INTRODUCTION
Falls are a major source of injury in older adults, and over 90% of all hip fractures are sustained after a fall (Grisso et al, 1991). Laterally directed falls in particular expose the hip to impact, placing a person at high risk for fracture. During normal gait, friction between the stance foot and the ground contributes to a moment about the hip, which arrests and reverses lateral trunk motion. During a slip this hip moment can be considerably reduced. We have recently observed a high incidence of laterally directed falls following a slip (Troy et al, in review). The purpose of the present study was to determine what factors contributed to this phenomenon.

METHODS
Twenty-one independent and community-dwelling older adults (8 males, age 70.9±5.1 years, height 165.6±10.9 cm, mass 72.2±13.2 kg) participated in this institutionally approved study and provided written informed consent prior to participation. Subjects were screened by a physician for exclusion factors that included neurological, musculoskeletal, and cardiovascular disorders. During testing they wore an instrumented safety harness that precluded contact of the hands, knees, or buttocks with the ground in the event of a fall. Subjects walked through a motion capture volume and over a 2.4 x 1.2 m Plexiglas sheet, the surface of which was coated with a film of water soluble lubricant allowed to dry. Several control trials during which the subject knew there was no threat of slipping were recorded both with and without the safety harness. Immediately prior to the slipping trial and without the subjects’ knowledge, the Plexiglas was sprayed with a mist of water, causing the lubricant to become very slippery. Each subject was only slipped once. Because most subjects slipped with their left foot, the data for those who slipped with their right foot were mirror-imaged so that comparisons between all subjects could be made. Data will be referenced to slip foot side or recovery foot side.

Data were recorded at 60 Hz from 22 passively reflecting markers, used to construct a 13 segment rigid body model. From motion capture data (Motion Analysis, Santa Rosa, CA) the onset of the slip and the instant of recovery (the instant the non-slipping foot contacted the surface) were identified. The following variables were calculated for each subject: heel-to-hip distance of the slipping foot in the mediolateral direction at heel strike, mediolateral foot displacement from heel strike to recovery, lateral displacement of the recovery foot from the body center of gravity, and trunk angle and angular velocity in the sagittal and frontal planes 133 ms after recovery. This time point was chosen to examine the effectiveness of the recovery response and because no subject had yet engaged the safety harness.

Subjects were classified as fallers if they were completely and continuously supported by the harness after losing their balance due to the slip. Fall direction was quantified using trunk position and angular velocity 133 ms after the instant of recovery. Subjects were classified as backwards fallers if their trunk was in extension and had an extension velocity of greater than 50 deg/s. Subjects were classified as lateral fallers if at recovery their trunk was laterally flexed and had a lateral flexion velocity of greater than 50 deg/s in the same direction (left/right).

For each group (lateral fallers and non-lateral fallers), Pearson correlations were
calculated for all variables. T-tests were used to compare lateral to non-lateral fallers.

RESULTS AND DISCUSSION
Eighteen of the 21 older adults fell after being slipped. Of the 18 who fell, 10 were classified as lateral fallers, 10 were classified as backwards fallers, 3 fell diagonally, and 1 had no rapid trunk motion (other than vertically down).

Two variables were significantly different between lateral and non-lateral fallers: frontal plane trunk velocity at rec+133 (lateral fallers: 88°±28°, non-lateral fallers: 32°±23°, p<0.001) and M/L slip distance (2.45±6.47 cm of medial displacement vs. 5.74±7.04 cm of lateral displacement, p=0.03). Only two of the eight subjects who did not fall laterally experienced medial foot displacement.

Table 1 Summary of Pearson correlation results.

<table>
<thead>
<tr>
<th></th>
<th>M/L slip displ</th>
<th>heel-to-hip dist</th>
<th>lateral dist recov. foot to body COG</th>
<th>frontal plane angle</th>
<th>Lateral Fallers</th>
<th>Non-Lateral Fallers</th>
</tr>
</thead>
<tbody>
<tr>
<td>heel-to-hip dist</td>
<td>0.59</td>
<td>-0.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>lateral dist recov. foot to body COG</td>
<td>0.02</td>
<td>-0.80**</td>
<td>0.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>frontal plane angle</td>
<td>-0.69*</td>
<td>-0.77**</td>
<td>0.06</td>
<td>0.93**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>frontal plane ang veloc</td>
<td>-0.76*</td>
<td>-0.80**</td>
<td>0.06</td>
<td>0.93**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01 (2-tailed)
+ M/L slip displ. Indicates the foot has moved laterally
+ angle/velocity indicates a tilt towards the slip foot
+ heel-to-hip dist. indicates the heel is lateral to the hip

For subjects who fell laterally, the more lateral the M/L foot displacement, the larger the trunk angle and angular velocity away from the slipping foot (Table 1). In this group of subjects heel-to-hip distance at heel strike was strongly associated with both frontal plane trunk angle and angular velocity. For the eight subjects who did not fall laterally heel-to-hip distance predicted M/L slip distance, which was associated with larger trunk angles but not angular velocity. Interestingly, heel-to-hip distance was negatively correlated with M/L slip distance in non-lateral fallers, but was positively correlated in lateral fallers (p=0.075).

As expected, six out of the seven individuals who fell laterally towards the slip foot side experienced medial slipping foot motion, whereas two of the three who fell away from the slip foot side experienced lateral foot motion.

To our knowledge this is the first report of laterally-directed falls after slips during forward walking. Nearly 86% of older adults fell after being slipped and over half of them experienced laterally-directed falls.

Many factors including trunk position and velocity in the frontal plane at heel strike, step width, ab- and adductor strength, and upper extremity motion may contribute to medial/lateral foot motion during the slip. However, the data suggest that medial slips may more frequently result in falls to the side than lateral slips, possibly because of the difficulty of executing a more medially placed recovery step requiring a backwards crossover step. Medial displacement of the foot during a slip may be influenced by foot placement and whole body kinematics at slip initiation. The data further highlight the importance of allowing unconstrained motion of the slipping foot (Troy and Grabiner, 2006) and trunk during and after laboratory slips.

ACKNOWLEDGEMENTS
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REFERENCES
Troy et al. Injury Prev. *in review*
Troy and Grabiner, Gait Posture 2006 Dec;24(4): 441-7