2.3.2. Day 2, Day 3 and Day 4:

Visits 2, 3 and 4 were again separated by a minimum of 24 hours and treated as experimental testing days. These experimental testing days followed the same testing protocol except with different alternative footwear (CC, FF & LT) which were chosen and provided to the participant using a counter balance design to remove order effects.

2.3.2.1. Participant Preparation:

Each visit will start the experimental testing day with a counter balanced allotment of the either the CC, FF or LT to the participants. Participants were also be provided black spandex shorts and t-shirts. Reflective markers were placed on the participant's lower extremity and on the footwear following a lower body plug-in gait model from the Helen-Hayes system.

2.3.2.2. Experimental Testing:

The experimental testing session began with the participant wearing the footwear given to them and had a series of practice gait trials across the vinyl floored testing surface under dry non slip conditions to get accustomed with the gait trials and the testing environment at a self-selected speed of walking. These practice gait trials were also used to make sure that the participants strike the center of the force plate with both their feet, unintentionally at their normal walking pattern and pace and to avoid any intentional modification of their step lengths during the data collection procedure.

Following the initial practice gait trials, the participants were strapped in the harness system to the fall arrest track and a static capture of the lower body plug-in model was performed. With the completion of the static capture, the participants again started a series of practice gait trials with the harness fall arrest system and the trolley being moved in-sequence with the participant. Practice trials were performed until the participants walked with ease in a similar pattern and with similar walking speed. Dynamic capture was done for 5 normal dry gait trials with no breaks or stops between the gait trials with the instruction "walk as normally as possible with the same speed". With the completion of the 5th normal dry gait trial, participants still walked with the same pattern and speed, but at the end of all further gait trials, the participants took 30-45 second breaks facing away from the walking surface and listened to music played on a noise-cancellation headphones, which would take away the knowledge of the potential slip trial, again with the same walking instructions.

Following a repeated number of gait trials under normal dry conditions, one particular trial was chosen randomly to be the unexpected slip (US) trial and the contaminant was applied to the force plate without the participant's knowledge. Participants were still given the same walking instruction to ensure that the walking trial will be treated as an unexpected slip event. On completion of the US, participants were allowed to rest briefly and the footwear removed for cleaning the contaminant. The force plate was also cleaned with a dry-wet vacuum and soap water and dried completely and made ready for the next gait trials. Participants then performed multiple normal dry gait trials with the same 30-45 second breaks and once a normal gait pattern resumed, participants were given the instruction that all of the following trials "may or may not be slippery". Multiple gait trials with the same protocol and instructions were performed in succession and one trial was randomly chosen to be the alert slip (AS) trial, where the contaminant was applied again without the knowledge of the participant, but differed from the US in terms of the instruction given to the participant. Finally, with the completion of NG, US and AS, participants visually saw the application of the contaminant on the force plate for one last walking trial and were given the instruction that the following trial "will be slippery" and treated as an expected slip (ES) trial.

2.4. Data Analysis:

The slip parameter dependent variables included the Heel Slip Distance (HSD) (mm) and the Mean Heel Slip Velocity (MHSV) (mm/s) during the first 120 ms following heel strike of the left leg. The left heel marker was used to determine HSD and MHSV and Vicon Nexus software was used to determine the moment of heel strike of the left leg during the gait trials. The raw data was cleaned removing unlabeled markers, filled gaps in the markers using a spline fill and edited to have two gait cycles starting with the right leg. The raw data was filtered using a Butterworth fourth order filter with zero lag and exported as excel files for further analyses. HSD which is the horizontal distance traveled by the left heel marker after the foot strikes the floor was calculated as the linear displacement of the left heel marker in the horizontal x-direction from the moment of heel strike to 120 ms into the gait cycle. MHSV which is the average of the horizontal velocity of the left heel marker after the foot strikes the floor and until 120 ms into the gait cycle, was calculated from the instantaneous heel contact velocity in the one-dimensional horizontal x-direction velocity.

2.5. Statistical Analysis:

A Within-Subjects Repeated Measures of Analysis of Variance (Repeated Measures ANOVA) was performed to compare the three alternative footwear across the gait trials. Hence, a 3 x 4 [3 Footwear (CC, FF, LT) x 4 Gait Trials (NG, US, AS, ES)] Repeated Measures ANOVA was used to analyze the dependent slip parameters of HSD and MHSV individually for footwear x gait trial interaction and main effect significance. A Greenhouse Geisser correction was used if the Mauchly's test of sphericity was significant and if the assumption of sphericity was violated. The dependent variables were tested initially for the footwear x gait trial interaction, and if a significant interaction existed, the main effects of footwear and gait trials were ignored and pairwise comparisons of the simple main effects for the existing significant interaction was performed using the Sidak Bonferroni multiple comparisons correction. This was done for the both the independent variables individually to identify how the simple main effects of one factor differ over the levels of the other factor. For all analyses, alpha level was set a priori at p = 0.05 and all statistical analyses was performed using the SPSS 21 statistical software package.

3. *Results:*

The repeated measures ANOVA revealed significant interactions between footwear and gait trials for both HSD and MHSV. Significant interaction between footwear and gait trials existed for HSD at F (2.732, 46.438) = 5.453, $p = 0.003$, $\eta_p^2 = 0.284$ (Fig.1). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for HSD. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC and FF between NG and US at $p = 0.04$ and $p = 0.002$ respectively, with significantly greater HSD for US compared to NG; and for FF between US and AS at $p = 0.048$ with significantly greater HSD for US compared to AS. No significant differences existed for LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for NG between CC and FF at $p = 0.0005$ with significantly greater HSD for CC compared to FF; for US between CC and LT at $p = 0.016$ and between FF and LT at $p = 0.002$, with significantly greater HSD for CC and FF compared to LT. No significant differences existed for AS and ES across all footwear.

Significant interaction between footwear and gait trails existed for MHSV at F (2.840, 48.288) = 4.923, p = 0.005, $\eta_p^2 = 0.225$ (Fig.2). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for MHSV. Pairwise comparisons for simple main effects for footwear revealed significant differences for FF between NG and US at p = 0.002 with significantly greater MHSV for US compared to NG. No significant differences existed for CC and LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for

NG between CC and FF at p = 0.0005 and between LT and FF at p = 0.027 with significantly greater MHSV for CC and LT compared to FF; for US between CC and LT at p = 0.047 and between FF and LT at p = 0.005 with significantly greater MHSV for CC and FF compared to LT. No significant differences existed for AS and ES across all footwear.

4. ***Discussion:***

The purpose of this study was to analyze the effect of alternative footwear, [Crocs with Clogs (CC), Flip-Flops (FF) and Low Top Slip Resistant Shoe (LT)] on the heel contact dynamics during normal gait trials [Normal Dry Gait (NG), Unexpected Slip (US), Alert Slip (AS) and Expected Slip (ES)]. The findings from this study demonstrate significant differences in the slip parameters for both Heel Slip Distance (HSD) and Mean Heel Slip Velocity (MHSV) between CC, FF and LT and across gait trials. Based on the magnitude of the slip, a greater or an increased HSD and MHSV have been shown to contribute or lead to a slip induced fall (Perkins, 1978; Strandberg & Lanshammar, 1981; Redfern et al, 2001, Cham & Redfern, 2001; Lockhart & Kim, 2006; McGorry et al, 2010; Moyer et al, 2006; Brady et al. 2000). On average, greater slip parameters (HSD and MHSV) were found in the unexpected slips and alert slips compared to normal dry gait and expected slips, more specifically in alternative footwear for crocs and flip flops. Recently, it has also been shown that once a slip is initiated, slip distance, rather than the slip velocity would be the variable that best describes the potential outcome of the slip event (Brady et al. 2000). However, a combination of the two slip parameters could be used to have a more precise representation of the outcome of the slip events.

Significant interactions between footwear and gait trials existed for both HSD and MHSV, suggesting the influence of both footwear and gait trial condition in the outcome of the slip parameters. The type of footwear worn during both the dry and slippery gait conditions were seen to impact the dependent slip parameters. For CC, significantly greater HSD was seen in US compared to NG and for FF, in US compared to NG and AS, while no significant differences were seen between NG and ES for both CC and FF. Similarly, for FF, significantly greater MHSV was seen in the US compared to NG, while no significant differences were seen between NG, AS and ES for both CC and FF. Hence, the significantly greater HSD and MHSV for the alternative footwear (CC & FF) existed only when there was no knowledge of the impending slippery flooring condition, but with the knowledge of the slippery flooring condition, the HSD and MHSV were closer to the NG. Contrary to the behavior of the alternative footwear (CC & FF), the LT had no significant differences in both HSD and MHSV across all gait trials, behaving the same way irrespective of the walking condition being dry non-slippery or slippery with the contaminant and with or without the knowledge of the slippery flooring conditions. Although there is a considerable amount of literature on the gait kinematics of such alternative footwear, the impact of these alternative footwear on slippery gait conditions have not been fully identified yet. The CC and FF demonstrate significantly greater slip parameters contributing to the increased incidence of slip induced falls compared to the LT which is being used in the industrial market as a slip-resistant shoe in slip prone occupational working conditions.

Data from the current study supported findings from previous researches by demonstrating significant differences when the participants transitioned from a normal gait condition on a dry floor surface (NG) to slippery gait conditions on a contaminated floor surface (US, AS & ES). The gait trial conditions during, either dry non-slippery or slippery flooring conditions had an impact on the outcome of the dependent slip parameters, based on the type of footwear worn. Significant differences in the dependent slip parameters were found even during NG with significantly lower HSD and MHSV for FF compared to CC and LT. Walking in flip-flops have been shown repeatedly to have lower step length, lower stride length and an overall decreased preferred walking speed including a different heel strike pattern compared to other shod conditions (Shroyer et al, 2010; Zhang et al. 2013; Majumdar et al. 2006), which might have contributed to the lower HSD and MHSV seen under the dry non-slip flooring conditions. However, during unexpected slips, significantly greater HSD and MHSV were found for both CC and FF compared to the LT, demonstrating greater potential for slip induced falls in alternative footwear (CC & FF). Both HSD and MHSV had no significant differences during AS and ES across all footwear. When transitioning from normal dry gait to an unexpected slippery flooring condition, the alternative footwear demonstrated significantly greater slip parameters leading to slip induced falls; however, all participants irrespective of the footwear worn, potentially reduced frictional demands which might be related to adjusted gait kinematics (Lockhart et al. 2007) during the AS and ES and lowering the HSD and MHSV, thereby preventing hazardous slip induced falls. Previous researches have shown gait modifications of both stance leg and swing leg, kinetically by increasing muscle activity and frictional utilization and kinematically, by reducing step length, stride length and heel contact velocity (Lockhart et al. 2007).

Extrinsic Factors - Footwear design characteristics as predictors of slips:

The footwear's geometrical design characteristics have been shown to affect human balance and gait (Chander et al. 2014; Perry, Radtke & Goodwin 2007; Menant et al. 2008; Menant et al. 2009; Divert et al. 2005; Bohm & Hosl 2010) and especially the sole design parameters such as the depth, width and orientation of the tread groove have been demonstrated as important factors affecting the coefficient of friction between the footwear-floor interface (Li & Chen, 2005; Li, Wu and Lin, 2006). Certain commonly worn alternative footwear, such as slippers and flip flops were found to be hazardous as they slowed down reactions to perturbations and also had adverse effects on postural reaction (Hosoda et al., 1997, Hosoda et al., 1998) and leading to an increased risk of falling. These alternative footwear combined with slippery environmental conditions could be very dangerous and lead to a greater incidence of slips and slip induced falls. Unlike other shod conditions, these alternative footwear of flip flops and crocs, do not secure the hind foot, the heel and the ankle joint, leading to changes in the joint kinematics.

Previous research has demonstrated that the average coefficient of friction gain per tread groove depth increase in millimeter under slippery conditions ranged from 0.018 to 0.108 (Li, Wu and Lin, 2006) and that wider grooved footwear pads resulted in a higher COF and the footwear pads with tread grooves perpendicular to the friction measurement direction had higher COF (Li & Chen, 2005). The tread patterns on the LT follow Occupational Health and Safety Administration (OSHA) and American National Standards Instrumentation (ANSI) which provides slip resistant and anti-slip “treadsafe” soles with hexagon shaped tread marks that are perpendicular to the direction of walking. Although, the tread patterns in the CC and FF are perpendicular to the direction of motion, the depth of these tread marks were lower in comparison to the LT. Moreover, the number of grooves in the surface area of the sole of the foot were higher in the LT compared to the CC and FF. All these factors contributed to the better anti-slip performance in LT while walking over slippery flooring conditions.

The age and the wear and tear on a footwear have also been shown to contribute to slip induced falls. A higher proportion of slip induced falls were seen in old slip resistant boots compared to new ones (Jensen & Laursen, 2010). The current study used all new footwear with no prior wear and tear, and the alternative footwear (CC & FF) had a greater proportion of falls compared to LT even when its new, suggesting that with age and wear and tear from repeated use, the alternative footwear could be potentially more dangerous in precipitating larger slip distances and velocities and leading to more slip induced falls. Although, few literature has shown gait modifications in alternative footwear, its behavior under slippery conditions haven't been fully analyzed yet. Based on the results from the current study, it appears that the alternative footwear which do not secure the hind foot and the ankle joint had a greater slip distances and slip velocities compared to LT in which the footwear and the foot move together as one rigid segment.

Intrinsic Factors - Perception and Anticipation as predictors of slips:

An intrinsic human factor as a predictor of slip events includes perception of a slip hazard which can be an interaction of various factors such as the prior knowledge of a slip prone environment, ability to use visual perception in the presence or absence of adequate lighting, arousal / alertness levels and mental workload while encountering a slip (Cohen & Cohen, 1994a; Cohen & Cohen, 1994b). Although, small forward heel displacements which have been shown to occur in regularly in normal gait, are often undetectable to the individual (Strandberg & Lanshammar, 1981; Hanson et al. 1999; Leamon & Murphy, 1995) for which the human postural control system is sufficient to adapt to these small magnitude slips (Redfern et al. 2001) and continue a normal gait pattern; previous studies have concluded that individuals are capable of differentiating the slipperiness of the floor while walking on dry or contaminated surfaces (Strandberg, 1983; Strandberg, 1985; Groqvist et al. 1993) using the tactile sliding resistance cues to determine slipperiness of the walking surface.

However, prior knowledge and anticipation of a slippery floor allows the individuals to reduce the potential slips by making adaptations to the biomechanics of gait (Cham & Redfern, 2002a; Lockhart et al. 2007). Subjective measures of slipperiness have been related to the coefficient of friction of the walking surface which have been shown to be effective with exposure to the contaminated walking surface (Chang et al. 2004), making use of the most sensitive tactile somatosensory information, however a mere observation of the walking surface have been shown to be poor predictors of slips (Li et al. 2004). Although, the subjective assessment of slipperiness is often considered an easy method for identifying potential slip hazardous situations, the use of such subjective assessment has been warranted with caution due to its weak associations with slip distances (DiDomenico et al. 2007). In the current study, the AS and ES demonstrated significantly lower HSD and MHSV compared to US. Even though the ES was the only gait trial condition in which the participants were visually allowed to see the slippery contaminant on the floor before walking across it, the AS also had similar slip parameter values with no significant differences between AS and ES. Cham and Redfern showed a 14-19% reduction in heel velocity during anticipation trials which were still dry trial with no contaminant (Cham & Redfern, 2002a), in which participants were given the same instruction as our study for AS (may or may not be slippery) from baseline dry condition in which all participants were assured that the walking surface was non-slippery. The anticipation trials (dry trials) in the Cham and Redfern study, still demonstrated a decreased heel velocity, suggesting that the heel contact kinematics were changed when there is a potential risk of slipping, even though the subjects were asked to walk as normally as possible. Chambers et al. also showed significantly higher slip distances and velocities in unexpected slips and significantly lower slip distance and velocities for alert and known slippery gait conditions (Chamber et al. 2003). The results from our study support previous literature, where the knowledge and the anticipation of the flooring surface which may or may not be slippery was crucial in bringing about kinematic heel contact adaptations governed by the human anticipatory postural control system, thereby preventing slips and slip induced falls.

Heel Slip Distance and Heel Slip Velocity Relationship:

The data from the current study was consistent with previous studies which looked at heel slip distances and heel slip velocities as predictors of slip outcomes. Heel slip distances of less than 30 mm were seen as micro-slips, with distances between 30 mm - 100 mm as midi-slips or slides and slip distances beyond 100 mm as macros-slips that lead to a slip induced fall (Strandberg & Lanshammar, 1981; Perkins, 1978; Redfern et al 2001; Cham & Redfern, 2001a; DiDomenico et al. 2007). Similarly, heel velocities less than 500 mm/s were seen as micro slips, with velocities between 500 mm/s - 1000 mm/s as midi-slips and heel velocities above 1000 mm/s as macro slips that lead to a slip induced fall (Redfern et al. 2001; Moyer et al. 2006). The data points from all participants in three footwear conditions are presented in figures (Fig.3, Fig.4, Fig.5 and Fig.6) for NG, US, AS and ES respectively.

Based on the slip distance and slip velocity, Moyer et al. classified the slip outcomes into (i) non-hazardous slips which had shorter slipping distance and slower slipper velocity and were unlikely leading to falls and (ii) hazardous slips which had greater slipping distances and faster slipping velocity and were more likely to lead to falls (Moyer et al. 2006). The concept of using hazardous and non-hazardous slips instead of falls and recoveries was suggested by Moyer et al. to further benefit studies investigating human locomotion under slippery conditions (Moyer et al. 2006). The current study utilizes this concept to demonstrate the interactions of the alternative footwear and slippery gait conditions and further suggesting three zones of the outcome of slip events. The zone below 30 mm of slip distance and 500 mm/s of slip velocity could be considered as the safe zone or the non-hazardous zone, in which the slips are often perceived by the postural control system and there is not often a need to have corrective postural responses. The zone encompassed within 30 mm - 100 mm slip distance and within 500 mm/s - 1000 mm/s could be considered as the potentially hazardous zone, in which the slip perturbations would require a corrective postural responses to prevent a slip induced fall, but not always lead to a fall. The zone beyond 100 mm of slip distance and 1000 mm/s slip velocity could be considered as the hazardous done, which requires a greater corrective postural response and is very likely to lead to a slip induced fall. During normal gait dry conditions, the slip parameters were predominantly in the safe zone irrespective of the type of footwear used. During unexpected slips, the alternative footwear had greater slip distances and velocities and were predominantly potentially hazardous or hazardous slips in comparison to LT, but decreased the slip parameters with the anticipation of a potential or known slippery condition, in AS and ES. The LT had gait trials predominantly in the safe zone, irrespective of the slippery conditions, leading to better performance and preventing slips.

5. *Conclusion:*

Based on the results from the current study, the interaction between the type of footwear and the gait trial conditions, contributed in determining if the outcome of the slip events were either non-hazardous, potentially hazardous or hazardous slips. It appears that the alternative footwear had greater instances where the gait trial was either potentially hazardous or hazardous in comparison to LT. However, with the knowledge and anticipation of the slippery conditions, the slip distances and velocities were minimized with potential gait modifications and thereby preventing any slips or slip induced falls. But, under all slippery conditions, the LT had better performance in preventing slips and given the conditions, the low top slip resistant shoe proves to be the choice of footwear for maneuvering slippery flooring conditions. Even though the alternative footwear serves for comfort and easy donning, it might not be the choice of footwear to prevent slips and slip induced falls. Future research should focus on the interactions of these alternative footwear and slippery conditions with physical workload, which is a common occurrence in occupational environments over the course of the work day.

Fig.1: Heel Slip Distance (mm) during 120ms post heel strike for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal dry gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

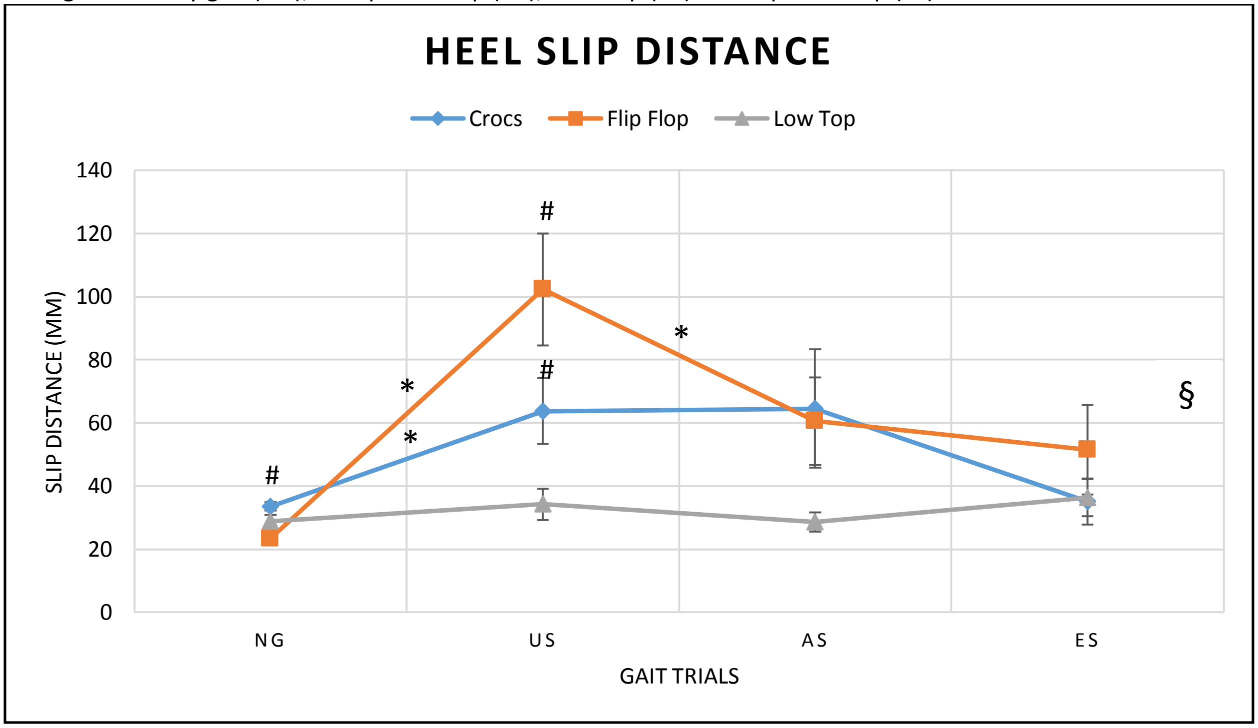
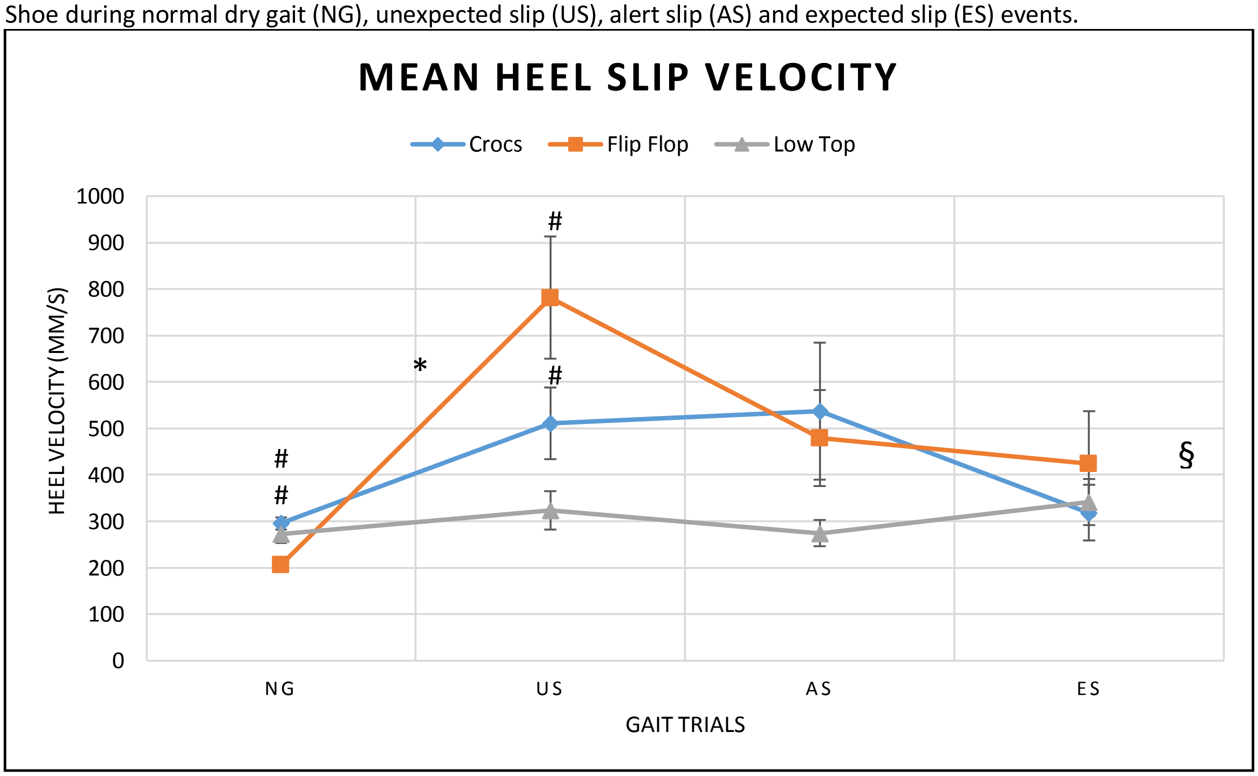


Fig.2: Mean Heel Slip Velocity (mm/s) during 120ms post heel strike for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal dry gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

Fig.3: Relationship between Heel Slip Distance (mm) and Mean Heel Slip Velocity (mm/s) during 120ms post heel strike during normal dry gait events.

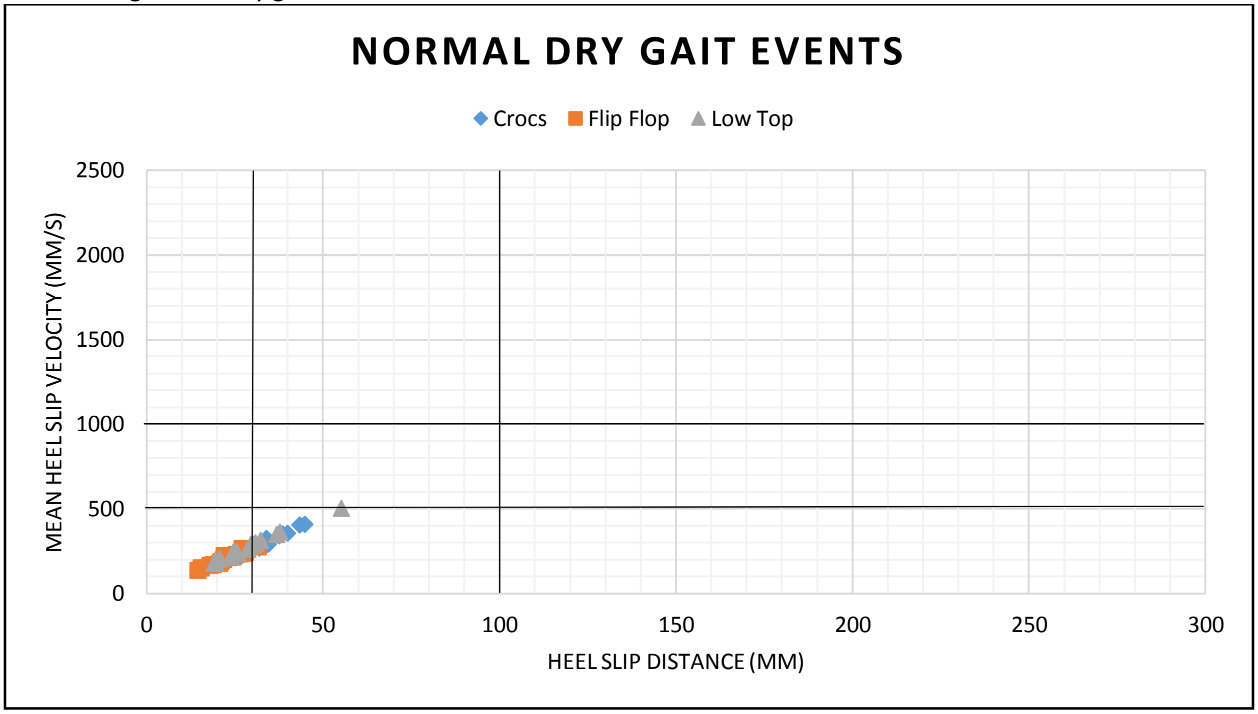


Fig.4: Relationship between Heel Slip Distance (mm) and Mean Heel Slip Velocity (mm/s) during 120ms post heel strike during unexpected slip events.

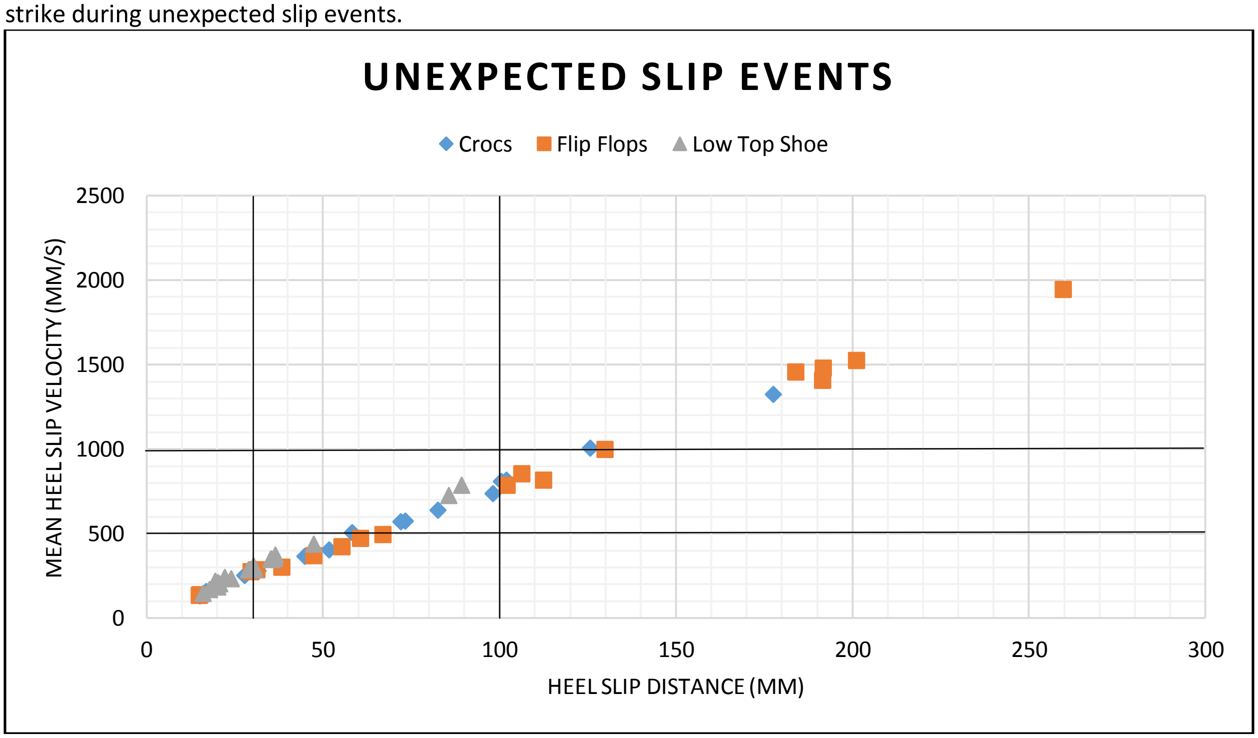


Fig. 5: Relationship between Heel Slip Distance (mm) and Mean Heel Slip Velocity (mm/s) during 120ms post heel strike during alert slip events.

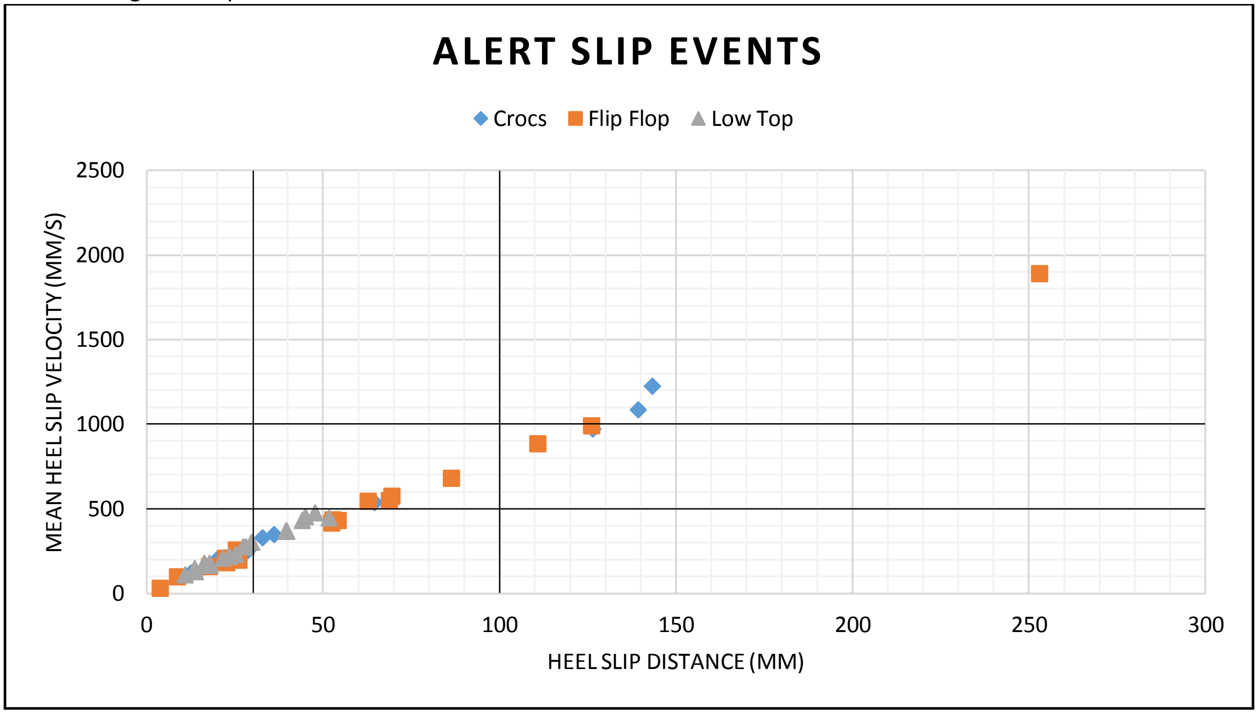
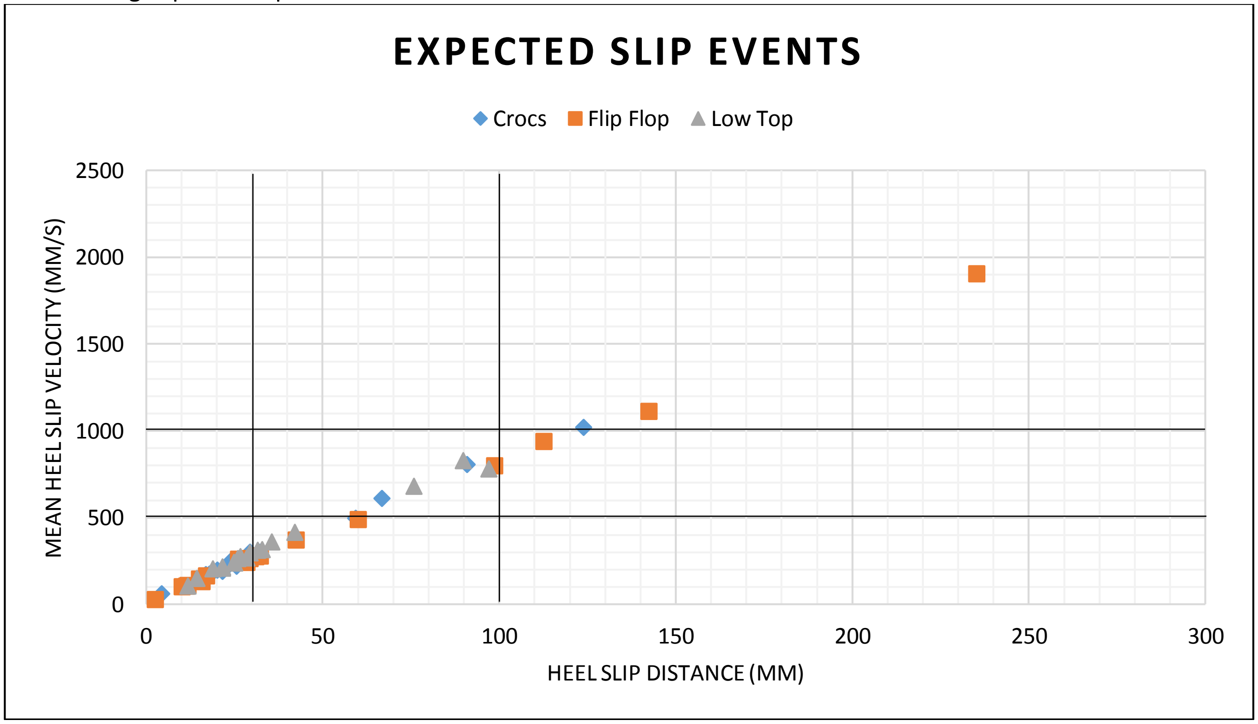


Fig. 6: Relationship between Heel Slip Distance (mm) and Mean Heel Slip Velocity (mm/s) during 120ms post heel strike during expected slip events.



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MANUSCRIPT II

IMPACT OF ALTERNATIVE FOOTWEAR ON LOWER EXTREMITY JOINT ANGLES AND GROUND REACTION FORCES DURING SLIP EVENTS

1. *Introduction:*

Increased probability of falls have been related to decrements in balance control and these falls are often a primary causative factor for injuries and disabilities in the general population as well as in the contemporary industrial population where postural stability is challenged with unfavorable and unfamiliar environment (Lin, Seol, Nussbaum & Madigan, 2008). These falls are not always from an elevation, and about 43% of the same level falls have been found to be triggered by slips (Courtney et al. 2001). Slips, trips and falls occur as a result of failure of normal locomotion and failure of attempts at equilibrium recovery following an induced imbalance (Davis, 1983; Gauchard, 2001). The coefficient of friction at the footwear-floor interface have been used as an applied approach in the prediction of outcome of slips. Under normal walking conditions the required or the utilized coefficient of friction have been shown to range from 0.17 to 0.20 (Redfern et al. 2001). When the utilized coefficient of friction exceeds the available coefficient of friction at the footwear-floor interface, the slip propensity increases (Redfern et al. 2001; Cham and Redfern, 2002b; Hanson et al, 1999; McGorry et al, 2010).

Gait kinematics are influenced by the available coefficient of friction and the slipperiness of the floor. A few kinematic variables are very commonly used as outcome variables to interpret the slip research. The most commonly reported are the slip parameters such as the heel slip distance, heel velocity and the foot-floor angle; joint angles of the ankle and the knee joints along with temporal-spatial parameters of gait including stride/step lengths, width of walking base, stride/step time and cadence (Perkins, 1978; Strandberg & Lanshammar, 1981). Joint angles have been investigated previously in normal walking on a dry surface (Winter, 1995) and under slippery conditions (Redfern et al. 2001; Lockhart et al. 2007; Brady et al. 2000; Moyer et al. 2006). During normal dry surface gait, at heel contact, the ankle is either in neutral or slight dorsiflexion and rapidly rolls into plantar flexion, over which the lower leg moves forward into midstance (Winter, 1995) and the hip joint is at its maximum flexion angle at heel contact and continues to move into extension throughout the stance phase of the gait cycle (Winter, 1995). However, under slippery conditions, the normal gait cycle pattern is disturbed due to the perturbation from the slip. The ankle joint have been shown to be in increased plantar flexion during slips and a greater foot floor angle contributing to a greater incidence of slips (Cham & Redfern, 2002a; Brady et al. 2000). A greater hip flexion angle at heel contact have, due to a bigger stride length have been shown to contribute to slips (Lockhart, 1997). However, during the slip, the hip movement is minimized, with increasing knee flexion as corrective movements, in an attempt to keep the center of mass within the base of support to prevent slip induced falls (Redfern et al. 2001).

The ground reaction forces occurring immediately post heel strike is vital in the prediction of the slips and falls. The first peak in the shear force which occurs at about 19% of the gait cycle (90-150ms post heel strike) is the crucial time period during which most slips occur (Redfern et al. 2001). The highest shear forces occur during the heel contact and push-off phases of the gait cycle and considered as the points during which the highest incidence for a slip exists (Redferen et al. 2001; Redfern & DiPasquale, 1997; Hanson et al, 1999). The general characteristics seen with ground reaction forces during slips are a reduction in the shear and normal forces, as the transfer of body weight to the supporting leg is not completed (Redfern et al. 2001).

The changes in the gait variables in response to the perception of slippery hazardous conditions include a shorter step / stride length, thereby producing low heel velocities, smaller shear forces and lower required COF and lower GRFs during heel strike and push-off phases to reduce the likelihood of a slip. Ankle joint angles are modified to have a flatter foot strike, when there is anticipation of slippery flooring conditions (Cham &Redfern, 2002b). Anticipation of slippery walking trials in comparison to dry normal walking, produced lower required coefficient of friction, reducing slip potential and failed to return to baseline normal dry walking values (Cham & Redfern, 2002a). This reduction in the peak RCOFs were brought about by postural changes and adaptations during the gait cycle, with decreased step length, low impact GRFs and with significant changes in joint moments (Cham & Redfern, 2002a; Cohen and Cohen, 1994b; DiDomenico et al, 2007).

Both extrinsic factors such as the type of footwear (Li & Chen, 2005; Li, Wu & lin, 2006) and intrinsic factors such as the knowledge or anticipation of a slip (Cham & Redfern, 2002a; Lockhart et al. 2007) have been shown to affect the outcome of a slip event. Extensive literature on kinematic gait analyses of barefoot and shod conditions during dry normal surface exists, which have focused on alternative open-toed footwear such as the flip-flops and slip-on footwear in comparison to close-toed shod conditions such as the athletic shoes or any shod condition that has a concealed foot with cushioning properties. Significant differences in gait kinematics in the alternative footwear included a shorter step-stride length (Shoryer et al. 2010a; Shoryer et al. 2010b; Carl et al. 2008; Majumdar et al. 2006) and a lesser dorsiflexion/ more plantar flexion angle at heel strike and during swing phase (Zhang et al. 2013; Menant et al. 2009). Flip flops and sandals have been shown to utilize a more flatter foot at contact when there is minimal cushioning (Zhang et al. 2013) and also during swing phase to hold the open-toed footwear in position during swing phase by gripping the footwear using the toes (Shroyer et al. 2010), while close-toed shod conditions have a longer step-stride lengths and greater dorsiflexion angles.

Contrarily and more recently, increased dorsiflexion angle have been reported at heel contact, suggesting a mechanism to retain the thong flip flops during weight acceptance (Chard et al. 2013). Ground Reaction Forces (GRF) in alternative footwear such as flip-flops, open-toed shoes and other shod conditions have been analyzed previously. Lower peak propulsive GRF and smaller loading rate of 1st peak vertical GRF were reported in shoes compared to barefoot, sandals and flip-flops (Zhang et al. 2013) and reduced peak vertical ground reaction force was reported in shoes compared to barefoot (Yan et al. 2012). Similarly, in another study, flip flops were found to have the highest GRFs compared to barefoot walking (Shakoor et al. 2010).

Although considerable amount of literature exists, analyzing the gait kinematics and kinetics in different footwear and shod conditions, the impact of these alternative footwear under slippery conditions haven't been fully addressed yet. The specific purpose of this paper is to analyze the impact of alternative footwear [Crocs with clogs (CC), Flip-Flops (FF) and Low Top Slip Resistant Shoe (LT)] under multiple gait conditions [Dry normal surface (NG); Unexpected Slip (US), Alert Slip (AS) and Expected Slip (ES)] on lower extremity joint angles (Ankle Angle and Hip Angle) and ground reaction forces (Mean Z-GRF and Peak Z-GRF). Based on previous literature, we hypothesized that the alternative footwear (CC & FF) will demonstrate greater plantar flexion ankle angle and lesser hip flexion angle at heel strike compared to LT, during dry gait and slip trials. We also hypothesized that the vertical ground reaction forces (Z-GRF) will be greater for alternative footwear (CC & FF) and minimized for during slip trials.

2. *Methodology:*

The purpose of the study was to examine the ground reaction forces during the stance phase of the gait cycle and to analyze the joint angles at heel strike. The Z-GRFs and ankle and hip joint angles were compared across the three alternative footwear [Crocs with clogs (CC), Flip-Flops (FF) & Low Top Slip Resistant Shoe (LT)] under four gait conditions [(Normal Dry Gait (NG), Unexpected Slip (US), Alert Slip (AS) & Expected Slip (ES)] using a within subjects repeated measures design.

2.1. Participants:

Eighteen healthy male participants [Age: 22.28 ± 2.2 years; Height: 177.66 ± 6.9 cm; Mass: 79.27 ± 7.6 kg] completed the study. Participants who had any history of musculoskeletal injuries, cardio-vascular abnormalities, neurological disorders, vestibular disorders, under medications or any inability to walk and stand without support were excluded from the study. All participants were recruited through flyers approved by the University's Institutional Review Board (IRB). All participants read and signed the informed consent and also filled out the physical activity readiness questionnaire (PAR-Q) to rule out any of the above mentioned health complications and cleared for participation in the study.

2.2. Instrumentation:

2.2.1. 3D Motion Capture:

Vicon Nexus (Oxford, UK) 3D motion capture system with 12 infra-red T-series cameras was used to collect and analyze kinematic gait data. A lower body plug-in gait model from the Helen-Hayes marker system was used as for the participant configuration model. The motion capture system was calibrated every day prior to data collection and the kinematic data was sampled at 100Hz and collected using the Vicon Nexus software. Of the 12 infra-red cameras, eight were mounted on the walls to create a larger capture volume and the remaining four cameras were placed on tripods and positioned in close proximity to the walking pathway focusing on the lower extremity and foot segment.

2.2.2. Force Plate:

Two force plates Bertec (Bertec Corporation, Columbus, OH) and AMTI (AMTI Force and Motion, Watertown, MA) embedded in the vinyl floored surface of the Applied Biomechanics Lab will be used to collect ground reaction forces. The force plates are positioned and set up in such a way that, during gait trials across the walkway, the right leg will strike the AMTI force plate and the left leg will strike the Bertec force plate. The force plate data is collected through the Vicon Nexus system as an analog device and sampled at 1000Hz.

2.2.3. Fall Arrest System:

A uni-track fall arrest system from Rigid Lines (Millington, TN); a lightweight horizontal rigid fall arrest track capable of supporting up to 900lb and installed with an inverted-U steel frame fixed to the laboratory floor was used as the safety fall arrest system to prevent any undesired falls. Participants were attached to the fall arrest track with the help of a back pack type harness system attaching to a moveable trolley inside the fall arrest track. The trolley was capable of locking itself without moving if there was greater than 50lb force imparted on the harness line. The fall arrest track and the harness along with the trolley were connected by a pulley system that allowed the investigators to move the trolley on top of the walking participant so that, the participants were not leading the trolley now was the trolley leading the participant. This was done to take away the closed kinematic chain between the participant and the fall arrest system and to minimize the impact of the harness and fall arrest system on the outcome of the slip events.

2.2.4. Slippery Agent or Contaminant:

Industrial vegetable based glycerol mixed with water in the ratio of 75% glycerol and 25% water was used as the slippery agent. The 75%-25% ratio was chosen for the study based on previous literature and with initial practice sessions in the laboratory prior to starting data collection. During the slip gait trials or slip events, glycerol was applied and evenly distributed on the Bertec force plate, on which the left leg of all participants, irrespective of their dominant extremity, would make contact during the gait trials. The application of the slippery agent was always performed by the primary investigator using the same measured and calibrated container to minimize the errors due to inter and intra rater reliability.

2.3. Experimental Procedures:

All participants visited the Applied Biomechanics Laboratory four times, separated by a minimum of 24 hours. A description of the experimental procedures for each visit is provided below.

2.3.1. Day 1:

The first visit was treated as a familiarization day, where all participants were exposed to the testing measures for gait trials and muscle activity. Informed consent was obtained from all participants following which they completed a physical activity readiness questionnaire (PAR-Q) and screened for any complications that might hinder them from completing the study. Anthropometric measurements such as height, weight, leg length, knee width, ankle width and foot/shoe size. Following this, participants were briefed on the walking gait conditions and were allowed to practice walking at their self-selected pace across the lab walkway. Participants were encouraged to walk at the same pace for every trial and their starting points were adjusted by the investigators to make sure there is clean contact with the dual force plates positioned in the middle of the walkway across the lab floor. Next the participants were positioned and strapped inside the harness connecting to the trolley and ultimately to the fall arrest track. Participants also performed the same practice gait trials with the harness while the investigators moved the trolley in-sequence along with the participant. A number of practice gait trials were performed until the subjects walked normally and with the same speed. Finally, the participants were assured of the fall arrest system catching them in the case of an undue fall, initiated by the slip. Participants were also asked to let go of their body weight and drop down on the harness system to further ensure that the fall arrest system would support their entire body weight and catch them preventing them hitting the floor, in the case of a slip. All participants were also asked to refrain from any physical workload especially to their lower extremities in terms of resistance or aerobic training and were also asked to avoid any pain medications until all their testing days were completed.

2.3.2. Day 2, Day 3 and Day 4:

Visits 2, 3 and 4 were again separated by a minimum of 24 hours and treated as experimental testing days. These experimental testing days followed the same testing protocol except with different alternative footwear (CC, FF & LT) which were chosen and provided to the participant using a counter balance design to remove order effects.

2.3.2.1. Participant Preparation:

Each visit will start the experimental testing day with a counter balanced allotment of the either the CC, FF or LT to the participants. Participants were also be provided black spandex shorts and t-shirts. Reflective markers were placed on the participant's lower extremity and on the footwear following a lower body plug-in gait model from the Helen-Hayes system.

2.3.2.2. Experimental Testing:

The experimental testing session began with the participant wearing the footwear given to them and had a series of practice gait trials across the vinyl floored testing surface under dry non slip conditions to get accustomed with the gait trials and the testing environment at a self-selected speed of walking. These practice gait trials were also used to make sure that the participants strike the center of the force plate with both their feet, unintentionally at their normal walking pattern and pace and to avoid any intentional modification of their step lengths during the data collection procedure.

Following the initial practice gait trials, the participants were strapped in the harness system to the fall arrest track and a static capture of the lower body plug-in model was performed. With the completion of the static capture, the participants again started a series of practice gait trials with the harness fall arrest system and the trolley being moved in-sequence with the participant. Practice trials were performed until the participants walked with ease in a similar pattern and with similar walking speed. Dynamic capture was done for 5 normal dry gait trials with no breaks or stops between the gait trials with the instruction "walk as normally as possible with the same speed". With the completion of the 5th normal dry gait trial, participants still walked with the same pattern and speed, but at the end of all further gait trials, the participants took 30-45 second breaks facing away from the walking surface and listened to music played on a noise-cancellation headphones, which would take away the knowledge of the potential slip trial, again with the same walking instructions.

Following a repeated number of gait trials under normal dry conditions, one particular trial was chosen randomly to be the unexpected slip (US) trial and the contaminant was applied to the force plate without the participant's knowledge. Participants were still given the same walking instruction to ensure that the walking trial will be treated as an unexpected slip event. On completion of the US, participants were allowed to rest briefly and the footwear removed for cleaning the contaminant. The force plate was also cleaned with a dry-wet vacuum and soap water and dried completely and made ready for the next gait trials. Participants then performed multiple normal dry gait trials with the same 30-45 second breaks and once a normal gait pattern resumed, participants were given the instruction that all of the following trials "may or may not be slippery". Multiple gait trials with the same protocol and instructions were performed in succession and one trial was randomly chosen to be the alert slip (AS) trial, where the contaminant was applied again without the knowledge of the participant, but differed from the US in terms of the instruction given to the participant. Finally, with the completion of NG, US and AS, participants visually saw the application of the contaminant on the force plate for one last walking trial and were given the instruction that the following trial "will be slippery" and treated as an expected slip (ES) trial.

2.4. Data Analysis:

The analog kinetic force plate measures and kinematic joint angles were analyzed using the Vicon Nexus software. The raw data was cleaned removing unlabeled markers, filled gaps in the markers using a spline fill and edited to have two gait cycles starting with the right leg. The raw data was filtered using a Butterworth fourth order filter with zero lag and exported as excel files for further analyses. Vicon Nexus software was used to determine the moment of heel strike and toe off phase of the left leg during the gait trials to determine the stance phase beginning and ending of the stance phase. The Ground Reaction Force in the Z direction (Z-GRF) from the Bertec force plate with left leg's stance phase was used for the kinetic measure. Mean Z-GRF and Peak Z-GRF were calculated from the exported excel files. The kinematic data was used to calculate relative joint angles for the ankle joint (dorsi-flexion/plantar flexion) angles (Ankle Angle) and for the hip joint (flexion/extension) angles (HipAngle) at heel strike. For the ankle angle, the foot vector is projected into the foot sagittal plane. The angle between the foot vector and the sagittal axis of the shank is the foot dorsi/plantar flexion. A positive number corresponds to dorsiflexion. Hip flexion is calculated about an axis parallel to the pelvic transverse axis which passes through the hip joint center. The sagittal thigh axis is projected onto the plane perpendicular to the hip flexion axis. Hip flexion is then the angle between the projected sagittal thigh axis and the sagittal pelvic axis. A positive (Flexion) angle value corresponds to the situation in which the knee is in front of the body.

2.5. ***Statistical Analysis:***

A Within-Subjects Repeated Measures of Analysis of Variance (Repeated Measures ANOVA) was performed to compare the three alternative footwear across the gait trials. Hence, a 3 x 4 [3 Footwear (CC, FF, LT) x 4 Gait Trials (NG, US, AS, ES)] Repeated Measures ANOVA was used to analyze the dependent kinetic variables of Mean Z-GRF and Peak Z-GRF; and the Ankle Angle and Hip Angle at heel strike individually for footwear x gait trial interaction and main effect significance. A Greenhouse Geisser correction was used if the Mauchly's test of sphericity was significant and if the assumption of sphericity was violated. The dependent variables were tested initially for the footwear x gait trial interaction, and if a significant interaction existed, the main effects of footwear and gait trials were ignored and pairwise comparisons of the simple main effects for the existing significant interaction was performed using the Sidak Bonferroni multiple comparisons correction. This was done for the both the independent variables individually to identify how the simple main effects of one factor differ over the levels of the other factor. For all analyses, alpha level was set a priori at p = 0.05 and all statistical analyses was performed using the SPSS 21 statistical software package.

3. Results:

The repeated measures ANOVA revealed significant interactions between footwear and gait trials for Mean Z-GRF and Ankle Angle. Significant interaction between footwear and gait trials existed for Mean Z-GRF at F (3.163, 53.766) = 4.236, $p = 0.008$, $\eta_p^2 = 0.199$ (Fig.1). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for Mean Z-GRF. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC between NG and US at $p = 0.019$; between NG and AS $p = 0.015$; and between NG and ES at $p = 0.0005$, with significantly greater Mean Z-GRF for NG compared to US, AS and ES; and for FF between NG and US at $p = 0.001$; between NG and AS $p = 0.011$; and between NG and ES at $p = 0.0005$, with significantly greater Mean Z-GRF for NG compared to US, AS and ES; for LT between NG and ES at p = 0.018, with significantly greater Mean Z-GRF for NG compared to ES. Pairwise comparisons for simple main effects for gait trials revealed significant differences for NG between CC and LT at $p = 0.008$, with significantly greater Mean Z-GRF for CC compared to LT; for US between CC and FF at $p = 0.02$ with significantly greater Mean Z-GRF for CC compared to FF; for AS between FF and LT at $p = 0.014$, with significantly greater Mean Z-GRF for LT compared to FF.

No significant differences existed for ES across all footwear. No significant footwear x gait trials interaction existed for Peak Z-GRF and for main effect in footwear. However, there was a significant difference in main effect for gait trials at F (3, 51) = 7.240, $p = 0.0005$, $\eta_p^2 = 0.299$ (Fig.2). Pairwise comparisons using a Bonferroni correction revealed significant differences between NG and AS p = 0.001 and between NG and ES at $p = 0.0005$, with significantly greater Peak Z-GRF for NG compared to AS and ES.

Significant interaction between footwear and gait trails existed for Ankle Angle at F (5.237, 89.034) = 2.403, p = 0.041, $\eta_p^2 = 0.124$ (Fig.3). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for Ankle Angle. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC between NG and US at p = 0.030, between NG and AS at p = 0.0005 and between NG and ES at p = 0.004, with significantly greater dorsi-flexion angle in NG compared to US, AS and ES; for FF between NG and AS at p = 0.010 and between NG and ES at p = 0.003, with significantly greater dorsi-flexion angle in NG compared to AS and ES. No significant differences existed for LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for NG between LT and CC at p = 0.0005 and between LT and FF at p = 0.0005, with significantly greater dorsiflexion angle in LT compared to both CC and FF; for US between LT and CC at p = 0.0005 and between LT and FF at p = 0.0005, with significantly greater dorsi-flexion angle in LT compared to both CC and FF; for AS between LT and CC at p = 0.0005 and between LT and FF at p = 0.0005, with significantly greater dorsi-flexion angle in LT compared to both CC and FF; for ES between LT and CC at p = 0.0005 and between LT and FF at p = 0.0005, with significantly greater dorsi-flexion angle in LT compared to both CC and FF. No significant differences existed between CC and FF for all gait trials. No significant footwear x gait trial interaction or significant difference for main effect footwear and main effect gait trials were found with Hip Angle (Fig.4).

4. *Discussion:*

The purpose of this study was to analyze the effect of alternative footwear, [Crocs with Clogs (CC), Flip-Flops (FF) and Low Top Slip Resistant Shoe (LT)] on lower extremity joint angles (Ankle Angle and Hip Angle) and ground reaction forces (Mean Z-GRF and Peak Z-GRF) during non-slip and slip gait trials [Normal Dry Gait (NG), Unexpected Slip (US), Alert Slip (AS) and Expected Slip (ES)]. The findings from the study demonstrate significant differences in both mean and peak vertical ground reaction forces during the stance phase and also in ankle angles at heel strike. On average, lower ground reaction forces were seen in all slip trials compared to normal dry surface gait. However, footwear differences were varied and were dependent upon the gait trial being either slippery or non-slippery. The LT appeared to maintain a normal dorsiflexion (close to neutral) ankle joint angle across all gait trials and alternative footwear exhibited a plantar flexed foot position across all gait trials with significantly greater plantar flexion in slip trials. The specific purpose of this paper is to analyze the impact of alternative footwear on lower extremity joint angles and ground reaction forces during slip events. The incidence of the slips and slip induced falls across different slip trials and across types of footwear are reported elsewhere, with significantly greater incidence of slips in alternative footwear (CC & FF) compared to LT and with significantly greater magnitude of slips in US followed by AS and ES compared to NG.

Significant interactions between footwear and gait trials existed for Mean Z-GRF and Ankle Angle at heel strike, suggesting the influence of both footwear and gait trial conditions in the outcome of lower extremity joint angles and ground reaction forces. Data from the current study demonstrated significantly lower mean and peak ground reaction forces for all slip trials (US, AS, ES) compared to the dry normal gait (NG) for all footwear, which explains the incomplete transfer of weight to the stance/support extremity during slips and slip induced falls. Individual footwear variations in each of the gait trial were varied where greater mean GRF was seen in CC compared to LT in NG and compared to FF in US. AS exhibited greater mean GRF in LT compared to FF, while no significant differences existed for ES, where slips were minimal irrespective of the footwear used and subsequently ground reaction forces were similar across all footwear during ES. Modifications in lower extremity gait kinematics appeared to be present only in the more distal ankle joint angles, while the more proximal hip joint angles showed no significant differences. Ankle angle at heel strike exhibited significant differences across all gait trials, where the LT had greater or more dorsi-flexion angle while both alternative footwear had more plantar flexion angle suggesting a flatter foot placement which may be attributed to a different "touch down geometry" associated with these alternative footwear (De Wit et al. 2000; Shroyer et al. 2010). The alternative footwear (CC & FF) also demonstrated greater plantar flexion angle at heel strike in the slip trials compared to the dry normal gait trial (NG) in an attempt to make contact with a more flatter foot position, and having a greater surface area of the foot and a lesser foot floor angle, thereby preventing slips and slip induced falls, while the LT, with lower incidence of slips, exhibited no differences across all gait trials. It also appeared that gait modifications due to nature of the slippery trial and footwear design characteristics were limited to the ankle joint, as the hip joint angles exhibited no significant differences across all footwear and all gait trials.

Extrinsic Factors – Impact of footwear design characteristics:

The footwear's geometrical design characteristics have been shown to affect human balance and gait (Chander et al. 2014; Perry, Radtke & Goodwin 2007; Menant et al. 2008; Menant et al. 2009; Divert et al. 2005; Bohm & Hosl 2010) and especially with the growing usage of alternative footwear such as the thong-styled flip flops and open-toed sandals, several studies have focused on their impact on the biomechanics of human gait (Zhang et al. 2013; Shroyer et al. 2010). The impact of flip flops on ground reaction forces reported from previous studies have shown an increased peak vertical ground reaction force in flip flops (Shakoor et al. 2010; Zhang et al. 2013) compared to other shod conditions and have attributed their findings to the reduced shock attenuation capabilities of the flip flops. The current study exhibited greater Mean Z-GRF in CC compared to LT, which again may be attributed to the lower shock attenuation capabilities of the crocs and the absence of a cushion type sole. Although the CC and FF had similar Mean Z-GRFs, significant differences were found only between CC and LT, but not between FF and LT. These findings were solely under dry normal gait conditions. The impact of these alternative footwear under slippery conditions is still unknown. The current study demonstrated significantly lower Mean Z-GRF for FF compared to CC in US and LT in AS, which may be attributed to the greater incidence of slips in FF with incomplete transfer of body weight to the lower extremity undergoing slips (Redfern et al. 2001), while individuals during the ES were able to minimize the slips and did not have significant differences between footwear. Across gait trials, both Mean and Peak Z-GRF were significantly lower in all slip trials compared to normal dry gait trial in all footwear conditions. The lower GRFs in slippery conditions can be related to the greater incidence of slips and due to the body weight not being completely transferred to the slipping extremity (Redfern et al. 2001) rather than to the design or geometric features of the footwear.

Existing literature on the ankle angle with alternative footwear is debatable with inconsistent findings (Zhang et al. 2013; Shroyer et al. 2010, Chard et al. 2013). Previous literature supporting an increased dorsiflexion angle at heel contact with alternative footwear have suggested it, as a mechanism to retain the flip flops during weight acceptance phase of the gait cycle (Chard et al. 2013), while studies supporting a greater plantar flexed angle or a more flatter foot placement with alternative footwear have suggested it, as a mechanism to grip the footwear using the toes (Shroyer et al. 2010; Zhang et al. 2013). Our results support Shroyer and Zhang's findings in demonstrating a greater plantar flexed angle or a more flat foot position at heel strike for normal dry surface gait and also for all slippery trials compared to LT shod condition.

Intrinsic Factors – Impact of perception and anticipation of slips:

The perception and anticipation of a slippery environment has been shown as a vital intrinsic factor in predicting the outcome of a slip event. The prior knowledge and anticipation of a slippery floor allows the individuals to reduce the potential slips by making adaptations to the biomechanics of gait (Cham & Redfern, 2002a; Lockhart et al. 2007). These gait adaptations which attempt to minimize the incidence of slips and slip induced falls include a shorter step length, a reduced foot floor angle and creating a more flat foot placement at heel strike and subsequently reducing the heel contact velocity, and also minimize the normal and shear forces during stance phase and thereby also lowering the required coefficient of friction when maneuvering slippery flooring conditions (Lockhart et al. 2007; Redfern et al. 2001; Cham and Redfern, 2002a; Moyer et al. 2006; Cham & Redfern, 2001). Based on the results from our study, the reduction in the ground reaction forces during the expected slip (ES) across all footwear can be attributed to these gait modifications that occur under slippery conditions. This was also evident by least number of slip incidences in the ES. However, the reduced Mean and Peak Z-GRF during the US cannot be treated as gait modifications. During these unexpected slippery gait trials the individuals had either no knowledge of the slippery flooring conditions and the highest incidence of slips. Hence, the reductions in the GRFs during US could only be attributed to the incomplete transfer of the body weight on to the supporting and slipping lower extremity (Redfern et al. 2001). The AS gait condition, provided the individuals with a warning of a slippery floor, but they were still unaware of which trial would be slippery. AS exhibited second highest incidence of slips followed by US. Hence, the reduction in the GRFs may be attributed to either one or both of the above mentioned reasons.

Previous studies have shown that a larger or a greater foot floor angle is directly related with slips and slip induced falls (Strandberg & Lanshammar, 1981; Moyer et al. 2006) and a reduced foot floor angle or a more flat foot position is utilized in the event of an anticipated slip (Cham & Redfern, 2002a). This was supported in our study, in which individuals utilized increasingly greater plantar flexion angle from US compared to AS compared to ES, in an attempt to minimize slips. Although, the design features and the touch down geometry were responsible for the alternative footwear to have greater plantar flexed joint angle during NG (De Wit et al. 2000), the increasing plantar flexion angle could be attributed to the gait modifications in an attempt to reduce slips. Decreasing the dorsiflexion angle and increasing the plantar flexion angle at heel contact increases the footwear-floor contact area at landing and attempt to minimize center of mass excursions outside the base of support and reducing the frictional requirements needed to prevent a slip (Gronqvist et al. 2001; Moyer et al. 2006). Contrary to the alternative footwear (CC & FF), the LT, just like other shod conditions which cover the complete foot and move as ne rigid segment, maintained similar dorsiflexion to neutral ankle angles at heel strike across all gait trials, as there was minimal need for gait modifications due to the slippery flooring conditions and subsequently, the LT had the almost minimal to no slip incidents across all gait trials.

5. Conclusion:

Based on the results from the current study, the interaction between the type of footwear and the gait trial conditions, contributed in determining the modifications in gait biomechanics during normal dry gait conditions due to the footwear design features and touch down geometry and during slippery flooring conditions, either during a slip or anticipating a slip. The GRFs during slip trials were lower compared to normal dry gait conditions across all footwear due to incomplete weight transfer on the slipping foot and in an attempt to minimize the required coefficient of friction and prevent slips, with anticipation of slips. It also appears that both alternative footwear (CC & FF) had plantar flexed, flat foot position angle at heel strike compared to LT both during normal dry gait and even greater plantar flexion angles in slip trials. The LT had better performance in preventing slips and given the conditions, the low top slip resistant shoe proves to be the choice of footwear for maneuvering slippery flooring conditions. Even though the alternative footwear serves for comfort and easy donning, it might not be the choice of footwear to prevent slips and slip induced falls. Future research should focus on the interactions of these alternative footwear and slippery conditions with physical workload, which is a common occurrence in occupational environments over the course of the work day.

Fig.1: Mean Z-Ground Reaction Force (N) during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

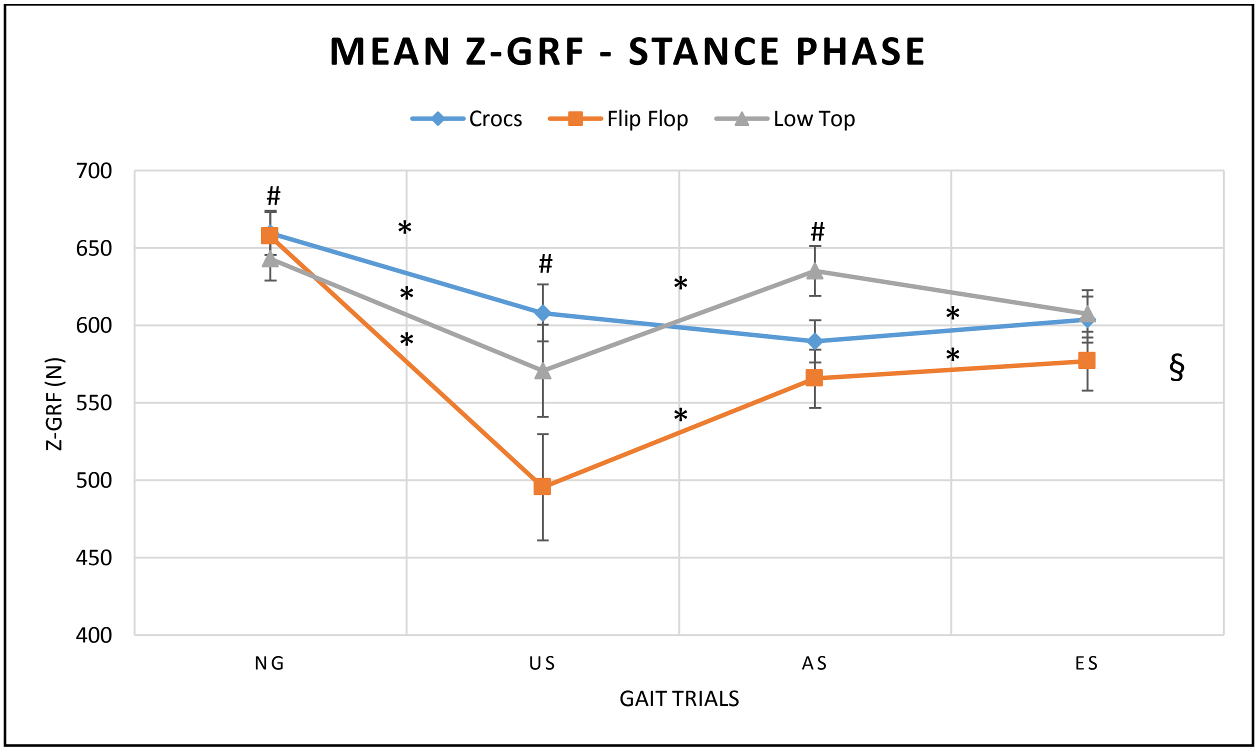
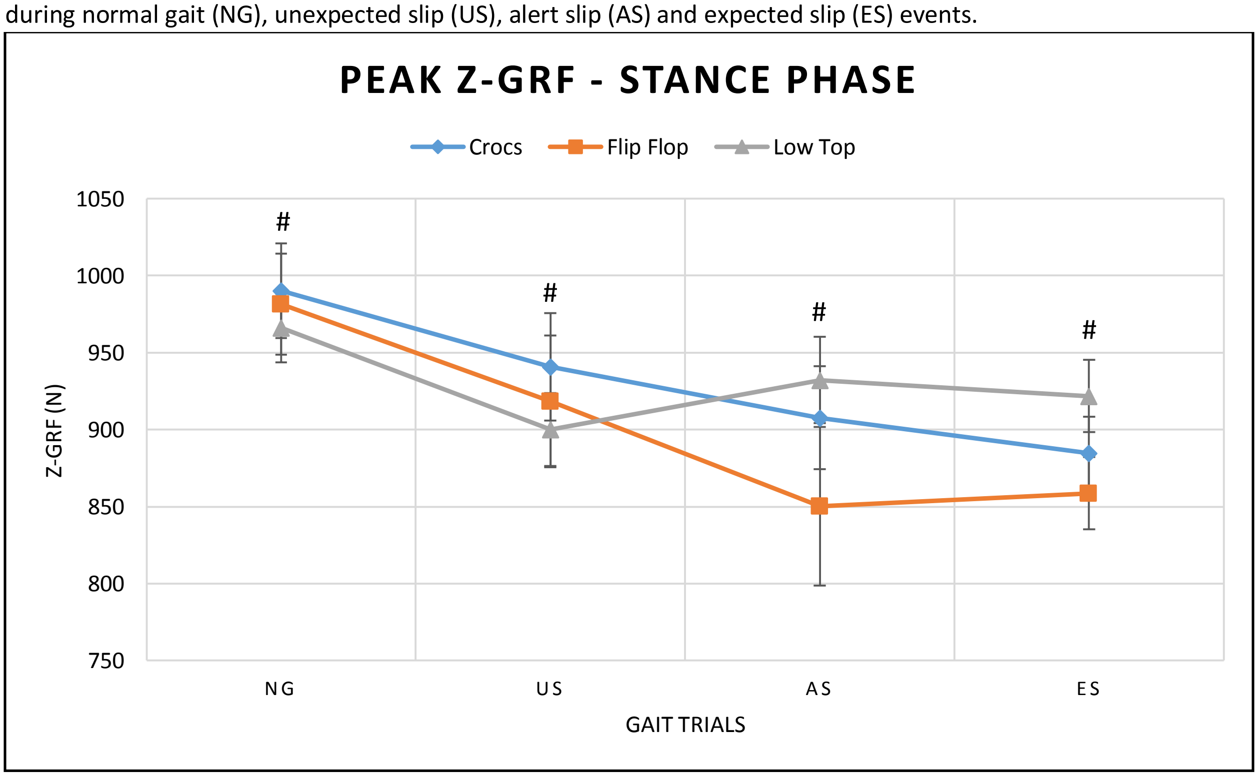


Fig.2: Peak Z-Ground Reaction Force (N) during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

Fig.3: Ankle angle (degrees) at heel strike for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal dry gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

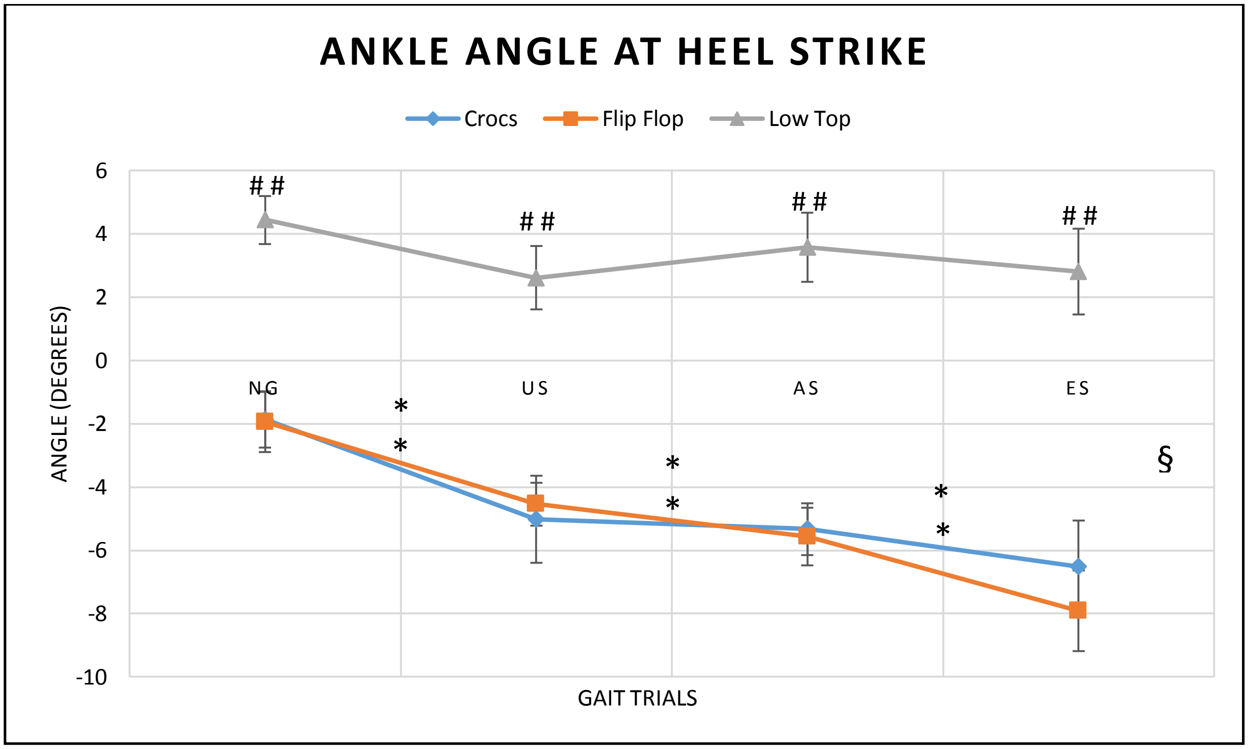
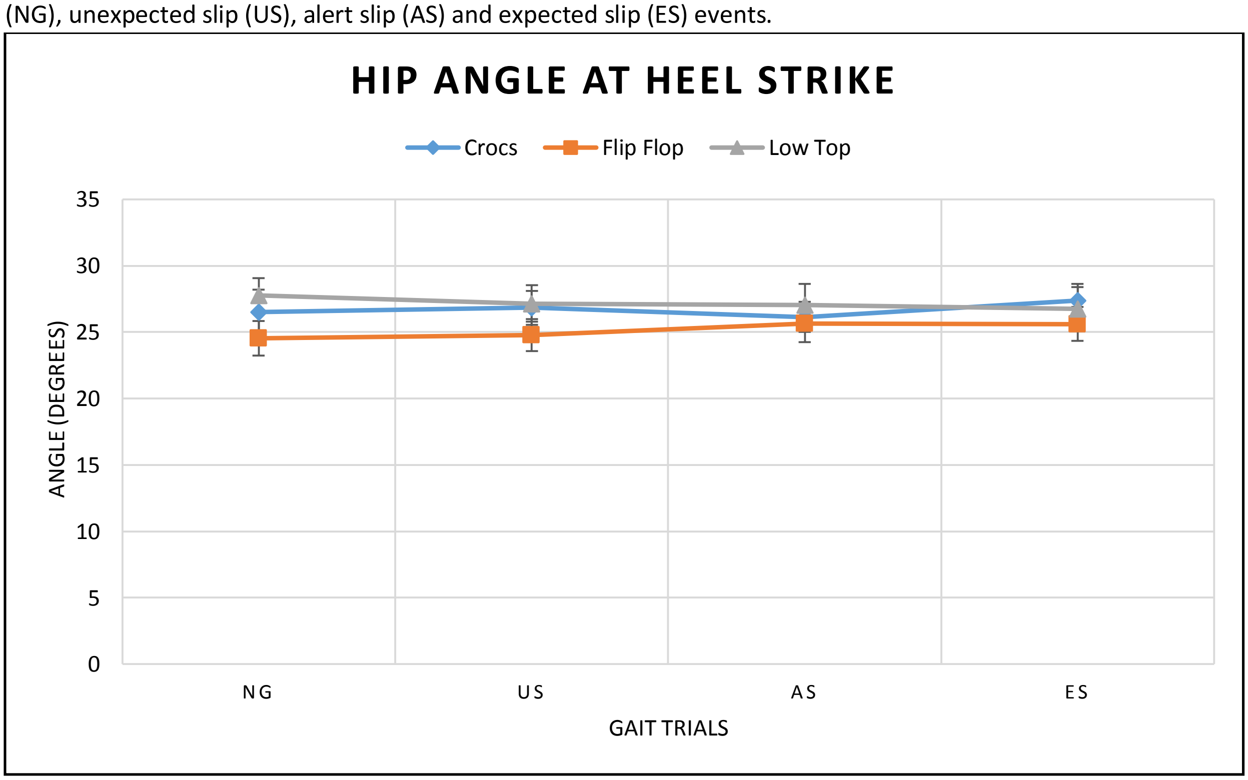


Fig.4: Hip Angle (degrees) at heel strike for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal dry gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

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MANUSCRIPT III

SLIP RELATED LOWER EXTREMITY MUSCLE ACTIVATION IN ALTERNATIVE FOOTWEAR

1. *Introduction:*

Slips, trips and falls occur as a result of failure of normal locomotion and failure of attempts at equilibrium recovery following an induced imbalance (Davis, 1983; Gauchard, 2001). The Bureau of Labor Statistics reported 15% of a total of 4,693 workplace fatalities and a total of 299,090 cases of non-fatal workplace injuries that were due to slips, trips and falls (BLS, 2011). The annual cost of workplace injuries due to slips, trips and falls in the United States was estimated to be over 6 billion US dollars with an expected cost of $43.8 billion by 2020 (Courtney et al, 2001a). In an occupational setting, postural instability can be hazardous due to an increased risk of falls, slips, trips and other accidents (Kincl et al, 2002). In addition to acute fall related injuries, overexertion injuries have very high incidences for slip induced falls and makes the effort of recovering from an induced slip very demanding (Courtney & Webster, 2001b).

Electromyography (EMG) analysis have been used to analyze neuromuscular mechanisms in human balance and gait. Muscle activity during normal human locomotion consists predominantly of isometric or eccentric muscle action of the lower extremity muscles that allows efficient storage and transfer of energy between limb segments with brief periods of high energy concentric muscle actions that help in forward motion of the body (Boakes & Rab, 2006). During unanticipated slips reactive strategies emerge which are defined as the primary corrective response brought about by muscular forces and corrective moments to re-establish dynamic balance following a slip. However, during an anticipated slip, proactive strategies are employed which are best described as the balance control mechanisms that occur prior to an impending slip (Chambers & Cham, 2007). Muscle activity from the lower extremity that are accountable for the reactive and proactive lower extremity moments are crucial factors in the human postural control system that are required both during a slip and for an impending slip.

EMG muscle activity under slippery conditions have been reported for lower extremity muscles such as the quadriceps, hamstrings and gastrocnemius-soleus (Lockhart, 2007; Parijat & Lockhart, 2008; Chambers & Cham, 2007). During slips, muscle activity from the lower extremity have been shown to be higher in magnitude and have longer activation periods (Tang et al. 1998; Tang et al. 1999; Ferber et al. 2002). A longer hamstring activity and a lower quadriceps activity during the stance phase and longer hamstring activity and decreased quadriceps mean activity during the swing phase was reported by Lockhart (Lockhart, 2007). Furthermore, lower mean and peak swing leg gastrocnemius activity was also reported during slippery conditions (Lockhart, 2007). Similar muscular responses were also seen under slip events when compared with young and old aged individuals, with a delayed latency from vastus lateralis activity in severe slips (Chamber & Cham, 2007). More commonly, corrective muscular responses have been shown to arise from the knee joint by producing large moments to help recover from a slip, whereas the hip joint seems to play a crucial role in stabilization (Parijat & Lockhart, 2007). Muscular activity during an alert or an expected slip resulted in a greater activation of the lower extremity musculature with the greatest increase in activity reported in the hamstrings and also with an early activation of the gastrocnemius muscle (Chambers & Cham, 2007). Greater muscle co-contraction analyzed with the co-contraction index (CCI) using the agonist / antagonist pairs of the ankle (tibialis anterior and medial gastrocnemius) and at the knee (vastus lateralis and medial hamstrings) were reported when anticipating a slippery surface and individuals who walked with a greater co-contraction were predisposed to experience less severe slips (Chambers & Cham, 2007).

Furthermore, different types of footwear have shown to impact normal balance and gait mechanisms (Chander et al. 2014; Perry, Radtke & Goodwin 2007; Menant et al. 2008; Menant et al. 2009; Divert et al. 2005; Bohm & Hosl 2010) and improper alignment of the foot due to the geometrical design characteristics of the footwear can lead to an increased metabolic cost, thereby potentially leading to a faster rate of development of muscular fatigue. More efficient walking patterns could possibly delay the onset of fatigue as physical activity progresses (Hanson et al. 2011). Certain commonly worn footwear, such as slippers were found to be hazardous as they slowed down reactions to perturbations and also had adverse effects on posture reactions (Hosoda et al., 1997). It is also suggested that wearing alternative footwear such as flip flops, sandals and crocs, which do not secure the hind foot and does not move with the foot as one rigid segment, decreases an individual's movement ability (Robinson et al. 2011) and may increase the required muscle activity from the lower extremity.

Although there is an increasing amount of literature assessing the impact of different types of footwear, including alternative footwear on human locomotion, there is still dearth of literature on the impact of these footwear on slippery conditions. Moreover the existing literature on alternative footwear have focused on the gait kinematics and kinetics. The specific purpose of this study was to analyze the impact of alternative footwear [Crocs with clogs (CC), Flip-Flops (FF) and Low Top Slip Resistant Shoe (LT)] under multiple gait conditions [Dry normal surface (NG); Unexpected Slip (US), Alert Slip (AS) and Expected Slip (ES)] on lower extremity muscle activity [Vastus Medialis (VM), Medial Hamstrings (MH), Tibialis Anterior (TA) and Medial Gastrocnemius (MG)]. Based on previous literature, we hypothesized that the alternative footwear (CC & FF) would demonstrate greater muscle activity compared to LT both during normal dry gait conditions and slippery gait conditions. We also hypothesized that the slippery conditions (US, AS & ES) will demonstrate greater muscle activity compared to the normal dry gait condition (NG).

2. Methodology:

The purpose of the study was to examine muscle activity during the stance phase of the gait cycle and also to analyze the maximal voluntary isometric contraction. Muscle activity from four lower extremity muscles were compared across the three alternative footwear [Crocs with clogs (CC), Flip-Flops (FF) & Low Top Slip Resistant Shoe (LT)] under four gait conditions [(Normal Dry Gait (NG), Unexpected Slip (US), Alert Slip (AS) & Expected Slip (ES)] using a within subjects repeated measures design.

2.1. Participants:

Eighteen healthy male participants [Age: 22.28 ± 2.2 years; Height: 177.66 ± 6.9 cm; Mass: 79.27 ± 7.6 kg] completed the study. Participants who had any history of musculoskeletal injuries, cardio-vascular abnormalities, neurological disorders, vestibular disorders, under medications or any inability to walk and stand without support were excluded from the study. All participants were recruited through flyers approved by the University's Institutional Review Board (IRB). All participants read and signed the informed consent and also filled out the physical activity readiness questionnaire (PAR-Q) to rule out any of the above mentioned health complications and cleared for participation in the study.

2.2. Instrumentation:

2.2.1. Electromyography:

Electromyography (EMG) data was collected using the NoraxonTelemyo DTS 900 system (Scottsdale, AZ) through the Vicon (Oxford, UK) Nexus software. The data was sampled at 1000Hz and an EMG pipeline was used to analyze the raw data. Vicon Nexus (Oxford, UK)

3D motion capture system with 12 infra-red T-series cameras was used to collect and analyze kinematic gait data using the lower body plug-in gait model from the Helen-Hayes marker system along with the analog EMG data. The motion capture system was calibrated every day prior to data collection and the kinematic data was sampled at 100Hz and collected using the Vicon Nexus software.

2.2.2. Fall Arrest System:

A uni-track fall arrest system from Rigid Lines (Millington, TN); a lightweight horizontal rigid fall arrest track capable of supporting up to 900lb and installed with an inverted-U steel frame fixed to the laboratory floor was used as the safety fall arrest system to prevent any undesired falls. Participants were attached to the fall arrest track with the help of a back pack type harness system attaching to a moveable trolley inside the fall arrest track. The trolley was capable of locking itself without moving if there was greater than 50lb force imparted on the harness line. The fall arrest track and the harness along with the trolley were connected by a pulley system that allowed the investigators to move the trolley on top of the walking participant so that, the participants were not leading the trolley now was the trolley leading the participant. This was done to take away the closed kinematic chain between the participant and the fall arrest system and to minimize the impact of the harness and fall arrest system on the outcome of the slip events.

2.2.3. Slippery Agent or Contaminant:

Industrial vegetable based glycerol mixed with water in the ratio of 75% glycerol and 25% water was used as the slippery agent. The 75%-25% ratio was chosen for the study based on previous literature and with initial practice sessions in the laboratory prior to starting data collection. During the slip gait trials or slip events, glycerol was applied and evenly distributed on the Bertec force plate, on which the left leg of all participants, irrespective of their dominant extremity, would make contact during the gait trials. The application of the slippery agent was always performed by the primary investigator using the same measured and calibrated container to minimize the errors due to inter and intra rater reliability.

2.3.Experimental Procedures:

All participants visited the Applied Biomechanics Laboratory four times, separated by a minimum of 24 hours. A description of the experimental procedures for each visit is provided below.

2.3.1. Day 1:

The first visit was treated as a familiarization day, where all participants were exposed to the testing measures for gait trials and muscle activity. Informed consent was obtained from all participants following which they completed a physical activity readiness questionnaire (PAR-Q) and screened for any complications that might hinder them from completing the study. Anthropometric measurements such as height, weight, leg length, knee width, ankle width and foot/shoe size. Following this, participants were briefed on the walking gait conditions and were allowed to practice walking at their self-selected pace across the lab walkway. Participants were encouraged to walk at the same pace for every trial and their starting points were adjusted by the investigators to make sure there is clean contact with the dual force plates positioned in the middle of the walkway across the lab floor. Next the participants were positioned and strapped inside the harness connecting to the trolley and ultimately to the fall arrest track. Participants also performed the same practice gait trials with the harness while the investigators moved the trolley in-sequence along with the participant. A number of practice gait trials were performed until the subjects walked normally and with the same speed. Finally, the participants were assured of the fall arrest system catching them in the case of an undue fall, initiated by the slip. Participants were also asked to let go of their body weight and drop down on the harness system to further ensure that the fall arrest system would support their entire body weight and catch them preventing them hitting the floor, in the case of a slip. All participants were also asked to refrain from any physical workload especially to their lower extremities in terms of resistance or aerobic training and were also asked to avoid any pain medications until all their testing days were completed.

2.3.2. Day 2, Day 3 and Day 4:

Visits 2, 3 and 4 were again separated by a minimum of 24 hours and treated as experimental testing days. These experimental testing days followed the same testing protocol except with different alternative footwear (CC, FF & LT) which were chosen and provided to the participant using a counter balance design to remove order effects.

2.3.2.1.Participant Preparation:

Each visit will start the experimental testing day with a counter balanced allotment of the either the CC, FF or LT to the participants. Participants were also provided black spandex shorts and t-shirts. EMG bipolar electrodes were placed with an inter-electrode distance of 2cm on the muscle belly of VastusMedialis (VM), Medial Hamstrings (MH), Tibialis Anterior (TA) and Medial Gastrocnemius (MG) with a ground electrode on the tibial tuberosity on the left leg. The electrode placement surface area was prepped adequately to minimize skin resistance by shaving hairy surfaces and scrubbing with alcohol rubs. In addition, reflective markers were placed on the participant's lower extremity and on the footwear following a lower body plug-in gait model from the Helen-Hayes system.

2.3.2.2.Experimental Testing:

The experimental testing session began with the participant wearing the footwear given to them and had a series ofpractice gait trials across the vinyl floored testing surface under dry non-slip conditions to get accustomed with the gait trials and the testing environment at a self-selected speed of walking. These practice gait trials were also used to make sure that the participants strike the center of the force plate with both their feet, unintentionally at their normal walking pattern and pace and to avoid any intentional modification of their step lengths during the data collection procedure. Isometric Maximal Voluntary Contractions (MVCs) of VM, MH, TA and MG were collected for 3 trails of 5 second isometric contractions performed in the middle range of motion of the ankle and knee joints. The participants were asked to rest for 5 minutes after the MVC protocol to avoid undue lower extremity muscular fatigue.

Following the initial practice gait trials, the participants were strapped in the harness system to the fall arrest track and a static capture of the lower body plug-in model was performed. With the completion of the static capture, the participants again started a series of practice gait trials with the harness fall arrest system and the trolley being moved in-sequence with the participant. Practice trials were performed until the participants walked with ease in a similar pattern and with similar walking speed. Dynamic capture was done for 5 normal dry gait trials with no breaks or stops between the gait trials with the instruction “walk as normally as possible with the same speed”. With the completion of the 5th normal dry gait trial, participants still walked with the same pattern and speed, but at the end of all further gait trials, the participants took 30-45 second breaks facing away from the walking surface and listened to music played on a noise-cancellation headphones, which would take away the knowledge of the potential slip trial, again with the same walking instructions.

Following a repeated number of gait trials under normal dry conditions, one particular trial was chosen randomly to be the unexpected slip (US) trial and the contaminant was applied to the force plate without the participant's knowledge. Participants were still given the same walking instruction to ensure that the walking trial will be treated as an unexpected slip event. On completion of the US, participants were allowed to rest briefly and the footwear removed for cleaning the contaminant. The force plate was also cleaned with a dry-wet vacuum and soap water and dried completely and made ready for the next gait trials. Participants then performed multiple normal dry gait trials with the same 30-45 second breaks and once a normal gait pattern resumed, participants were given the instruction that all of the following trials "may or may not be slippery". Multiple gait trials with the same protocol and instructions were performed in succession and one trial was randomly chosen to be the alert slip (AS) trial, where the contaminant was applied again without the knowledge of the participant, but differed from the US in terms of the instruction given to the participant. Finally, with the completion of NG, US and AS, participants visually saw the application of the contaminant on the force plate for one last walking trial and were given the instruction that the following trial "will be slippery" and treated as an expected slip (ES) trial.

2.4.Data Analysis:

The analog EMG measures were analyzed using the Vicon Nexus software. The raw data was cleaned removing unlabeled markers, filled gaps in the markers using a spline fill and edited to have two gait cycles starting with the right leg. The raw data was filtered using a Butterworth fourth order filter with zero lag with cut off frequency of 300Hz and exported as excel files for further analyses. Vicon Nexus software was used to determine the moment of heel strike and toe off phase of the left leg during the gait trials to determine the stance phase beginning and ending of the stance phase. The raw muscle activity data from the four left lower extremity muscles (VM, MH, TA and MG) were rectified and used to calculate Mean Muscle Activity during MVCs(mV) (VM MVC, MH MVC, TA MVC and MG MVC) , Mean Muscle Activity (mV) (Mean VM, Mean MH, Mean TA and Mean MG), Peak Muscle Activity (mV)(Peak VM, Peak MH, Peak TA and Peak MG) and %MVC (%MVC VM, %MVC MH, % MVC TA and %MVC MG) during the stance phase of the gait cycle.

2.5. ***Statistical Analysis:***

A Within-Subjects Repeated Measures of Analysis of Variance (Repeated Measures ANOVA) was performed to compare the three alternative footwear across the gait trials. Hence, a 3 x 4 [3 Footwear (CC, FF, LT) x 4 Gait Trials (NG, US, AS, ES)] Repeated Measures ANOVA was used to analyze the dependent EMG variablesof Mean Muscle Activity (Mean VM, Mean MH, Mean TA and Mean MG), Peak Muscle Activity (Peak VM, Peak MH, Peak TA and Peak MG) and %MVC (%MVC VM, %MVC MH, % MVC TA and %MVC MG) individually for footwear x gait trial interaction and main effect significance. A 1 x 4 [1 Time x 3 Footwear (CC, FF, LT)] Repeated Measures of ANOVA was performed to compare MVCs of four muscles (VM, MH, TA, MG) across all three footwear. A Greenhouse Geisser correction was used if the Mauchly's test of sphericity was significant and if the assumption of sphericity was violated. The dependent variables were tested initially for the footwear x gait trial interaction, and if a significant interaction existed, the main effects of footwear and gait trials were ignored and pairwise comparisons of the simple main effects for the existing significant interaction was performed using the BonferroniSidak multiple comparisons correction. This was done for the both the independent variables individually to identify how the simple main effects of one factor differ over the levels of the other factor. For all analyses, alpha level was set a priori at p = 0.05 and all statistical analyses was performed using the SPSS 21 statistical software package.

3. Results:

The 3x4 within subjects repeated measures ANOVA revealed significant interactions between footwear and gait trials for Mean Muscle activity (Mean VM, Mean MH & Mean TA). Significant interaction between footwear and gait trials existed for Mean VM at F (3.598, 61.171) = 5.662, p = 0.001, η_p^2= 0.250 (Fig.1). Pairwise comparisons using the BonferroniSidak correction was performed to analyze the simple main effects across both factors of footwear and gait trials for Mean VM. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC between NG and US at p = 0.001 and between NG and ES p = 0.031, with significantly lower Mean VM during NG compared to US and ES;and between US and ES at p = 0.028, with significantly lower Mean VM during ES compared to US; for FFbetween NG and US at p = 0.0005 and between NG and AS p = 0.015, with significantly lower Mean VM during NG compared to both US and AS;and between US and ES at p = 0.015, with significantly lowerMean VM duringES compared to US.No significant differences existed for LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for US between CC and LT at p = 0.012, and between FF and LT at p = 0.001, with significantly lower Mean VM for LT compared to CC and FF; for AS between FF and LT at p = 0.001, with significantly lower Mean VM for LT compared to FF. No significant differences existed for NG and ES across all footwear.

Significant interaction between footwear and gait trials existed for Mean MH at F (4.381, 74.476) = 2.661, p = 0.035, η_p^2= 0.135 (Fig.2). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for Mean MH. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC between NG and US at $p = 0.006$ and between NG and ES at $p = 0.001$, with significantly lower Mean MH during NG compared to US and ES; for FFbetween NG and US at $p = 0.0005$, between NG and AS $p = 0.001$ and between NG and ES at p = 0.028, with significantly lower Mean MH during NG compared to US, AS and ES; for LT between NG and US at $p = 0.015$, with significantly lower Mean MH during NG compared to US. No significant differences existed for LT between NG, AS and ES. Pairwise comparisons for simple main effects for gait trials revealed significant differences for US between FF and LT at $p = 0.0005$, with significantly lower Mean MH in LT compared to FF; for AS between FF and LT at $p = 0.024$, with significantly lower Mean MH for LT compared to FF. No significant differences existed for NG and ES across all footwear.

Significant interaction between footwear and gait trials existed for Mean TA at $F(2.451, 41.667) = 3.876$, $p = 0.022$, $\eta_p^2 = 0.186$ (Fig.3). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for Mean TA. Pairwise comparisons for simple main effects for footwear revealed significant differences for FFbetween NG and US at $p = 0.0005$ and between NG and AS $p = 0.005$, with significantly lower Mean MH during NG compared to US and AS; and between US and ES at $p = 0.002$, with significantly lower Mean MH during ES compared to US. No significant differences existed for CC and LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for US between FF and LT at $p = 0.001$, with significantly lower Mean TA in LT compared to FF; for AS between FF and LT at $p = 0.006$, with significantly lower Mean TA for LT compared to FF. No significant differences existed for NG and ES across all footwear. No significant footwear x gait trials interaction existed for Mean MG and no main effect for gait trials was found. However, significant main effect for footwear existed at F (2, 34) = 4.972, p = 0.013, η_p^2= 0.226 (Fig.4). Pairwise comparisons with a Bonferroni correction revealed significant differences between CC and FF at p = 0.006 and between LT and FF at p = 0.038, with significantly lower Mean MG for CC and LT compared to FF.

The 3x4 within subjects repeated measures ANOVA revealed significant interactions between footwear and gait trials for Peak Muscle Activity (Peak VM, Peak MH & Peak TA). Significant interaction between footwear and gait trials existed for Peak VM at F (2.869, 48.766) = 4.686, *p* = 0.0005, η_p^2= 0.216 (Fig.5). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for Peak VM. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC between NG and US at *p* = 0.035; for FF between NG and US at *p* = 0.006 and between US and ES at *p* = 0.020, with significantly lower Peak VM during NG and ES compared to both US. No significant differences existed for LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for US between CC and LT at *p* = 0.040, and between FF and LT at p = 0.002, with significantly lower Peak VM for LT compared to CC and FF; for AS between FF and LT at p = 0.028, with significantly lower Peak VM for LT compared to FF. No significant differences existed for NG and ES across all footwear.

Significant interaction between footwear and gait trials existed for Peak MH at F (3.362, 57.157) = 3.020, *p* = 0.035, η_p^2= 0.151 (Fig.6). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for Peak MH. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC between NG and US at $p = 0.005$, between NG and AS at $p = 0.022$, between NG and ES at p = 0.020 with significantly lower Peak MH during NG compared to US, AS and ES; for FF between NG and US at $p = 0.0005$, between NG and AS $p = 0.003$ and between NG and ES at $p = 0.033$, with significantly lower Peak MH during NG compared to US, AS and ES. No significant differences existed for LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for US between FF and LT at $p = 0.001$, with significantly lower Peak MH in LT compared to FF; for AS between FF and LT at $p = 0.009$, with significantly lower Peak MH for LT compared to FF. No significant differences existed for NG and ES across all footwear.

Significant interaction between footwear and gait trials existed for Peak TA at $F(3.400, 57.801) = 5.661$, $p = 0.001$, $\eta_p^2 = 0.250$ (Fig.7). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for Peak TA. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC between NG and US at $p = 0.047$, and between US and AS $p = 0.027$, with significantly lower Peak TA during NG and ES compared to US; for FF between NG and US at p = 0.0005 and between NG and AS at p = 0.003, with significantly lower Peak TA during NG compared to both US and AS, and between US and ES at p = 0.013, with significantly lower Peak TA during ES compared to US. No significant differences existed for LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for US between FF and LT at $p = 0.005$, with significantly lower Peak TA in LT compared to FF; for AS between FF and LT at $p = 0.032$, with significantly lower Peak TA for LT compared to FF. No significant differences existed for NG and ES across all footwear. No significant footwear x gait trials interaction existed for Peak MG and no main effect for gait trials was found. However, significant main effect for footwear existed at F (2, 34) = 6.847, p = 0.003, η_p^2= 0.287 (Fig.8). Pairwise comparisons with a Bonferroni correction revealed significant differences between CC and FF at p = 0.006 and between LT and FF at p = 0.006, with significantly lower Peak MG for CC and LT compared to FF.

The 3x4 within subjects repeated measures ANOVA revealed significant interactions between footwear and gait trials for %MVC (%MVC VM and %MVC TA). Significant interaction between footwear and gait trials existed for %MVC VM at F (2.346, 39.890) = 2.979, p = 0.045, η_p^2= 0.149 (Fig.9). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for %MVC VM. Pairwise comparisons for simple main effects for footwear revealed significant differences for FF between NG and US at p = 0.041, with significantly lower %MVC VM during NG compared to US. No significant differences existed for CC and LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for US between FF and LT at p = 0.041, with significantly lower %MVC VM for LT compared to FF. No significant differences existed for NG, AS and ES across all footwear. No significant footwear x gait trial interaction existed for %MVC MH and no significant difference existed for main effect footwear. However, there was a significant difference for main effect gait trials at F (2.061, 35.031) = 9.433, p = 0.0005, η_p^2= 0.357 (Fig.10). Pairwise comparisons with a Bonferroni correction revealed significant differences between NG and US at p = 0.002 and between NG and AS at p = 0.0005, with NG significantly lower % MVC MH during NG compared to US and AS.

Significant interaction between footwear and gait trials existed for %MVC TA at F (2.739, 46.565) = 4.710, p = 0.007, η_p^2= 0.217 (Fig.11). Pairwise comparisons using the Sidak Bonferroni correction was performed to analyze the simple main effects across both factors of footwear and gait trials for %MVC TA. Pairwise comparisons for simple main effects for footwear revealed significant differences for CC between NG and US at $p = 0.039$, with significantly lower %MVC TA during NG compared to US; for FF between NG and US at p = 0.001 and between US and AS at p = 0.005, with significantly lower %MVC TA during NG and ES compared to US. No significant differences existed for LT across all gait trials. Pairwise comparisons for simple main effects for gait trials revealed significant differences for US between FF and LT at $p= 0.007$, with significantly lower %MVC TA in LT compared to FF. No significant differences existed for NG, AS and ES across all footwear. No significant footwear x gait trials interaction existed for %MVC MG and no main effect for footwear was found. However, significant main effect for gait trials existed at F (2.065, 35.099) = 4.140, p = 0.023, $\eta_p^2= 0.196$ (Fig.12). Pairwise comparisons with a Bonferroni correction did not reveal significant differences between footwear. The 1x4 within subjects repeated measures ANOVA revealed no significant differences across CC, FF and LT for maximal voluntary contractions (MVCs) for all four lower extremity muscles (MVC VM, MVC MH, MVC TA and MVC MG) (Fig.13).

4. Discussion:

The purpose of this study was to analyze the effect of alternative footwear, [Crocs with Clogs (CC), Flip-Flops (FF) and Low Top Slip Resistant Shoe (LT)] on lower extremity muscle activity [EMG Mean (Mean VM; Mean MH, Mean TA & Mean MG), Peak (Peak VM, Peak MH, Peak TA & Peak MG) and % Maximal Voluntary Contraction (MVC) (%MVC VM, %MVC MH, %MVC TA & %MVC MG)] during non-slip and slip trials [Normal Dry Gait (NG), Unexpected Slip (US), Alert Slip (AS) and Expected Slip (ES)]. Significant interactions between footwear and gait trials existed for Mean, Peak, %MVC for VM and TA, Mean and Peak for MH, suggesting the influence of both footwear and gait trial conditions in the outcome of lower extremity muscle activity. The knee extensors and flexors (VM and MH) and ankle dorsi flexor muscle (TA) demonstrated very similar muscle activation patterns across footwear and across gait trials. Our results indicated significant differences in mean and peak muscle activity and %MVC across all gait trials for the alternative footwear (CC & FF), while the LT had no significant differences across all gait trials either non-slip or slip trials, except for one variable (Mean MH). On average, a greater magnitude of lower extremity muscle activity was seen in the slip trials, particularly the US and AS. The ES demonstrated similar muscle activity as the NG with no significant differences between them, suggesting that the individuals did not alter their muscle activity to maneuver an expected slippery flooring condition.

The alternative footwear (CC & FF), particularly the FF, exhibited greater muscle activity compared to the LT, during US and AS. The LT appeared to have the best performance in terms of low levels of muscle activity, both during non-slip and slippery gait trials with no significant differences across these gait trials. Main effect significance in footwear for Mean and Peak MH and main effect significance in gait trials for %MVC MH also existed, indicating a greater magnitude of muscle activation during US and AS, in an attempt to recover from an induced slip, while LT and CC had similar and significantly lower muscle activation compared to FF which may attributed to the footwear design features rather than the slip recovery, as they denote merely a main effect significance for footwear. The specific purpose of this paper is to analyze the impact of alternative footwear on lower extremity muscle activity during slip events. The incidence of the slips and slip induced falls across different slip trials and across types of footwear are reported elsewhere, with significantly greater incidence of slips in alternative footwear (CC & FF) compared to LT and with significantly greater magnitude of slips in US followed by AS and ES compared to NG. Furthermore, it has been previously reported that footwear with elevated boot shafts that support the ankle may improve static balance performance (Chander et al. 2014) and that it may restrict joint range of motion and may hinder muscle activity around the ankle joint plantar flexors and dorsi-flexors (Chander et al. 2013). The MVCs from the four lower extremity muscles demonstrated no significant differences, supporting previous literature, as the footwear tested in this study did not have elevated boot shafts and did not hinder muscle activity.

Extrinsic Factors – Impact of footwear design characteristics:

The footwear's geometrical design characteristics have been shown to affect human balance and gait (Chander et al. 2014; Perry, Radtke & Goodwin 2007; Menant et al. 2008; Divert et al. 2005; Bohm & Hosl 2010) and especially with the growing usage of alternative footwear such as the thong-styled flip flops and open-toed sandals, several studies have focused on their impact on the biomechanics of human gait (Zhang et al. 2013; Shroyer et al. 2010a; Shroyer et al. 2010b). Footwear serves as the interface between the human body and the supporting surface and can affect human balance and gait adversely (Menant et al. 2008). Efficient transformation of the mechanical power output produced by the musculoskeletal system through the footwear is responsible for a good performance in gait. Hence, the design and type of the footwear becomes important in gait and posture (Bohm & Hosl, 2010). Based on the results from the current study, the footwear worn did not seem to affect any of the lower extremity muscles, during baseline dry normal surface gait and expected slip conditions. No significant differences were seen during NG and ES across all footwear. However, during US and AS conditions, footwear differences affected the amount of muscle activity required to recover from slips. FF appeared to have the greatest amount of muscle activity, followed by CC and finally the LT, requiring the least amount of muscle activity, emphasizing its better performance with the lowest incidence of slips and being efficient in requiring minimal muscle activity. The LT exhibited the least Mean, Peak and

%MVC for VM, MH, TA and MG compared to the both alternative footwear (CC & FF) and across all gait trials. Although modifications in gait kinematics have been reported with use of alternative footwear (Zhang et al. 2013; Shroyer et al. 2010, Chard et al. 2013), the current study did not reveal differences in lower extremity stance phase during normal dry gait. However, the alternative footwear exhibited greater muscle activity and were least efficient during US and AS, while the LT proved to be the choice of footwear while maneuvering slippery flooring conditions.

Intrinsic Factors – Impact of perception and anticipation of slips:

Muscle activation during unexpected and anticipated slips have been studied previously (Lockhart et al. 2007; Chambers & Cham, 2007). The results from the current study support previous findings from Chambers & Cham, who reported a longer duration and great power muscle activity during hazardous slips compared to non-hazardous slips. Mean and Peak muscle activity from VM, MH and TA exhibited similar patterns of activation, with greater magnitude muscle activity in stance phase during US and AS, which represent the gait trials with a greater incidence of slips, compared to NG and ES. The recovery from a slip has been usually related muscular response strategies from the knee and hip muscles with relatively less responses from the ankle (Redfern et al. 2001; Chambers & Cham, 2007). The greater magnitude of the knee/upper leg muscles (VM and MH) could be related to the required muscle activity to recover from the slips during US. The increased activity in VM may be attributed to the need for moving the body center of mass over the base of support and accelerate the limb loading rate while the increased activity in MH may be attributed to the knee flexion moment that is often reported with anticipation, during AS (Chamber & Cham, 2007). In addition, the greater activation of both the knee flexors and extensors may suggest a co-contraction between the agonist-antagonist pair of muscles. Contrastingly, the lower leg muscles (TA and MG) did not exhibit similar patterns as the upper leg musculature. The TA exhibited greater muscle activity in stance phase of slippery gait trials, while there were no differences in MG muscle activity across trials. The increased activity in TA during early stance phase have been related to a delayed achievement of foot-flat, which has been reported as an important aspect in slip recovery and gait continuation (Cham & Redfern, 2002a) while, a null ankle moment during severe slips were also reported (Cham & Redfern, 2001). In the current study, the increased activity in TA was seen only in US and AS, which may be due to the reverse origin action of the TA to limit the forward movement of the foot and the leg after the initiation of the slip. The MG did not show an increased muscle activity in stance phase, for slip trials which may be attributed to the decreased stance phase push-off needed during a slip event.

Alerting the participants of the possibility of a slippery surface (AS) also resulted in an increased Mean, Peak and %MVC for VM, MH and TA, supporting previous literature (Chambers & Cham, 2007). The anticipation of the slippery flooring condition during the ES condition, exhibited similar muscle activity levels as the NG condition. The incidence of slips in the ES was significantly lower and suggests no extra requirement of muscle activity from the NG. Chambers & Cham, also reported greater levels of co-contraction between the agonist and antagonist pairs of lower extremity flexors and extensors during an expected slip (Chambers & Cham, 2007). Our study did not account for co-contractions in this paper, but reports mean, peak and %MVC lower extremity muscle activity that were not different from the baseline dry normal surface gait, suggesting modifications in the gait kinematics rather than modifications in lower extremity muscle activity.

5. Conclusion:

In conclusion, greater lower extremity muscle activation in stance phase were seen in unexpected and alert slip conditions compared to normal dry gait and expected slip. The results also indicate that individuals did not use greater magnitude of lower extremity muscle activity during an ES and did not rely on muscle activity in an attempt to reduce slips. Differences in gait kinematics have been reported previously with alternative footwear, however, based on the results from this study, during the normal dry conditions, muscle activity was not significantly different across footwear. In addition, footwear differences were seen for the alternative footwear (CC & FF) during US and AS, while the low top slip resistant shoe had no differences across all gait trials, suggesting it as the most efficient footwear of choice especially when maneuvering slippery flooring conditions, either with or without the knowledge of an impending slip. Even though the alternative footwear serves for comfort and easy donning, it might not be the choice of footwear to improve muscular efficiency and prevent slips and slip induced falls.

Fig.1: Mean Muscle activity (mV) for Vastus Medialis during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

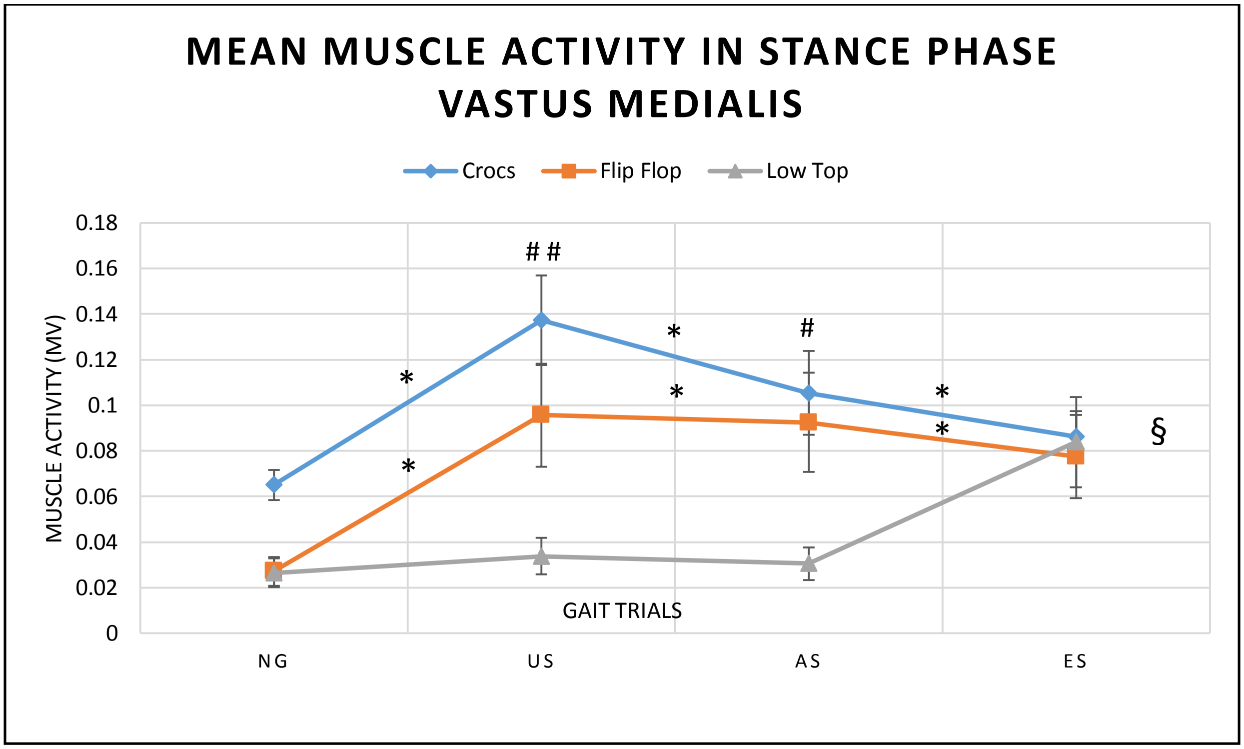
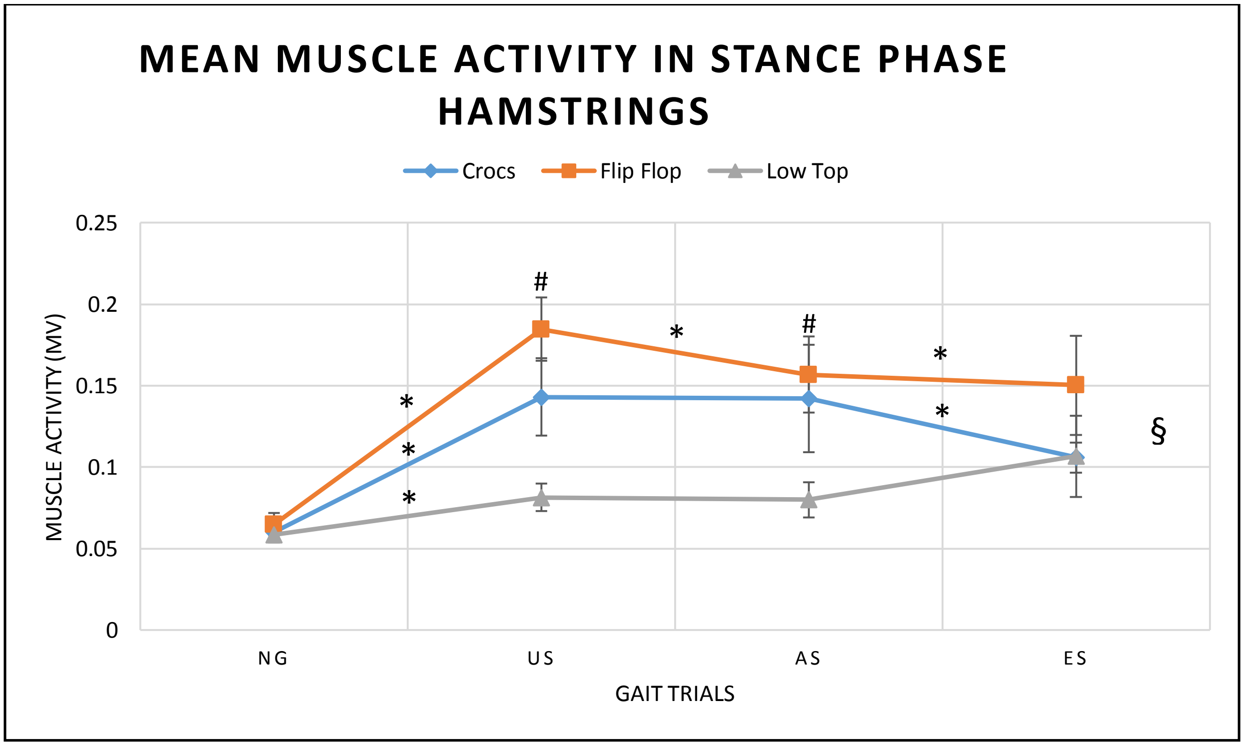


Fig.2: Mean Muscle activity (mV) for Medial Hamstrings during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

Fig.3: Mean Muscle activity (mV) for Tibialis Anterior during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

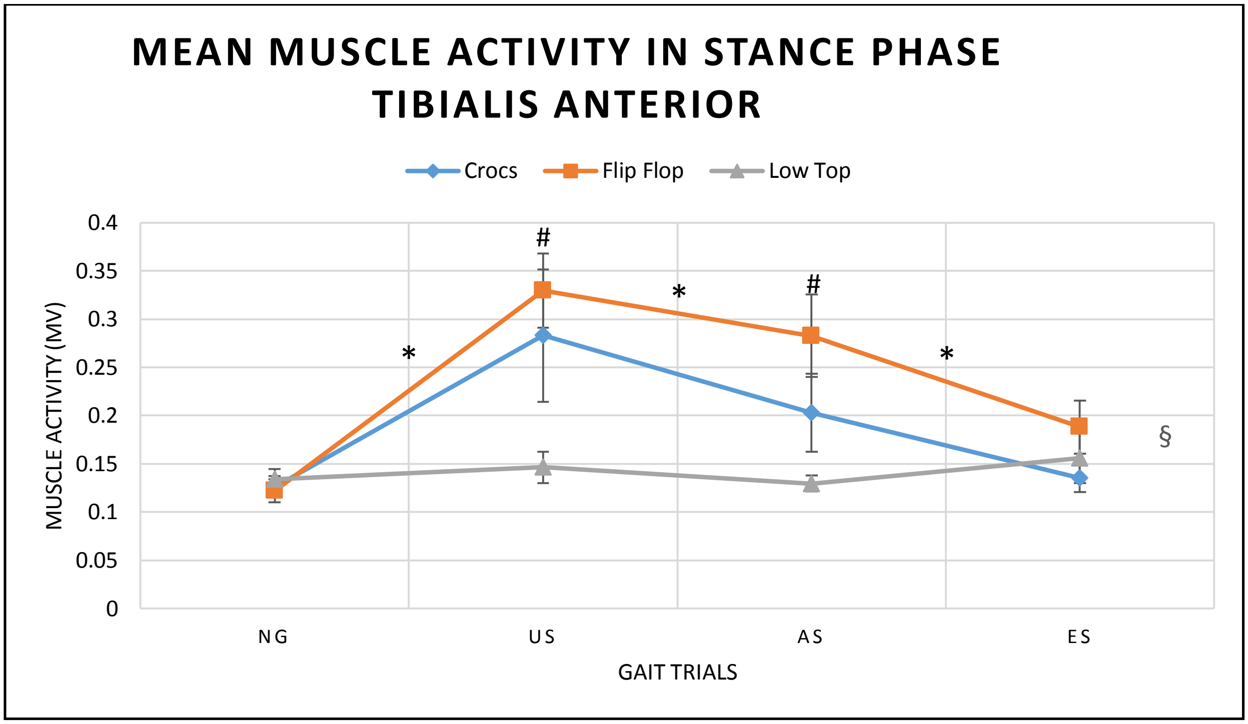
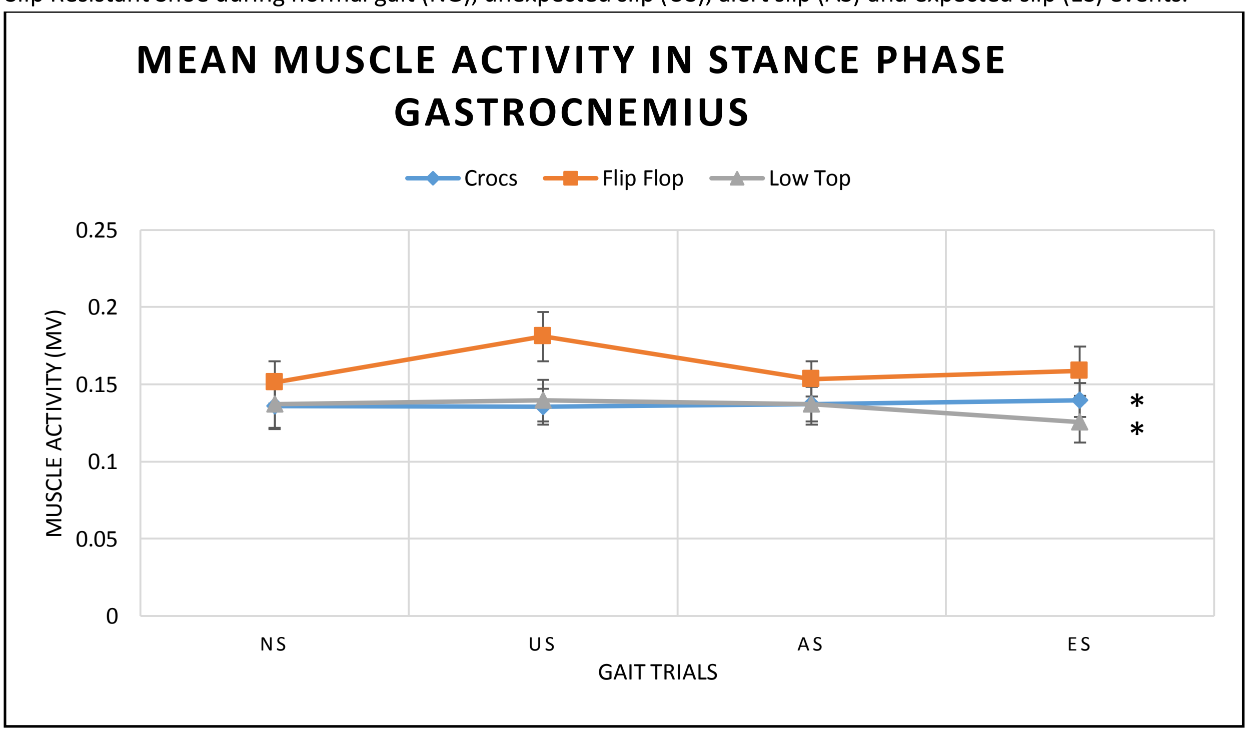


Fig.4: Mean Muscle activity (mV) for Medial Gastrocnemius during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

Fig.5: Peak Muscle activity (mV) for Vastus Medialis during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

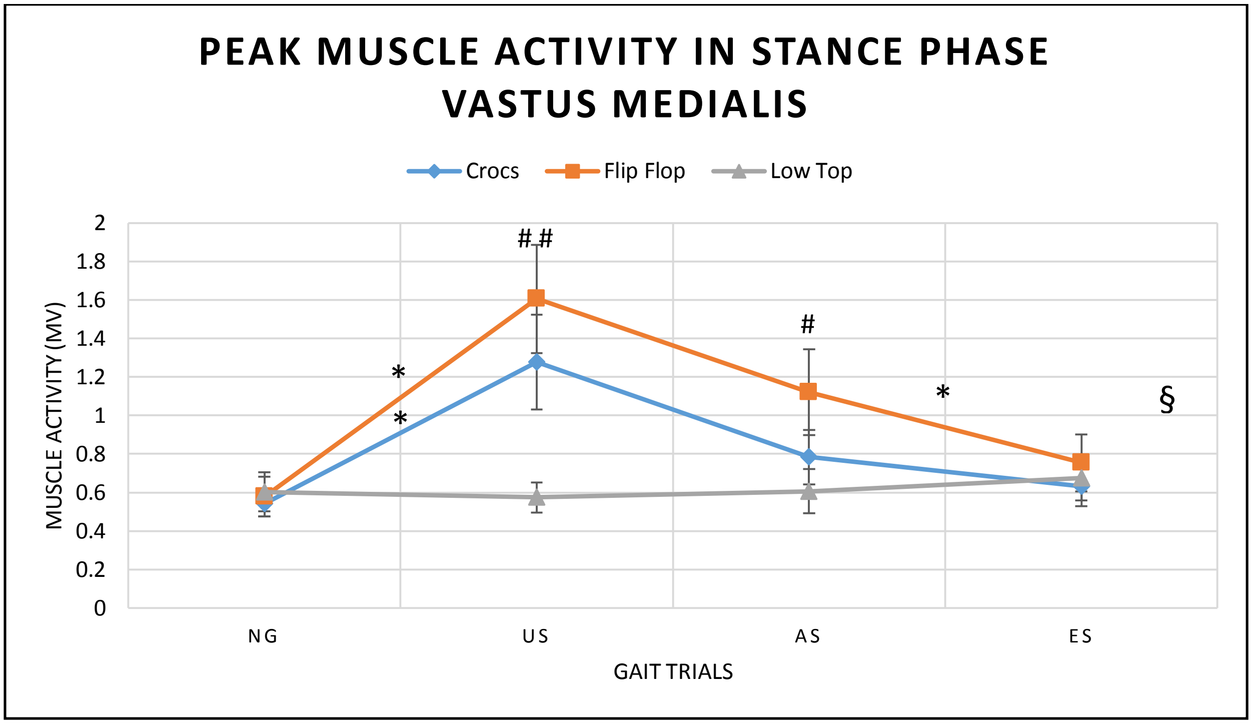
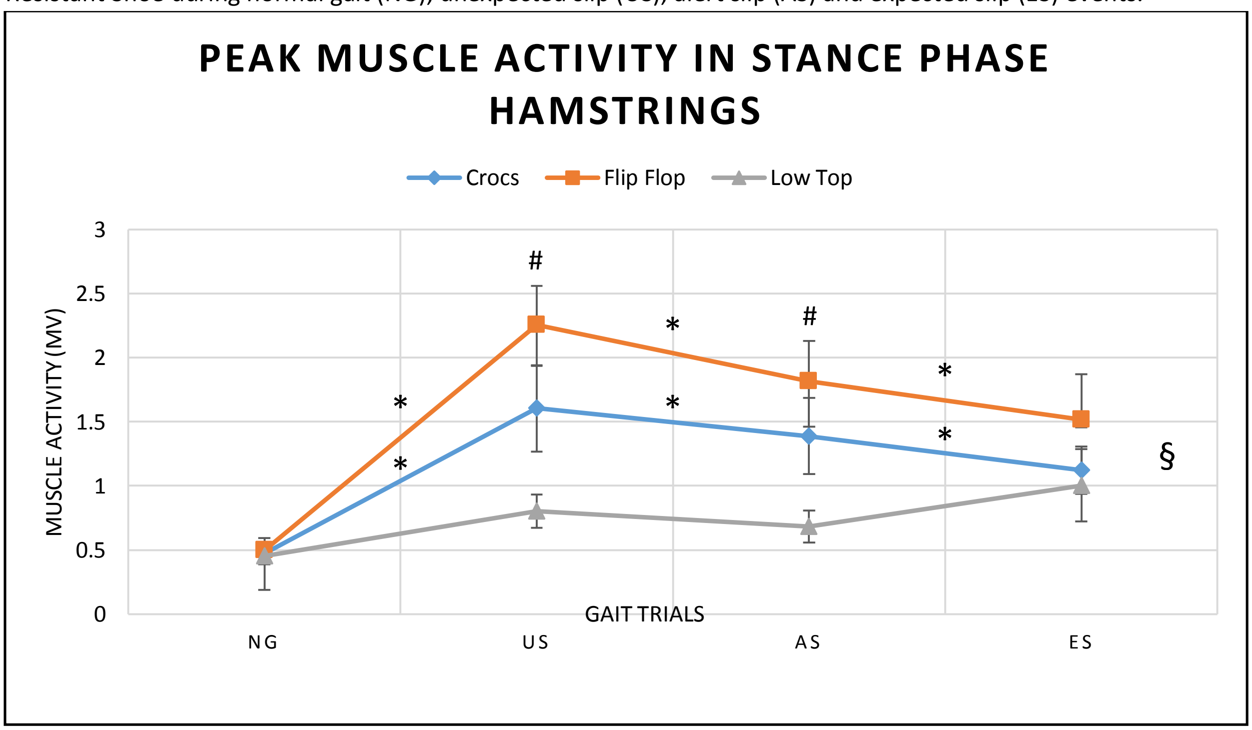


Fig.6: Peak Muscle activity (mV) for Medial Hamstrings during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

Fig.7: Peak Muscle activity (mV) for Tibialis Anterior during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

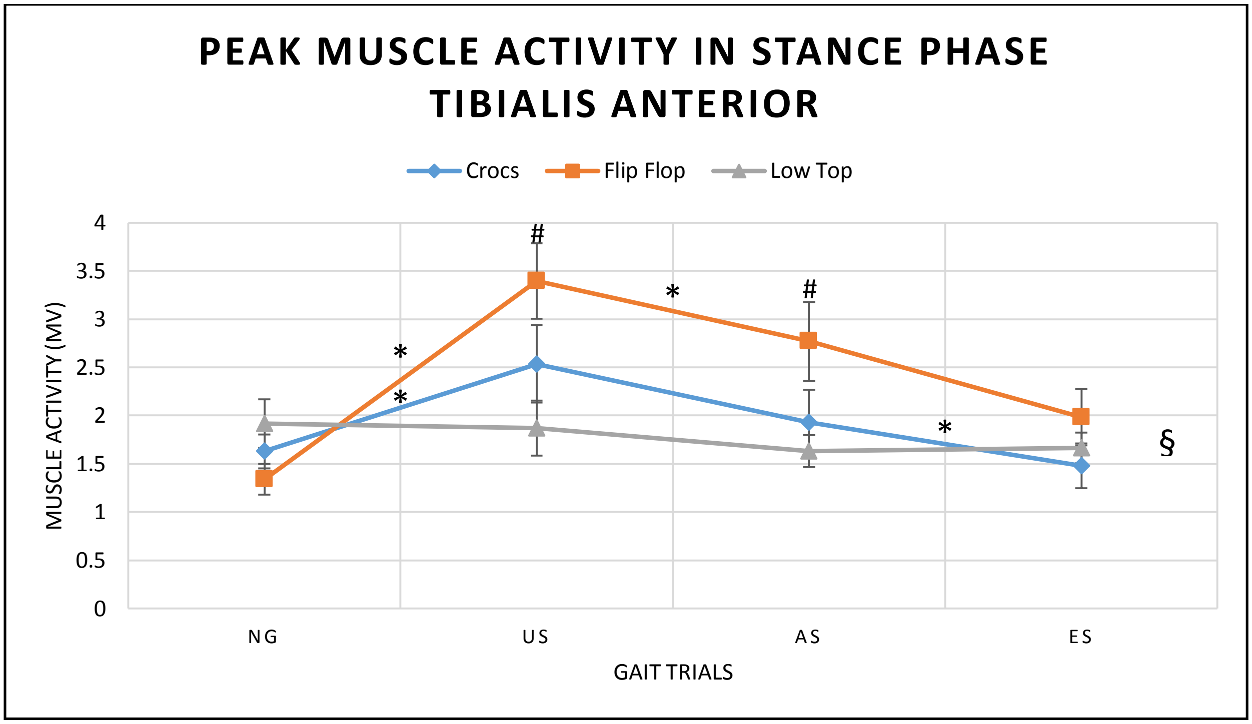
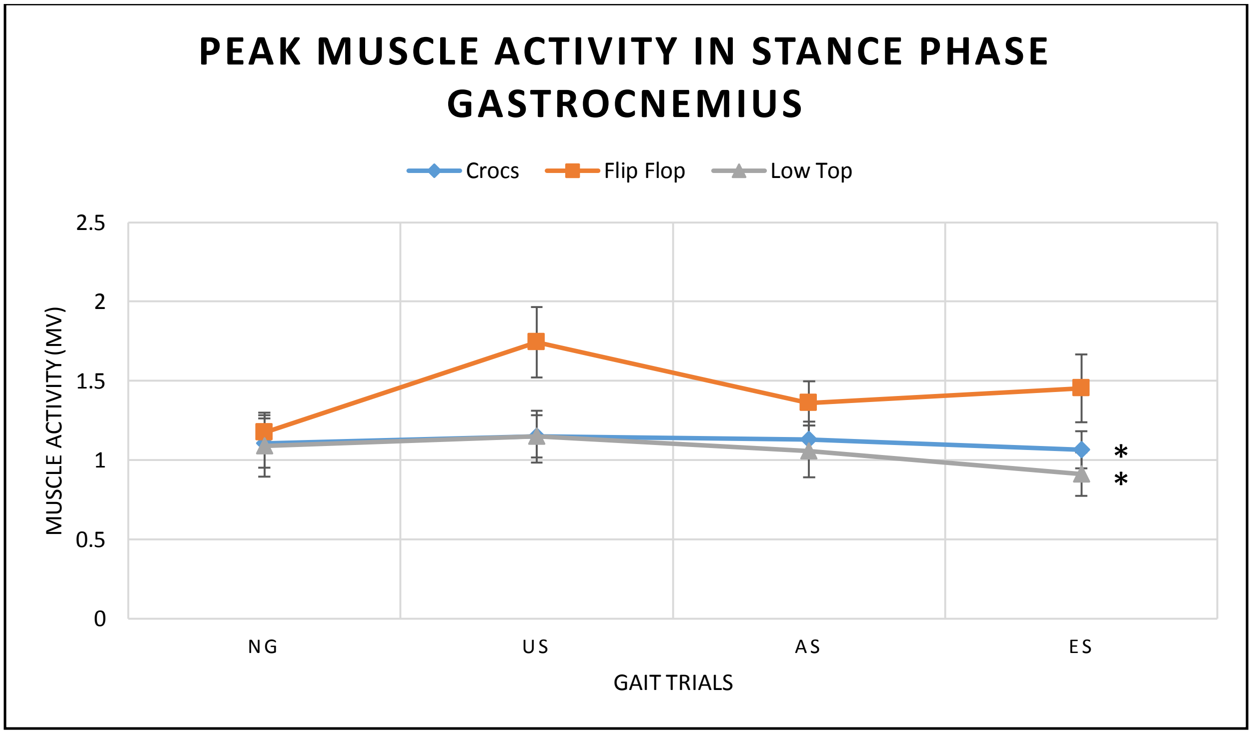


Fig.8: Peak Muscle activity (mV) for Medial Gastrocnemius during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

Fig.9: %MVC Muscle activity for Vastus Medialis during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

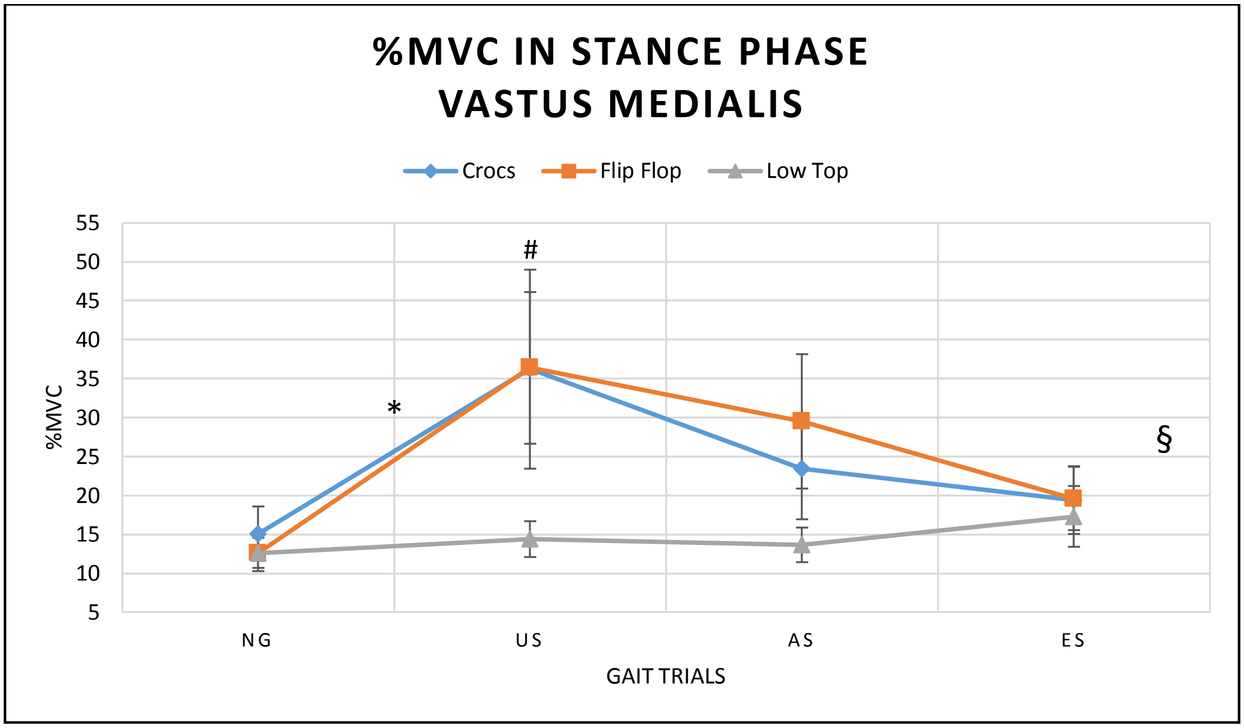
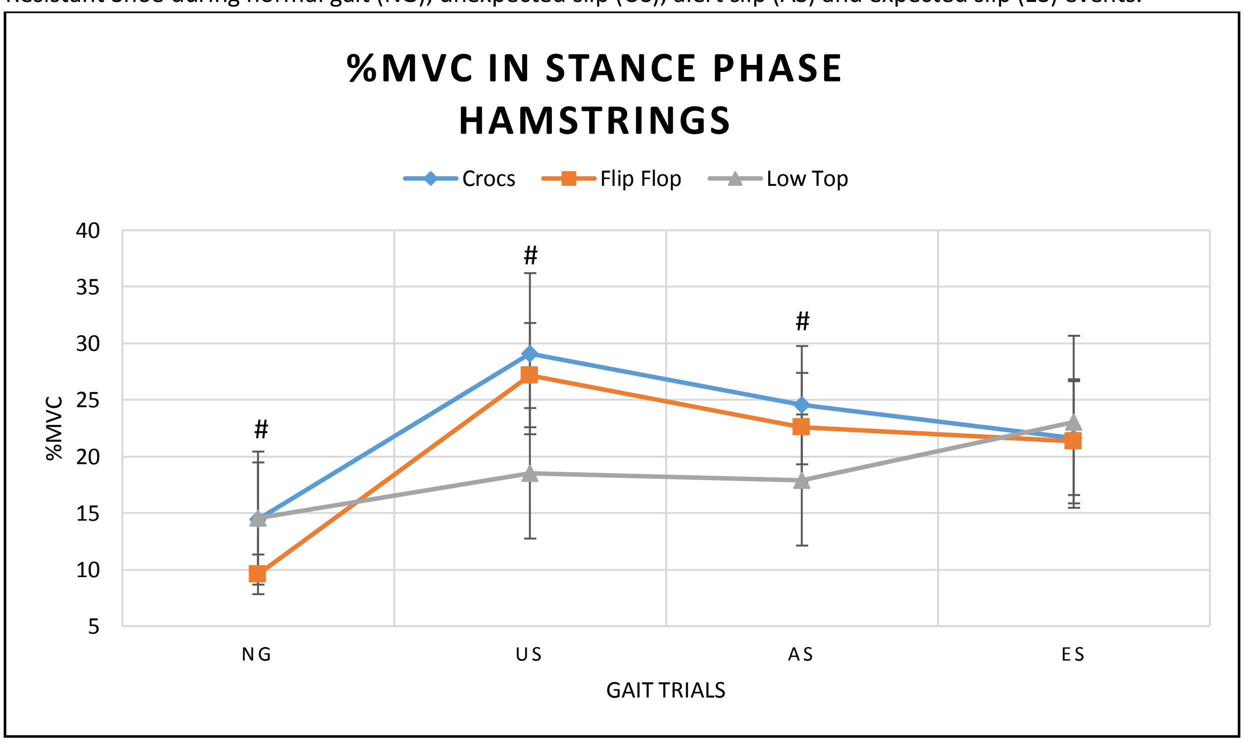


Fig.10: %MVC Muscle activity for Medial Hamstrings during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

Fig.11: %MVC Muscle activity for Tibialis Anterior during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.

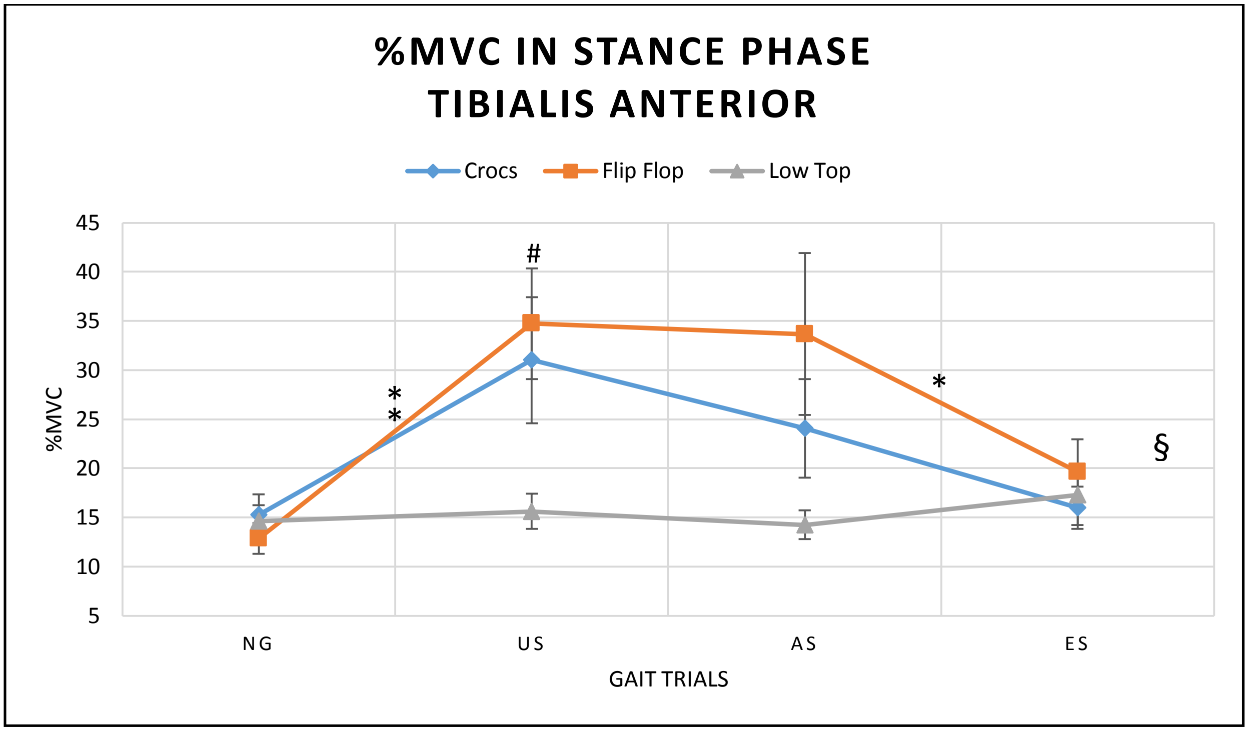
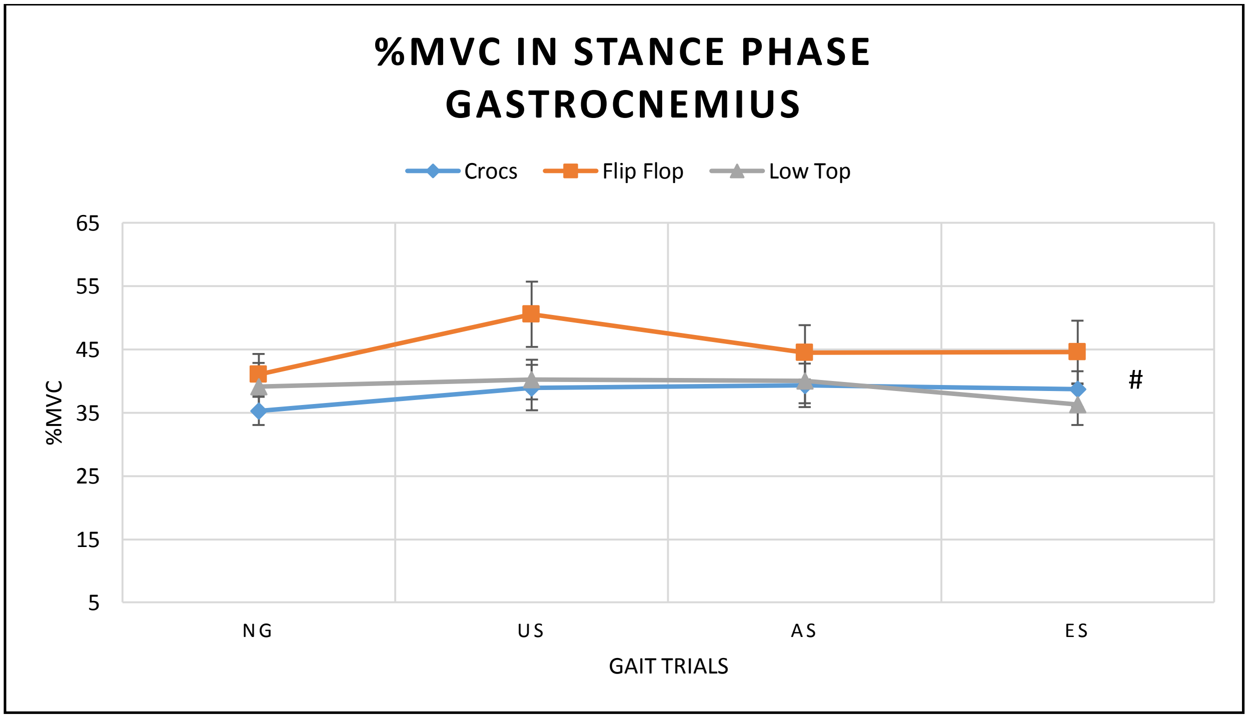
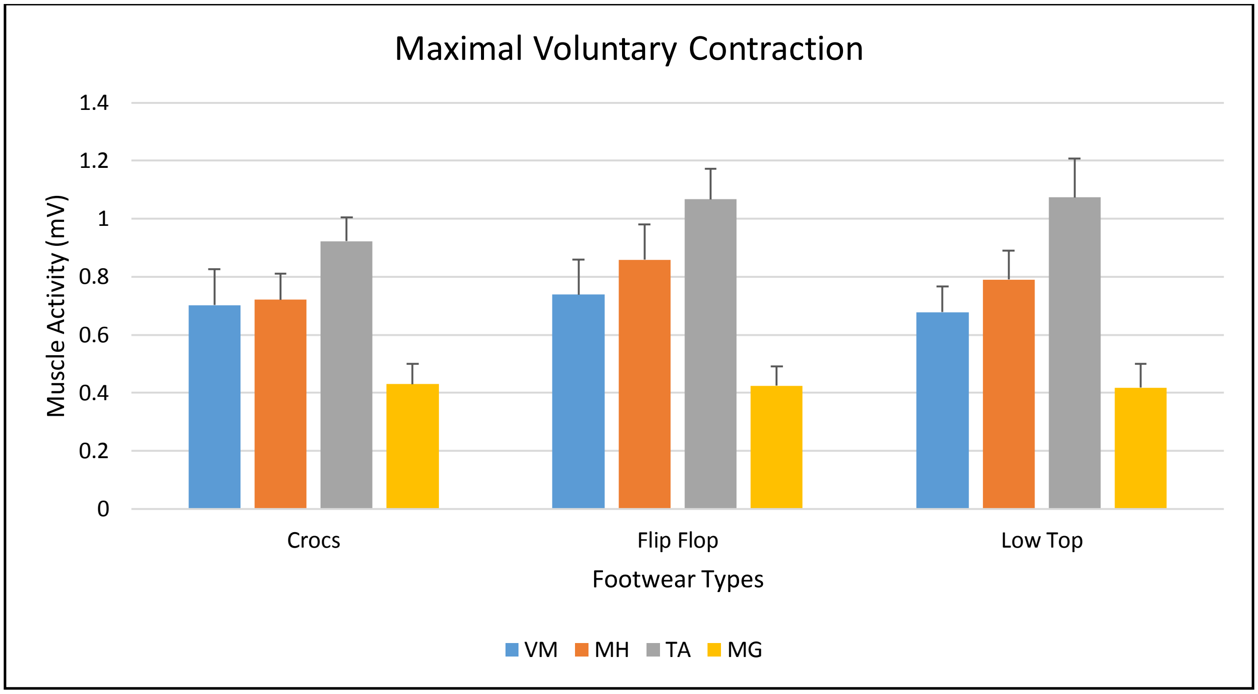


Fig.12: %MVC Muscle activity for Medial Gastrocnemius during stance phase for Crocs, Flip-Flops and Low Top Slip Resistant Shoe during normal gait (NG), unexpected slip (US), alert slip (AS) and expected slip (ES) events.



§ denotes significant interaction; * denotes significant difference for footwear across gait trials and # denotes significant difference for gait trials across footwear. All differences were significant at alpha level p=0.05.

Fig.13: Maximal Voluntary Contraction MVC Muscle activity (mV) for Vastus Meadialis (VM), Medial Hamstrings (MH), Tibialis Anterior (TA) and Medial Gastrocnemius (MG) during 5 second maximal voluntary contraction for Crocs, Flip-Flops and Low Top Slip Resistant Shoe



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LIST OF APPENDICES

APPENDIX A: DESCRIPTIVE STATISTICS

Table 1: Heel Slip Distance for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_HSD_NG	33.535531666666700	5.603208254703680	18
CC_HSD_US	63.778777777777800	44.534045252362600	18
CC_HSD_AS	64.523260000000000	79.613928705709200	18
CC_HSD_ES	35.174111111111100	30.753003644195000	18
FF_HSD_NG	23.411394444444400	4.616242716178730	18
FF_HSD_US	102.324365882353000	75.123449587197900	18
FF_HSD_AS	60.558727777777800	59.047384797254700	18
FF_HSD_ES	51.448261666666700	60.222868168432900	18
LT_HSD_NG	28.889355555555600	8.601234871617680	18
LT_HSD_US	34.235482222222200	21.070825513017800	18
LT_HSD_AS	28.568477777777800	13.005748198011000	18
LT_HSD_ES	36.308466666666700	24.927630691050700	18

Table 2: Mean Heel Slip Velocity for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_MHSV_NG	295.367055039683000	57.122398477634900	18
CC_MHSV_US	510.778988492064000	329.633869087038000	18
CC_MHSV_AS	536.903424369748000	625.428265998339000	18
CC_MHSV_ES	318.063285555556000	254.586842035121000	18
FF_MHSV_NG	205.706557142857000	39.445712188602000	18
FF_MHSV_US	781.550469327731000	560.556303470302000	18
FF_MHSV_AS	479.200681349206000	440.594219164638000	18
FF_MHSV_ES	423.891316071428000	479.105181464299000	18
LT_MHSV_NG	272.374055952381000	79.110310726389600	18
LT_MHSV_US	323.538519761905000	175.386928043799000	18
LT_MHSV_AS	274.381630277778000	121.432998464090000	18
LT_MHSV_ES	341.302983349206000	207.931394656081000	18

Table 3: Mean Z-GRF for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_MeanZ_NG	659.742325102670000	60.800332614417700	18
CC_MeanZ_US	607.998257989949000	77.949791711017400	18
CC_MeanZ_AS	589.585140638354000	57.739847284873100	18
CC_MeanZ_ES	603.943540476129000	63.226688921341600	18
FF_MeanZ_NG	657.393056094623000	66.443515973980800	18
FF_MeanZ_US	495.592438654763000	145.633837615579000	18
FF_MeanZ_AS	565.658074196515000	79.897600514194100	18
FF_MeanZ_ES	576.808368599767000	80.948316206778400	18
LT_MeanZ_NG	642.931607533414000	59.595429212005200	18
LT_MeanZ_US	570.630643569808000	126.489246677102000	18
LT_MeanZ_AS	635.189041867925000	68.162544285045100	18
LT_MeanZ_ES	607.490620048573000	65.246973779240500	18

Table 4: Peak Z-GRF for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_PeakZ_NG	990.07172	130.692593	18
CC_PeakZ_US	940.65478	148.024359	18
CC_PeakZ_AS	907.72241176470600	142.374968703011000	18
CC_PeakZ_ES	884.54033	101.130382	18
FF_PeakZ_NG	981.54944	138.974945	18
FF_PeakZ_US	918.261647058824000	181.964670601980000	18
FF_PeakZ_AS	850.285689	219.1040982	18
FF_PeakZ_ES	858.71172	99.854259	18
LT_PeakZ_NG	965.97078	94.394215	18
LT_PeakZ_US	900.24261	100.363574	18
LT_PeakZ_AS	932.22550	118.674629	18
LT_PeakZ_ES	921.83861	100.116640	18

Table 5: Ankle Angle at Heel Strike for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_AnkAngle_NG	-1.87006650	3.777563974	18
CC_AnkAngle_US	-5.012412444	5.8583129644	18
CC_AnkAngle_AS	-5.32672494	3.476818603	18
CC_AnkAngle_ES	-6.52325644	6.184563237	18
FF_AnkAngle_NG	-1.935019867	4.0439527741	18
FF_AnkAngle_US	-4.540286812500	2.8844994681052	18
FF_AnkAngle_AS	-5.5641954978	3.89589487199	18
FF_AnkAngle_ES	-7.9091394	5.44260103	18
LT_AnkAngle_NG	4.44425467	3.212230114	18
LT_AnkAngle_US	2.61677417	4.249430044	18
LT_AnkAngle_AS	3.57990467	4.624557355	18
LT_AnkAngle_ES	2.81141794	5.772116715	18

Table 6: Hip Angle at Heel Strike for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_HipAngle_NG	26.525744	7.0943810	18
CC_HipAngle_US	26.829206	5.3557336	18
CC_HipAngle_AS	26.143428	4.8481773	18
CC_HipAngle_ES	27.358467	5.3237780	18
FF_HipAngle_NG	24.539552941176500	5.563019030655250	18
FF_HipAngle_US	24.7769562500	5.17283931591	18
FF_HipAngle_AS	25.616572	5.8678152	18
FF_HipAngle_ES	25.602994	5.4291069	18
LT_HipAngle_NG	27.749635294117600	5.571459621926230	18
LT_HipAngle_US	27.143039	5.8280101	18
LT_HipAngle_AS	27.016028	6.8790203	18
LT_HipAngle_ES	26.740644	6.9193436	18

Table 7: Mean VM activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_StanceVM_NG	.065063337507053	.027685748235291	18
CC_StanceVM_US	.137325075482974	.083555007599550	18
CC_StanceVM_AS	.105330670034302	.078026943617497	18
CC_StanceVM_ES	.086330731893493	.047137742876206	18
FF_StanceVM_NG	.062038424615409	.027193138830861	18
FF_StanceVM_US	.160196987294758	.095623124559054	18
FF_StanceVM_AS	.128005300949153	.092468497275801	18
FF_StanceVM_ES	.099053095129026	.077499346648488	18
LT_StanceVM_NG	.064469702091030	.026574373200715	18
LT_StanceVM_US	.072711219031021	.033816431288226	18
LT_StanceVM_AS	.068364185401433	.030571317589550	18
LT_StanceVM_ES	.086817503764368	.083938164780775	18

Table 8: Mean MH activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_StanceMH_NG	.060193981841489	.024995413240942	18
CC_StanceMH_US	.143034601081705	.100912732868054	18
CC_StanceMH_AS	.141940138587489	.139842701151190	18
CC_StanceMH_ES	.105850239187630	.039449176770369	18
FF_StanceMH_NG	.064971914338811	.028923522031708	18
FF_StanceMH_US	.184662821786631	.082193895201234	18
FF_StanceMH_AS	.156788035862867	.099007616991638	18
FF_StanceMH_ES	.150203934547718	.128574136841347	18
LT_StanceMH_NG	.058726341989867	.019978079837579	18
LT_StanceMH_US	.081376336242114	.035562213524876	18
LT_StanceMH_AS	.079968495604586	.045773126305683	18
LT_StanceMH_ES	.106716137335423	.105651054122313	18

Table 9: Mean TA activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_StanceTA_NG	.126294432135467	.046714280376010	18
CC_StanceTA_US	.282829817580508	.291161061349213	18
CC_StanceTA_AS	.202879437985464	.172370749321589	18
CC_StanceTA_ES	.135557118775249	.062418826506153	18
FF_StanceTA_NG	.122010050203077	.049654663923190	18
FF_StanceTA_US	.329601651139684	.163282220606930	18
FF_StanceTA_AS	.282582315147777	.181799898742145	18
FF_StanceTA_ES	.188175666166406	.117232423492791	18
LT_StanceTA_NG	.134098284891447	.045867472224685	18
LT_StanceTA_US	.146303147327922	.069268617415020	18
LT_StanceTA_AS	.129363498376262	.035157579633473	18
LT_StanceTA_ES	.156197913119134	.111874145738929	18

Table 10: Mean MG activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_StanceMG_NG	.135751766915221	.059722557598133	18
CC_StanceMG_US	.135438047205180	.048747724209540	18
CC_StanceMG_AS	.137342407984399	.047520865446338	18
CC_StanceMG_ES	.139783628583462	.046459045505680	18
FF_StanceMG_NG	.151297105160060	.057819772510524	18
FF_StanceMG_US	.180995145567853	.067976678067058	18
FF_StanceMG_AS	.153502562421986	.048347153664234	18
FF_StanceMG_ES	.158696647642651	.067605033852469	18
LT_StanceMG_NG	.137103499380503	.068395348701656	18
LT_StanceMG_US	.139493815624935	.056666800774196	18
LT_StanceMG_AS	.137334453889501	.056792503914457	18
LT_StanceMG_ES	.125442796412086	.055748864857423	18

Table 11: Peak VM activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_StancePeakVM_NG	.54279622	.288453598	18
CC_StancePeakVM_US	1.27665150	1.049617046	18
CC_StancePeakVM_AS	.783046411764706	.597794234790953	18
CC_StancePeakVM_ES	.63182906	.435358593	18
FF_StancePeakVM_NG	.57889361	.434365707	18
FF_StancePeakVM_US	1.605138470588240	1.195181133363480	18
FF_StancePeakVM_AS	1.12087778	.947280395	18
FF_StancePeakVM_ES	.75331322	.624098063	18
LT_StancePeakVM_NG	.60308367	.433465261	18
LT_StancePeakVM_US	.57372056	.325928615	18
LT_StancePeakVM_AS	.60592617	.487662725	18
LT_StancePeakVM_ES	.67536178	.489562800	18

Table 12: Peak MH activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_StancePeakMH_NG	.47127444	.351686025	18
CC_StancePeakMH_US	1.60363156	1.421752578	18
CC_StancePeakMH_AS	1.387976294117650	1.255976613555680	18
CC_StancePeakMH_ES	1.12316383	.783537298	18
FF_StancePeakMH_NG	.49917072	.393610239	18
FF_StancePeakMH_US	2.252222235294120	1.307232382413120	18
FF_StancePeakMH_AS	1.81364383	1.342733529	18
FF_StancePeakMH_ES	1.515025756	1.5003933980	18
LT_StancePeakMH_NG	.45507494	.248061131	18
LT_StancePeakMH_US	.80201033	.550829663	18
LT_StancePeakMH_AS	.682985911	.5262537804	18
LT_StancePeakMH_ES	1.00340067	1.198384257	18

Table 13: Peak TA activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_StancePeakTA_NG	1.63034683	.748574680	18
CC_StancePeakTA_US	2.53630589	1.694104118	18
CC_StancePeakTA_AS	1.927337647058820	1.456668339068100	18
CC_StancePeakTA_ES	1.47966217	.987706099	18
FF_StancePeakTA_NG	1.34079372	.672048597	18
FF_StancePeakTA_US	3.394005117647060	1.664186733981000	18
FF_StancePeakTA_AS	2.77067128	1.730302072	18
FF_StancePeakTA_ES	1.98316717	1.250103133	18
LT_StancePeakTA_NG	1.91656828	1.077761937	18
LT_StancePeakTA_US	1.86970228	1.212509870	18
LT_StancePeakTA_AS	1.63075850	.713273586	18
LT_StancePeakTA_ES	1.66671478	.671538031	18

Table 14: Peak MG activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_StancePeakMG_NG	1.10688400	.660438016	18
CC_StancePeakMG_US	1.15016311	.562756268	18
CC_StancePeakMG_AS	1.12795500	.484615555	18
CC_StancePeakMG_ES	1.06434672	.498663089	18
FF_StancePeakMG_NG	1.17482283	.529197938	18
FF_StancePeakMG_US	1.744386588235290	.945083654588876	18
FF_StancePeakMG_AS	1.35874789	.588846755	18
FF_StancePeakMG_ES	1.45272283	.901788510	18
LT_StancePeakMG_NG	1.08866083	.823181227	18
LT_StancePeakMG_US	1.14895467	.692317003	18
LT_StancePeakMG_AS	1.05672817	.693444421	18
LT_StancePeakMG_ES	.91079989	.580543047	18

Table 15: %MVC VM activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_MVCVM_NG	15.074790991051000	14.815340673124400	18
CC_MVCVM_US	36.212753865273800	54.162804085854800	18
CC_MVCVM_AS	23.420923475059200	27.422140374092200	18
CC_MVCVM_ES	19.435632912288800	18.432432544473300	18
FF_MVCVM_NG	12.580823574620100	9.582263545311520	18
FF_MVCVM_US	36.368047921341000	41.311923480770900	18
FF_MVCVM_AS	29.506643079782000	36.728976228678400	18
FF_MVCVM_ES	19.608075843056100	17.326260855207100	18
LT_MVCVM_NG	12.606681857628900	8.195634727467390	18
LT_MVCVM_US	14.413604257258300	9.665633648637790	18
LT_MVCVM_AS	13.673495552989100	9.331209686805690	18
LT_MVCVM_ES	17.305555846548500	16.632847783021100	18

Table 16: %MVC MH activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_MVCMH_NG	14.415054453164900	21.453865051618000	18
CC_MVCMH_US	29.087327969083900	30.245396252788100	18
CC_MVCMH_AS	24.533513169842300	22.161886970304400	18
CC_MVCMH_ES	21.636456304979800	21.311978748286500	18
FF_MVCMH_NG	9.570432158086540	7.477918519942550	18
FF_MVCMH_US	27.184412408757100	19.545706969152700	18
FF_MVCMH_AS	22.589813696264200	20.319956402354000	18
FF_MVCMH_ES	21.350245523120000	23.291687621015900	18
LT_MVCMH_NG	14.556630302855900	24.981252344914500	18
LT_MVCMH_US	18.510232438752200	24.385030489480900	18
LT_MVCMH_AS	17.917368427202100	24.523933320776900	18
LT_MVCMH_ES	23.050232717252300	32.322464350972000	18

Table 17: %MVC TA activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_MVCTA_NG	15.278293189701500	8.738319228463020	18
CC_MVCTA_US	31.009152403206600	27.307996787275700	18
CC_MVCTA_AS	24.072199016581300	21.284674045326200	18
CC_MVCTA_ES	15.988840266753500	9.151355095482000	18
FF_MVCTA_NG	12.847991991995500	6.698506680640940	18
FF_MVCTA_US	34.724780221827000	23.903144319073000	18
FF_MVCTA_AS	33.673412588971100	34.934557912050300	18
FF_MVCTA_ES	19.606483187525900	14.163091814131600	18
LT_MVCTA_NG	14.629479634273800	6.890121527584400	18
LT_MVCTA_US	15.616082625298700	7.576942707199430	18
LT_MVCTA_AS	14.238024497495500	6.244851862819590	18
LT_MVCTA_ES	17.313589094490700	13.011179306289200	18

Table 18: %MVC MG activity in stance phase for CC, FF and LT during NG, US, AS and ES:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_MVCMG_NG	35.257254270782400	9.472974527561270	18
CC_MVCMG_US	38.958448475340500	15.228040361932900	18
CC_MVCMG_AS	39.294517387633900	14.545203809810600	18
CC_MVCMG_ES	38.735860587087800	11.925838905252800	18
FF_MVCMG_NG	41.059278246119900	13.864942559580600	18
FF_MVCMG_US	50.524283276532600	21.795649340306700	18
FF_MVCMG_AS	44.491701554057800	18.260991707693200	18
FF_MVCMG_ES	44.570723262390700	21.053466138900500	18
LT_MVCMG_NG	39.152030071032100	15.659089921161200	18
LT_MVCMG_US	40.222868298784300	13.224043183409400	18
LT_MVCMG_AS	40.064769762405500	15.285113770432200	18
LT_MVCMG_ES	36.296901906682800	13.888763592696800	18

Table 19: MVC in CC, FF and LT:

Descriptive Statistics			
	Mean	Std. Deviation	N
CC_MVCVM	0.701874313	0.526135358	18
FF_MVCVM	0.739027196	0.514309362	18
LT_MVCVM	0.677864155	0.38087428	18
CC_MVCMH	0.721012135	0.377959659	18
FF_MVCMH	0.858316885	0.518780255	18
LT_MVCMH	0.790826559	0.422814401	18
CC_MVCTA	0.923196098	0.349524078	18
FF_MVCTA	1.066904881	0.450446242	18
LT_MVCTA	1.073221652	0.569208064	18
CC_MVCMG	0.429905345	0.297343056	18
FF_MVCMG	0.425030477	0.278308127	18
LT_MVCMG	0.418109987	0.34354589	18

APPENDIX B: INFORMED CONSENT

INFORMED CONSENT

Consent to participate in an experimental study
Title: Biomechanics of Slips in Alternative Footwear

Investigator

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Tel: (662) 915-7573

Description

You are being asked to participate in a research study for the purpose of investigating the effects of wearing different types of casual alternative footwear such as the flip flops, crocs and low top shoes on walking and slip trials. The long-term goal of this proposed research is to minimize the risk of falling and injuries in individuals who wear these alternative footwear, and also to lead towards implementing appropriate intervention strategies. The use of this knowledge might improve injury prevention among the population such as the hospital staff who wear these alternative footwear in working conditions that are very prone for slips. In this study, we will focus on assessing walking during normal trials, slips trials and obstacle avoidance trials using motion capture and also assess the muscle activity using electromyography during these trials.

Your participation is voluntary. If you decide to participate in the research study, three visits are required to complete the testing that will last approximately 45 minutes for each visit. During thatvisit, you will be briefed on the experimental procedure related to gait, slips and obstacle avoidance with different footwear (explained below).

The "experimental procedures" are used to generate the measurements needed to achieve the goals of this study. If the screening results indicate that you qualify to participate in this study, then you would undergo the below mentioned experimental procedures. You will participate in three testing sessions, with a similar experimental protocol and be exposed tothree different footwear during those three sessions. The types of footwear are: flat sole-low top shoe (restaurant type), flip-flops (casual alternative footwear) and crocs (hospital type).
Protocol 1) 3-4 Normal Walking Trials (Non-Slippery Conditions)
Protocol 3) EMG Muscle Activity Testing

Protocol 2) 3 Slip Trials (Unexpected, Alert, Expected)
Protocol 3) 1 Obstacle Avoidance Trial

In summary, you will be asked to walk on dry and slippery floors, while we measure the activity of your muscles in your legs, your movement and forces exerted by your feet onto the ground. Your body movements will be recorded using light reflective spherical markers that we will attach to your body at various locations using 2-sided tape. The forces exerted by your feet onto the ground will be measured when you walk across the force platform embedded into the ground. The activity of your muscles will be recorded using self-adhesive electrodes attached onto your body skin on the legs over the muscle groups of interest. You will be harnessed at all times during testing to minimize injury from hitting the ground if you slip and loose balance.

More specifically, during the testing session, you will be asked to undergo the following steps:

1. Prior to walking experiments, you will wear the alternative footwear that we will provide.
2. This experiment involves a risk of slipping. Thus, a safety harness will be put on you so that if you lose your balance, we will catch you in the harness before you touch the floor.
3. During the experiment, you will be asked to walk several times across a walkway at a comfortable pace. The flooring surface may be slippery. It is very important that you walk naturally throughout the session.
4. For muscle testing you will be asked to sit in a chair with both feet placed flat on the floor. EMG electrodes will be placed on your leg corresponding to a muscle. On instruction the muscle being tested, you will be asked to contract that muscle. The muscle consist of the ankle and knee muscles.
5. If the floor you just walked on had the slippery substance on it, you will be asked to wear a clean pair of boots prior to continuing the experiment. At least two seated rest periods will be allowed during the experiment. And, at least two qualified researchers will be in the room should you need assistance.
6. During the obstacle avoidance walking trial, you will be asked to walk across the walkway with normal curb height obstacles (4-8 inches high) that you will be required to clear and finish walking across the walkway.

This complete cycle will occur for each of the 3 footwear on 3 different days. Your total time will be 45 minutes for each session.

As part of the research study, we will record video of your movements while walking. These images will consist of your face, body, and body movements while walking. The confidential CD will be kept indefinitely. Your name will not be recorded in any way on the CD. Only your subject number and date of testing will be written on the CD's label. Unless you give separate permission below, only the investigators associated with this study will have access to the CD. The CD and any identifiable material will be stored in a locked filing cabinet within the Applied Biomechanics Laboratory, in which only the investigators will have access. This recording will be studied by the research team for use in the research project. We would also like you to indicate below to what other uses of these digital recordings you are willing to consent. In each of the uses listed below, images, such as your face and movements recorded on the CD will be used for the purpose of describing the research procedures and in discussion of research findings. If you are not willing to consent to other uses of the digital recordings, you are still eligible to participate in the study. We will only use the CDs in the ways to which you agree. In any use of these CDs, your name would not be identified; however, such use does present a risk for loss of confidentiality because your image will not be altered to prevent your identification. These CDs will be kept indefinitely.

1. The digital recordings can be shown to subjects in other experiments… ______
Initials
2. The digital recordings can be used for scientific publications………… ______
Initials
3. The digital recordings can be shown at meetings of scientists………… ______
Initials
4. The digital recordings can be shown in classrooms to students………. ______
Initials
5. The digital recordings can be shown in public presentations to Non-scientific groups……………………………………………………. ______
Initials
6. The digital recordings can be used on television……………………… ______
Initials
7. The digital recordings can be used on a public website maintained by the research group……………………………………………..… ______
Initials

Risks and Benefits

There is a potential risk of falling due to slipping during the walking trials. This potential risk has been minimized by the inclusion of a harness system that will catch you should you slip and cannot recover balance on your own. With the proper functioning of the harness system, there is no risk for falling to the floor. For each testing session and prior to any walking trials, the rope/pulley system of the harness apparatus will be checked for malfunction. Therefore the potential of hitting the floor after slipping is rare. You will wear the safety harness at all times during walking trials on both dry and slippery floor conditions and also during the obstacle avoidance trials to prevent such accidents.

There are other potential risks for injuries even if the subject does not fall onto the ground: Muscle pull, muscle tear, skin abrasion, chafing, and sudden movement-related injuries (e.g. being jerked), which may occur in the event of an equilibrium loss. At all times during balance testing, the subject will wear a safety harness designed to eliminate the risk of falling during the balance testing protocol. There are some risks for minor skin irritation and redness, associated with the use of the 2-sided tape to attach markers and with the use of the EMG electrodes.

You will likely receive no direct benefit from taking part in this research study. Should the testing procedures performed yield results that are abnormal, e.g. abnormal balance, abnormal walking, you will be advised. If you decide to speak to your physician, it will be your responsibility set up an appointment with him/her. The results will be available at no cost, should you or your physician request them.

Confidentiality

Any information about you obtained from or for this research study will be kept as confidential (private) as possible. The records identifying your name will be (1) stored in a locked file cabinet and/or in a password-protected computer file, (2) kept separate from the rest of the research records, and (3) be accessible to only the researchers listed on the first page of this form and their staff. Your identity on the other research records will be indicated by a case number rather than by your name. You will not be identified by name in any publication of the research results unless you sign a separate form giving your permission (release).

Right to Withdraw

Your participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above, is completely voluntary. (Note, however, that if you do not provide your consent for the use and disclosure of your identifiable information for the purposes for the use of the recordings described above, you will still be allowedto participate in the research study, and the recordings will not be used for anything other than analysis by the staff.) Whether or not you provide your consent for participation in this research study will have no affect on your current or future relationship with the University of Mississippi.

You may withdraw, at any time for any reason, your consent for participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above. This voluntary withdraw can be for any reasons such as: physical discomfort of any kind, emotional distress, feeling uneasy about the testing procedure, time constraints, and/or lack of interests in participation. Any reason for which you feel as though you do not wish to continue can be a means of discontinuing the study. Any and all identifiable research information (CDs) recorded for, or resulting from, your participation in this research study prior to the date that you formally withdrew your consent will be destroyed immediately.

If you start the study and decide that you do not want to finish, all you have to do is to tell Mr. Harish Chander, Dr. John Garner or Dr. Chip Wadein person, by letter, or by telephone at the Department of Health, Exercise Science, and Recreational Management, 215 Turner Center, The University of Mississippi, University MS 38677, or 915-5561. Whether or not you choose to participate or to withdraw will not affect your standing with the Department of Health, Exercise Science, and Recreational Management, or with the University, and it will not cause you to lose any benefits to which you are entitled.

IRB Approval

This study has been reviewed by The University of Mississippi's Institutional Review Board (IRB). The IRB has determined that this study fulfills the human research subject protections obligations required by state and federal law and University policies. If you have any questions, concerns or reports regarding your rights as a participant of research, please contact the IRB at (662) 915-7482.

Statement of Consent

I have read the above information. I have been given a copy of this form. I have had an opportunity to ask questions, and I have received answers. I consent to participate in the study.

Signature of Participant Date

Signature of Investigator Date

Statement of consentto be contacted for future studies

The staff of the Applied Biomechanics and Ergonomics Laboratory and/or Body Composition Laboratory may be of interested in contacting you to participate in future studies. Signing below allows us to contact you to contact you with information on future studies.

Signature of Participant Date

Signature of Investigator Date

NOTE TO PARTICIPANTS: DO NOT SIGN THIS FORM
IF THE IRB APPROVAL STAMP ON THE FIRST PAGE HAS EXPIRED.

APPENDIX C: RECRUITMENT SCRIPT

“RECRUITMENT SCRIPT” (verbal, in person)

(*This should be a brief version of the consent document.*)

My name is Mr. Harish Chander, Dr. Garner, Dr. Wade or Dr. Fu, a (*graduate student, faculty member*) from the Department of HESRM at the University of Mississippi. I would like to invite you to participate in my research study, the effect of alternative footwear such as the flip flops, crocs and low top shoes on gait and slip trials.

You may participate if you do not have any musculoskeletal disorders or medical conditions that may be aggravated by exercise. Please do not participate if you have any injury to the lower or upper extremities, or balance disorders.

As a participant, you will be asked to walk across dry and slippery floor conditions and to clear and walk across a normal curb height obstacle while wearing each of the three alternative casual footwear.

This protocol may cause possible falls due to lack of balance under slippery flooring conditions. However, injuries and falls are highly unlikely, and will be controlled for with the use of a harness. Subjects are responsible for any and all medical costs that may result from injury during or related to the study. To complete the study you will be required to attend three testing sessions each lasting for about 45 minutes. Your decision whether or not to participate will not affect your course credit or university standing.

If you are interested in participating, please place your name and email address on the sign-up sheet that is being passed around. A member of the Biomechanics lab staff will be in contact to set up testing times.

Do you have any questions now? If you have questions later, please contact me following class.

VITA

Harish Chander, BPT. MS
Doctoral Candidate (ABD) – PhD in Health & Kinesiology
Applied Biomechanics Laboratory
Department of Health, Exercise Science & Recreation Management
University of Mississippi
hchander@go.olemiss.edu, harrytherapy@gmail.com
662-202-7977
215 Turner Center, PO Box 1848, University, MS 38677

ACADEMIC RECORD:

Doctor of Philosophy University of Mississippi,
Department of Health, Exercise Science & Recreation Management, University, MS
Major Area: Biomechanics / Neuromechanics
Minor Area: Exercise Physiology
Research Concentration: Ergonomics and Fall Prevention
Expected Graduation, May 2014

Doctoral Dissertation: Biomechanics of Slips in Alternative Footwear

Master of Science University of Mississippi,
Department of Health, Exercise Science & Recreation Management, University, MS
Major Area: Neuromechanics
Minor Area: Exercise Physiology
Research Concentration: Ergonomics and Fall Prevention
May 2012

Masters' Thesis: "Impact on Balance While Walking in Occupational Footwear"

Bachelor of Physical Therapy The Tamil Nadu Dr. MGR Medical University
Sree Balaji College of Physiotherapy
Major Area: Orthopedic and Pediatric Physical Therapy
Work Concentration: Neuro-Developmental Therapy and Sports Injury Rehabilitation
May 2008

Under-Grad Dissertation: The Effects of Cryotherapy and Massage in the Treatment of Delayed Onset of Muscle Soreness (DOMS)

EMPLOYMENT HISTORY:

2010 – Present

Graduate Teaching Assistant
Department of Health, Exercise Science and Recreation Management, University of Mississippi

- Motor Control and Learning Instructor
- Kinesiology Instructor and Teaching Assistant
- Care and Prevention of Athletic Injuries Instructor
- Biomechanics Laboratory Instructor
- Exercise Physiology Instructor
- Weight Training Instructor

Graduate Research Assistant
Applied Biomechanics Laboratory, University of Mississippi

- Undergraduate Practicum and Independent Study Student Advisor
- Equipment Management
- Research Design, Evaluation and Implementation
- Data Collection and Analysis
- Programing and Coding for Data Analysis

2008 – 2009

Physical Therapist and Fitness Coordinator
Talwalkars Better Value Fitness Pvt. Ltd, Chennai, India

- Exercise Prescription and Testing
- Fitness Trainer
- Administrative official for promoting health & fitness

2007 – 2008

Peadiatric Physical Therapist
Vinayaga Physio Point, Chennai, India

- Pediatric Neuro-Development Therapy
- Pain Relief of Musculoskeletal Injuries
- Rehabilitation of Orthopedic and Neurological Conditions

RESEARCH AND CLINICAL EXPERIENCE:

May 2012 – Present — **Graduate Student Director** - Applied Biomechanics Laboratory, University of Mississippi

2010 – Present — **Graduate Student Advisor** - Honors Thesis Students - Sally McDonnell Barksdale Honors College

2009 – Present — **Graduate Research Assistant** - Applied Biomechanics Laboratory, University of Mississippi

Research Experience

Biomechanics of gait and balance:

- Biomechanics of Slips in Alternative Footwear (PI)
- Biomechanics of Human Energy Expenditure, Balance and Gait with Alternative Footwear (PI)
- Kinematics and Kinetics of Slip Trials in Firefighters (CO-I)
- The Effect of Occupational Footwear on Dynamic Balance (PI)
- The Effect of Extended Durations of Walking in Occupational Footwear on Balance (PI)
- The Effect of Cold Suit on Balance Measures Among the Young and Elderly (Data Analysis)
- Pilot testing Kinematics of Walking on Ballast and Non-Ballast Surfaces
- The Acute Effect of Whole-Body Vibration on Functional Stability Measures in Older Women.
- Balance, Body Composition and Jumping Performance in Collegiate Female Athletes

Sport performance and enhancement:

- The Influence of Body Composition on Selected Jump Performance Measures in Varsity Collegiate Female Varsity Athletes
- Three-Dimensional Examination of the Influence of Differently Weighted Warm-up Bats on Swing Kinematics
- The Effects of Whole-Body Vibration on Rest Intervals in Jumping Performance
- The Effect of a TMJ Device on Athletic Performance Measures

2004 – 2008 **Sree Balaji College of Physiotherapy**
Department of Physical Therapy
The Effect of Cryotherapy and Massage in the Treatment of Delayed Onset of Muscle Soreness (PI)
Physical therapy outpatient department

- Orthopedic, Cardio-respiratory and Neurological Rehabilitation
- Pediatric and Geriatric Rehabilitation
- Exercise Therapy Rehabilitation
- Electrotherapy Treatment Modalities
- Manual Therapy

TEACHING CURRICULUM:

UM - ES 338 – Motor Control and Learning (Fall 2013; Spring 2014)
UM - ES 346 – Kinesiology (Spring 2012, Spring 2014)
UM - HP 303 – Prevention and Care of Athletic Injuries (Fall 2012; Spring 2013)
UM - ES 447 – Biomechanics Laboratory (Fall 2009, 2010; Spring 2010, 2011; Summer 2011, 2012)
UM - ES 349 – Exercise Physiology Laboratory (Summer 2013)
UM - HP 191 – Personal and Community Health (Summer 2012, 2012, 2013; Winter 2014)
UM - EL 151 – Resistance Training and Weight Lifting (Fall 2009, Spring 2010)

INVITED PRESENTATION / TALKS / LECTURES:

- Ergonomics Assessment of Workplace Settings (Administrative Office), Ole Miss Theatre, University of Mississippi, USA, 2013
- Ergonomics Awareness and Workplace Safety (Slips, Trips and Fall Prevention) Schwing Stetter India Pvt. Ltd, Chennai, India, 2013

Undergraduate Lectures:

- UM 2013, ES 346 Kinesiology – Ankle and Foot Complex
- UM 2013, ES 446 Biomechanics of Human Movement – Introduction to Biomechanics
- UM 2013, ES 446 Biomechanics of Human Movement – Mechanical Levers in Humans
- UM 2012, ES 446 Biomechanics of Human Movement – Gait

Graduate Lectures:

- UM 2013, ES 632 Advanced Structural Kinesiology – Structure and Biomechanics of the Foot and Ankle Complex
- UM 2013, ES 632 Advanced Structural Kinesiology – Structure and Biomechanics of the Hip Complex

- UM 2013, ES 632 Advanced Structural Kinesiology – Structure and Biomechanics of the Spine
- UM 2012, ES 512 Foundations of Biomechanics – Biomechanics of Balance and Gait
- UM 2011, ES 632 Advanced Structural Kinesiology – Spine Structural Kinesiology
- UM 2011, ES 632 Advanced Structural Kinesiology – Gait
- UM 2011, ES 632 Advanced Structural Kinesiology – Postural Control and Balance
- UM 2011, ES 612 Instrumentation and Analysis in Biomechanics – Assessment of Posture and Balance

PROFESSIONAL ORGANIZATIONS AND SERVICE:

2013 – Present	**Director** – Academic and Professional Development Committee - Graduate Student Council - The University of Mississippi
2013 – Present	**Graduate Student Council Representative** Standing Committee - Office of the Chancellor; Recreational Facilities
2012 – 2013	**Chair** – Academic Affairs Committee - Graduate Student Council - The University of Mississippi
2012 – Present	**Senator** - Graduate Student Council - The University of Mississippi
2011 – Present	Southeast Regional Chapter: American College of Sports Medicine
Life Member	Indian Association of Physiotherapists

CERTIFICATIONS:

- Licensed Physical Therapist – Indian Association of Physiotherapists
- Eligible to sit for US PT Licensure – National Physical Therapy Examination, USA
- Certified Manual Therapist – Orthopedic Manipulative Rehabilitation
- Certified Instructor for CPR/AED; Adult, Children & Infant, American Red Cross

RESEARCH FUNDING:

Chander, H
The effect of extended durations of walking in occupational footwear on postural control
University of Mississippi Graduate Student Council Research Grant 2011
Role: Primary Investigator
Funding Request: $500.00
Status: Funded

Chander, H
Biomechanical analysis of barefoot and shod conditions in human gait and balance
University of Mississippi Graduate Student Council Research Grant 2013
Role: Primary Investigator
Funding Request: $1000.00
Status: Not Funded

Cody Morris & **Chander, H**
Impact of Alternative Footwear on Human Energy Expenditure, Balance and Gait
University of Mississippi Graduate Student Council Research Grant 2013
Role: Co-Investigator
Funding Request: $1000.00
Status: Funded

Chander, H
Recipient of the UM Summer Thesis and Dissertation Scholarship, Summer 2012

AWARDS AND RECOGNITIONS:

- Grand Prize Winner, University of Mississippi 3 Minute Thesis Competition - Representing University of Mississippi at the South Council of Graduate Schools at San Antonio in February 2014.
- Winner of the Student of the Month, School of the Applied Sciences - October 2013
- Winner of University of Mississippi - Annual Research Day and Symposium - 2nd Place; 2012

PEER-REVIEWED JOURNAL PUBLICATIONS:

1. **Chander H,** Garner JC, & Wade C. (2013). Impact on balance while walking in occupational footwear. *Footwear Science*, (ahead-of-print), 1-8.
2. Garner JC, Wade C, Garten R, **Chander H**, & Acevedo E. (2013). The effect of boot type on postural stability of professional firefighters. *International Journal of Industrial Ergonomic, 43(1),* 77-81.
3. MacDonald CJ, Israetel M, Dabbs NC, **Chander H**, Allen CR, Lamont H, & Garner JC**.** (2013) Influence of Body Composition on Selected Jump Performance Measures in Collegiate Female Athletes. *Journal of Trainology*, 2: 33-37.
4. **Chander H,** MacDonald CJ, Dabbs NC, Lamont HS, & Garner JC. Balance Performance in Varsity Collegiate Female Athletes. *Sports Biomechanics* (In review)

5. **Chander H,** Garner JC, & Wade C. The Effect of Occupational Footwear on Dynamic Balance. *Footwear Science* (Awaiting final review for submission)
6. Wade C, **Chander H**, & Garner JC. The influence of boot type on slips in professional firefighters. Fire Safety Journal (Awaiting final review for submission)
7. **Chander H**, Dabbs NC, Wade C. & Garner JC. Temporal and Spatial Parameters of Slip Trials in Firefighters. (Manuscript in Preparation)
8. **Chander H**, Dabbs, NC, MacDonald CJ, Lamont HS, & Garner JC. The relationship of anthropometrics and postural balance in female varsity athletes. *International Journal of Exercise Science* (Manuscript in Preparation)
9. **Chander H,** Garner JC & Wade C. The effect of extended durations of walking in occupational footwear on Muscle Activity. Footwear Science (Manuscript in Preparation)
10. Garner JC, **Chander H**, Dabbs NC, & Wade C. Joint Kinetics during Slip Trials in Firefighters. Journal of Applied Biomechanics (Manuscript in Preparation)

PUBLISHED ABSTRACTS:

1. **Chander H**, Wade C, Allen CR, Cazas VL, Lundahl J & Garner JC. Muscle Activity during Balance Perturbations in Occupational Footwear. Submitted to the World Congress of Biomechanics 2014. Boston, MA, July 6-11, 2014.
2. Waddell DE, **Chander H**, Brewer CB. Exploring measures to better assess the effect of cold on dynamic balance in a young and older female population. International Society for Posture & Gait Research. 2014 ISPGR World Congress, Vancouver, Canada, June 29-July 3, 2014.
3. Garner JC, **Chander H**, Wade C, Dabbs NC, Allen CR, Cazas VL, Lundahl J & Borland CE. The Influence of Occupational Footwear on Lower Extremity Muscle Activity During Balance Perturbations. ACSM 61st Annual Meeting, Orlando, FL, 2014.
4. Dabbs NC, **Chander H**, Cazas VL, Allen CR, Lundahl J, Terrell E & Castles C, Brown LE & Garner JC. Effects of Whole Body Vibration on Vertical Jump Height and Power Output Following Exercise Induced Muscle Soreness in Women. SWACSM 32nd Annual SWACSM Meeting, Newport Beach, CA, October 18-19, 2013.
5. **Chander H**, Wade C, Dabbs NC, Allen CR, Cazas VL, Lundahl J, & Garner JC. The Effect of Occupational Footwear on Dynamic Balance. Abstracted: *Proceedings of the American Society of Biomechanics* Annual Meeting, Omaha, NE, Sept 4-7, 2013
6. Dabbs NC, **Chander H**, Allen CR, Lundahl J, Cazas VL, Hilton MS, Italia MA, & Garner JC. The Effects of Whole-body Vibration on Ground Reaction Forces and Rate of Force Development in College Aged Females. NSCA Annual Meeting, Las Vegas, NV, July 11-13, 2013. *Journal of Strength and Conditioning Research.*
7. Allen CR, Lundahl J, **Chander H**, Zachay C, Dabbs NC, & Garner JC. The Acute Effects of a Performance Mouthpiece on Whole Body Reaction Time to Balance Perturbations. NSCA Annual Meeting, Las Vegas, NV, July 11-13, 2013. *Journal of Strength and Conditioning Research.*

8. Cazas, VL, Brown, LE, Coburn, JW, Galpin AJ, Tufano JJ, Garner JC, Dabbs NC, & **Chander H.** Influences of Rest Intervals Following Assisted Jumping on Peak Velocity, Rate of Velocity Development & Rate of Force Development. NSCA Annual Meeting, Las Vegas, NV, July 11-13, 2013. *Journal of Strength and Conditioning Research.*
9. Garner JC, **Chander H**, Wade C, Dabbs NC, Waddell DE, & Lundahl J. Impacts of Muscle Activity while Walking in Occupational Footwear. Abstracted: *Medicine & Science in Sports & Exercise*, ACSM 60th Annual Meeting, Indianapolis, IN, 2013.
10. Dabbs NC, **Chander H**, Lundahl J, Allen CR & Garner JC. The Effects of Wholebody Vibration on Vertical Jump Height and Peak Power. ACSM Annual Meeting, Indianapolis, IN, May 28-June 1, 2013. *Medicine and Science in Sports and Exercise*, 45(5S): S, 2013.
11. **Chander H**, Garner JC, Wade C, Dabbs NC, Waddell DE & Lundahl J. Impacts of Muscle Activity while Walking in Occupational Footwear. SEACSM Regional Meeting, Greenville, SC, Feb 14-16, 2013.
12. Dabbs NC, **Chander H**, Lundahl J, Allen CR & Garner JC. The Effects of Wholebody Vibration on Vertical Jump Height and Peak Power. SEACSM Regional Meeting, Greenville, SC, Feb 14-16, 2013.
13. Lundahl J, Allen CR, Dabbs NC, **Chander H** & Garner JC. The Acute Effects of a performance Mouthpiece on Measures of strength and power. SEACSM Regional Meeting, Greenville, SC, Feb 14-16, 2013.
14. **Chander H,** Garner JC, Wade C, Roche J, Dabbs NC & MacNeill RL. The Effect of extended durations of walking in occupational footwear. Abstracted: *Proceedings of the American Society of Biomechanics,* Gainesville, FL*, 2012.*
15. Dabbs NC, Garner JC, Ricks RC, **Chander H,** Wilkerson C, & Young J. The Influence of different weighted warm-up bats on swinging performance. Abstracted: *Medicine and Science in Sports and Exercise 44(5), S401, 2012.*
16. Garner JC, **Chander H,** Dabbs NC, Roche J & Wade C. The Influence of occupational footwear on balance. Abstracted: *Medicine & Science in Sports & Exercise 44(5), S336,* 2012
17. Dabbs NC, Garner, JC, **Chander, H,** & Brown, LE. Preliminary Three-Dimensional Examination of the Influence of Different Weighted Warm-up Bats on Swing Kinematics. *Journal of Strength and Conditioning Research 27(1s),* 2012
18. **Chander H,** Wade, C, Garner, JC, Garten, R, & Acevedo, E. The Influence of Firefighter Boot Type on Postural Measures. Abstracted: *Proceedings of the American Society of Biomechanics,* Long Beach, CA, 2011
19. MacDonald CJ, Garner JC, **Chander H**, Gray H, Gentles J, Kavanaugh A, Israetel M, Carter C, Mizuguchi S, & Hornsby W. Comparisons between Body Composition and Power Production during Jumps in Collegiate Female Athletes. Abstracted: NSCA Annual Meeting, Las Vegas, July 6 -9, 2011. *Journal of Strength and Conditioning Research.*

RELEVANT GRADUATE COURSEWORK:

Neuromechanics:

UM ES 512 Foundations of Biomechanics
UM ES 609 Motor Control and Learning
UM ES 612 Instrumentation and Analysis in Biomechanics
UM ES 632 Advanced Structural Kinesiology
UM ES 644 Control of Voluntary Movement
UM ES 548 Biomechanics of Injury
UM ES 514 Applied EMG

Exercise Physiology:

UM ES 611 Exercise Physiology I - ES 611
UM ES 613 Health Aspects of Physical Activity - ES 613
UM ES 608 Methods and Procedures of GXT - ES 608
UM ES 614 Cardiovascular Physiology - ES 614
UM ES 618 Advanced Muscle Physiology - ES 618

Statistics and Research Methodology:

UM ES 625 Research Methodology, Design and Statistics
UM ES 620 Introduction to Statistics
UM PSY 604 Advanced Statistics
UM PHAD 680 General Linear Models
UM PHAD 681 Multivariate Analysis
UM HP 651 Effective Journal Writing

Supporting Course Work:

UM ES 651 Independent Study (Dr. Hugh Lamont - WBV & Vertical Jump)
UM ES 651 Independent Study (ENGR 312 Dr. Elizabeth Ervin - Mechanics of Materials)
UM ES 651 Independent Study (ENGR 309 Dr. Elizabeth Ervin – Statics and Dynamics)
UM ES 653 Independent Research (Dr. John C. Garner - Slip Parameters in Firefighters)
UM ES 653 Independent Research (Dr. John C. Garner - Occupational Footwear & Balance)
UM ES 620 (Dr. Dwight E. Waddell – Visual Basic & MATLAB Coding)
UM ES 650 Graduate Seminar (Dr. John C. Garner)

RFERENCES:

John C. Garner III, **Ph.D., C.S.C.S**
Interim Chair & Associate Professor of Exercise Science
Director: Applied Biomechanics Laboratory (ABL)
The University of Mississippi
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Turner Center 226, All American Drive
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Chip Wade, Ph.D., CPE
Assistant Professor, Risk Management, Insurance, & Financial Planning
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Department of Finance and Economics
312M McCool Hall
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Mark Loftin, Ph.D., FACSM
Associate Dean, School of Applied Sciences and Professor of Exercise Science
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Nicole C. Dabbs, Ph.D.
Assistant Professor of Biomechanics
California State University, San Bernardino
Department of Kinesiology, HP 210
5500 University Parkway
San Bernardino, CA 92407
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