DISCREPANCIES IN KINEMATICS AND DYNAMICS OF MILD AND SEVERE SLIPPING

[1] Mohammad Moein Nazifi, [2] Kurt Beschorner, PhD, and [1] Pilwon Hur, PhD

[1]Department of Mechanical Engineering, Texas A&M University, College Station, TX, USA
[2]Department of Bioengineering, University of Pittsburgh, PA, USA
email: {moeinnazifi,pilwonhur}@tamu.edu, beschorn@pitt.edu, web: http://hurgroup.net

INTRODUCTION

Slips, trips, and falls were identified as the second leading cause of fatal occupational injuries during 2014-2015 [1]. These injuries cost over $180 billion damage each year, nationally [2]. Hence, studying slips and falls is necessary to avoid this damage. Additionally, studies have shown that slips can be classified into "mild" and "severe", where severe slips are more dangerous and more prone to result in a fall [1]. Consequently, methods that can help diagnose severe slippers are highly valuable.

Several studies have tried to use kinematic, dynamic, and neuromuscular variables to classify mild and severe slippers [3]. These methods targeted both gait and slipping behaviors of individuals to identify persons with high risk of fall. However, to the best of our knowledge no studies have tried to study the center of mass (COM) height, sagittal angular momentum (*H*, a representation of rotation of a body, equal to body's angular velocity multiplied to its inertia), and single/double support phase's length in different severity groups. These measures have been proven to be of crucial importance in gait control and may be critical in slip severity as well [4, 5].

The objective of this study is to compare COM's height, sagittal angular momentum, and single/double support (SS/DS) phase length between mild and severe slippers, during walking and slipping, to identify differences. We hypothesize that mild and severe slippers would differ in these measures, indicating their different gait and slip control.

METHODS

Eleven male and nine female healthy adults, free of gait disorders, participated in this IRB approved study by signing a written consent. Subjects first performed several walking trials in a long pathway at their convenient speed. After several walking trials, the pathway was contaminated to collect slip data. Subjects donned reflective markers (Vicon 612, Oxford, UK; collecting at 120Hz), PVC-soled shoes, and a harness throughout the experiment.

Markers' data was low-pass filtered at 10Hz, with a zero-lag second order Butterworth filter. Using markers data, subjects were classified to mild and severe slippers. A slip was considered severe if the Peak Heel Speed (PHS) exceeded 1.44 m/s [1]. COM and H were calculated using segmental analysis method, using markers and anthropometric data [4]. *H* was calculated as sum of the creoss product of the distance from COM to each limb's relative velocity (to COM) and mass. Also, heel strike and toe-off moments were identified and used to calculate the SS/DS lengths. These analyses were done for a full gait cycle before the slip initiation (i.e. heel strike on the slippery surface), and 30% of each individuals' gait cycle time length while slipping. The gait cycle was normalized to 100 points (percent) for everyone to facilitate the inter-subject comparisons. COM was normalized to subjects' height and reported as a percent of their height. *H* was reported as a dimensionless value, normalized to each individual's mass, height, and gait speed [5].

An independent *t*-test (SPSS, IBM, Chicago, IL) was performed on COM, *H* and support to check if the discrepancies between different severities are significant at level of 0.05.

RESULTS AND DISCUSSION

For COM height, there was no significant differences between mild and severe slippers preceding heel contact on the contaminant. However, severities differed post-slipping, starting during 24%-30% of the gait into slipping (Fig. 1a). Also, severe slippers had a significant larger post-slip angular momentum (Fig. 1b), from 3%-27%. There were also two gait discrepancies found in *H* presented in Fig. 1b. Lastly, mild slippers showed a longer single support phase after slip initiation (Fig. 1c, SS2).

The results suggest a strong association between COM height post-slip and slip severity (Fig. 1a, *p*-value<0.05). Subjects who could maintain their COM experienced less severe slips. Previous research also claimed a significant height drop can be used to identify "falls" in presence of harness.

Sagittal angular momentum found to be different in two small windows (-93%~-81%) and (-26%~-23%) within the gait (pre-slip) (Fig. 1b, *p*-value=0.05), and a large window during slipping (3%~27%) (Fig. 1b, *p*-value<0.001). The values calculated for *H* stayed consistent with previous studies [5]. The post-slip difference, can clearly be due to rapid lower extremity movement in severe slippers. The excessive *H* seems to be eventually restrained around 27% post-slipping, which coincides with rapid counter-balance hand movements in subjects [6] to lower the excessive angular momentum. The pre-slip differences however, require further investigations in future studies.

Lastly, severe slippers exhibited a significant shorter single support post-slipping (Fig. 1c, *p*-value<0.001). This can be interpreted as an enforced "toe-touch" response [6] from the unperturbed limb as a measure to increase base of support to provide more stability throughout slipping, where mild slippers did not require such a support to maintain their balance.

CONCLUSIONS

This study examined COM height, sagittal angular momentum, and single/double support phase length in mild and severe slippers and found several significant differences. Mild slippers could maintain their COM higher and regulate their *H* compared to severe slippers. These differences may help understand the underlying causes of severe slipping to prevent them and eventually, prevent falls, and also be useful in designing preventive devices to warn severe slippers before fall incidents. Future work will investigate if these observed associations are causal for severe slipping or not.

ACKNOWLEDGEMENT

We appreciate Dr. Rakie Cham providing the data (collected under NIOSH R01 OH007592) for this analysis.

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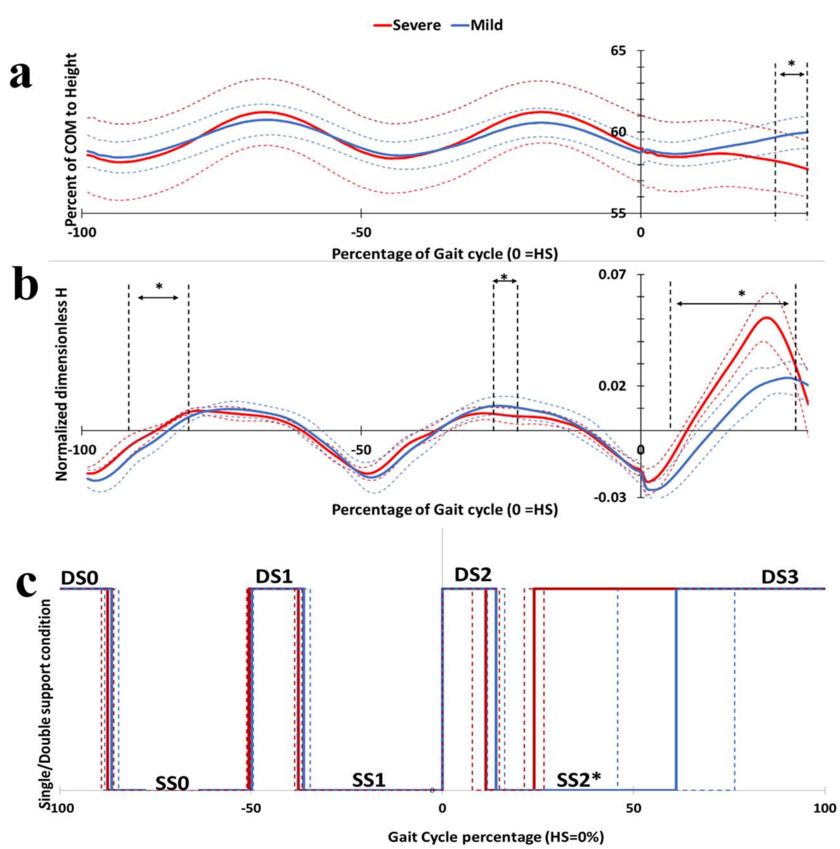

Figure 1: The COM height (a), sagittal H (b), and SS/DS (c) in mild and severe slippers. Asterisks show significant differences and dashed lines present SD.