

MODELING OF THE ONSET OF SLIP DURING WALKING

Philip Requejo,¹ Judith M. Burnfield,^{1,2} and Jason Leach³

¹Pathokinesiology Lab, Rancho Los Amigos National Rehabilitation Center, Downey, CA

²Movement Sciences Center, Madonna Rehabilitation Hospital, Lincoln, NE

³The Rockport Company, Ronks, PA

Contact: prequejo@larei.org

Introduction

Slips are a leading cause of falls and injuries in the home and work environments.¹ During walking, the forces generated by the body are transmitted through the foot to the floor. In order to prevent a slip, sufficient friction (traction) is required at the foot floor interface. The probability of a slip event rises as either the friction that a person utilizes (COF_U) increases or the friction that is available from the floor surface (COF_A) decreases.² In the research setting, a person's COF_U during walking is calculated from force plate recordings. The COF_U is defined as the ratio between the shear and vertical components of the ground reaction force. The COF_A of the floor surface can be measured using a device called a tribometer. The objectives of this work was to develop a dynamic model of slip to determine the interaction between human (center of mass velocity; COF_U) and environmental factors (COF_A) on slip outcome using experimentation and dynamic simulation approach.

Statement of Clinical Significance

The reduction of deaths from falls has been identified as a national priority in *Healthy People 2010 Objectives for Improving Health*. Modeling and simulation can be used to identify specific individuals or environmental conditions that pose the greatest risk for slip onset and could serve as a basis for proactive human (gait, strengthening) and environmental (footwear, flooring) interventions to reduce the risk of falls and injuries.

Methods

Experimental kinematic (120Hz, VICON), kinetic (1200Hz, AMTI), and video data were recorded simultaneously as a healthy 30 year old female (height, 1.59 m; mass 65.7 kg) walked at a self-selected speed under conditions of normal and reduced floor surface slip resistance. Prior to her participation, she signed an informed consent form approved by the Institutional Review Board of the University of Southern California Health Sciences. The subject wore a fall-arresting body harness to ensure safety, and was provided with a pair of Rockport World Tour walking shoes (model MWT18) for use during testing. Following multiple non-slip walking trials, WD-40 was applied to the surface of the force platform to initiate a forward heel slip. Whole body center of mass (CM) velocity in the horizontal direction was calculated from kinematic data. The peak COF_U value during weight acceptance was determined from ground reaction forces recorded during speed matched non-slip walking trials. The COF_A of the clean and contaminated floor surface was measured using a variable incidence tribometer. To determine the material properties associated with the forefoot and heel regions of Rockport walking shoes, ten separate pairs were tested.

A two-dimensional 8-segment model representing the combined head and torso, arms, and right and left thighs, shanks, and feet plus non-linear visco-elastic elements representing the shoe/floor contact forces at the heel and toe region were implemented into a dynamics simulation software package (ADAMS, Mechanical Dynamics). Experimental data from the walking trials were integrated into the modeling and simulation process. The stiffness (k) and damping (C) constants of the vertical contact force were modeled using material testing results. The coefficient of friction parameter range of the

horizontal contact force model was determined from experimental results and modified to simulate non-slip and slip walking.

A simulation study was performed to assess the influence of CM horizontal velocity (CMv_x) and floor surface slip resistance on the magnitude of slips. The CMv_x at heel strike was incrementally adjusted for each available slip resistance value (COF_A). At each simulated condition, the stance leg heel horizontal displacement 400ms after heel strike was measured. The result showed the causal relationship between these mechanical conditions and the magnitude of forward heel displacement.

Results

The peak COF_U during non-slip walking trials was $\mu = 0.246 (\pm .014)$ while the available slip resistance (measured with the tribometer) was $\mu = 0.88$. The available slip resistance during the slip walking trial was $\mu = 0.17$. An exponential function with $k = 3.8 \times 10^8$ (heel), 8.4×10^8 (toe) and $C = 2.0 \times 10^7$ (heel), 9.0×10^7 (toe) was fitted to the force-deformation data (Figure 1a).

From the simulation study, maximum slip occurred at lowest slip resistance ($\mu = 0.1$) and highest heel strike CM velocity ($CMv_x = 1.81$ m/s). At the experimentally observed velocity ($CMv_x = 1.61$ m/s), the slip resistance ($\mu < 0.1625$) resulted in a slip condition. In order to minimize forward heel slip displacement at faster CM velocities, greater available slip resistance was required (Figure 1b).

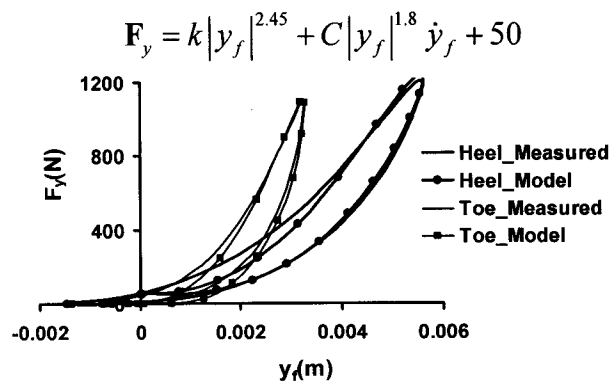


Figure 1a. Measured versus modeled force-deformation curves for both the heel and toe region of the shoes used for non-slip and slip walking trials.

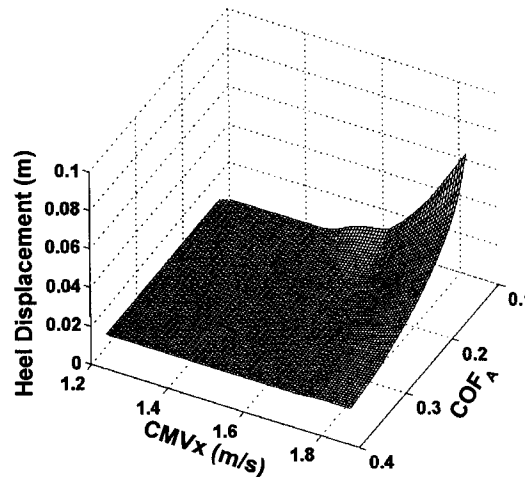


Figure 1b. Simulated relationship between horizontal CM velocity, available slip resistance (COF_A), and forward heel displacement during weight acceptance period of walking.

Discussion

Both greater horizontal CM velocity and reduced floor surface slip resistance were associated with increased simulated forward heel displacement during walking. Future work will be directed at improving the model and simulating the impact of other human (e.g., impact angle of the leg, strength) and environmental factors (shoe stiffness) on slip onset and recovery potential.

References

1. Berg et al (1997). *Age and Ageing*, 26(4), 261-268.
2. Hanson et al (1999). *Ergonomics*, 24(12), 1619-1633.