THE PRESENCE OF AN OBSTACLE INFLUENCES THE STEPPING RESPONSE DURING SIMULATED AND REAL TRIPS

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INTRODUCTION Falling is a frequent cause of serious injury in the older adult population and trips are a dominant cause of falls. Although there are few laboratory protocols that induce actual trips, there are many studies that utilize surrogate tasks. Performance of surrogate tasks require similar biomechanical characteristic stepping responses, but unlike a trip, these tasks do not involve an obstacle.

Recovery from a trip over a previously unseen obstacle requires safe and rapid negotiation of an obstacle for which limited information has been acquired, followed by restoration of dynamic equilibrium. We hypothesized that the stepping kinematics following an actual trip would be significantly different than those of surrogate tasks having similar rapid execution requisites but that did not involve an obstacle. Specifically, we expected that steps following a trip would be higher and faster than those of the surrogates.

METHODS Thirteen subjects each participated in three different protocols, performed on three separate days. During the experiments the participants were protected from a fall to the ground by a safety harness attached to an instrumented dynamic rope. The first task was a trip that was induced during locomotion (Pavol et al. 1999). No information about the means by which the trip would be induced was provided. The trip was induced during mid-to late-swing by a pneumatically-powered obstacle that was part of the laboratory floor and was not visible to the subject at any time. After being remotely triggered, it rose to a height of 5 cm in about 150 ms. Data from only one trip per subject was collected.

The second task used a motorized treadmill to induce a rapid forward-directed postural disturbance (Owings et al, 2000). Initially the subject stood quietly on the belt of the treadmill (Series 1800, Marquette Electronics, Milwaukee, WI, USA) which, when activated, accelerated to the designated velocity in approximately 150 ms. The subjects were instructed to recover their balance and then continue walking. A maximum of 11 trials were performed by each subject and the fastest treadmill speed was 1.12 m/s (2.5 mph). In the present analysis, only data from the first successful recovery at this speed were used.

In the third task, subjects were released from a static forward leaning position and instructed to recover with a single step (Owings et al, 2000). The subject was positioned at the initial static lean angle with their arms folded across their chest, feet aligned forward with their heels on the ground, shoulder width apart. The lean angle was increased until the maximum recoverable lean angle was determined. Data from the first trial at the maximum recoverable lean angle were used in the present study.

Maximum step height, step length of the leading and trailing limbs (in the leaning task there was no trailing limb data), and peak vertical and peak horizontal velocity of the leading and trailing feet were derived from the kinematics of the reflective markers placed bilaterally over the lateral malleoli.

RESULTS AND DISCUSSION The trajectories of the leading and trailing limbs following the trip were higher and faster than those during the treadmill recovery (Figure 1). MANOVA revealed a significant effect of task (p<0.001). The between-task differences in maximum step height, step length, and peak vertical velocity were all significant (p<0.001). Maximum step height and peak vertical velocity of the leading and trailing limbs were significantly larger during recovery from the trip compared to the treadmill recovery (p<0.01). The step heights of the leading and trailing legs were 12.8±7.3 and 19.0±6.9 cm higher following the trip than
variables were not significantly different between leaning and treadmill tasks.

These results demonstrate important differences in stepping kinematics resulting from a trip compared to surrogate tasks. The state variables associated with recovery from a trip are considerably different than those associated with recovery from a lean or treadmill task, both of which have been implied as surrogates to study recovery from a forward-directed trip (Schillings et al., 1996; Schillings et al., 2000; Owings et al., 2000).

Although the onset of the disturbance was difficult to predict for the leaning and treadmill tasks, the tasks share similarities such as the unambiguous nature of the postural disturbance. During the leaning and treadmill tasks it was obvious to the participants that the floor/treadmill belt was devoid of objects that might obstruct the stepping responses. We believe that these features enhance pre-planning of the recovery task execution, including the specification of a smaller safety factor in terms of maximum step height.

The results of the present study strongly suggest the presence of important differences between the surrogate tasks for forward-directed trips examined here and actual trips. Further, these important differences appear to be related to the presence of an obstacle. If task-specific training is a plausible approach to reducing the incidence of falls and fall-related injuries, then the extent to which the training task resembles the actual task is a key design consideration.

REFERENCES
Pavol et al. (1999) *J Gerontol* 54:M583-590
Schillings et al. (1996) *J Neurosc Meth* 67:11-17
Schillings et al. (2000) *J Neurophysiol* 83:2093

Table 1: *Post hoc* comparisons of recovery leg variables from tripping, treadmill, and leaning tasks, for the reduced data set (7 subjects, all with the same maximum recoverable lean angle).

<table>
<thead>
<tr>
<th></th>
<th>Trip</th>
<th>Treadmill</th>
<th>Lean</th>
<th>p (trip vs. lean)</th>
<th>p (trip vs. tread.)</th>
<th>p (tread. vs. lean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>max height (m)</td>
<td>0.327</td>
<td>0.232</td>
<td>0.216</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.271</td>
</tr>
<tr>
<td>step length (m)</td>
<td>0.935</td>
<td>0.599</td>
<td>0.605</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.816</td>
</tr>
<tr>
<td>peak vertical velocity (m/s)</td>
<td>2.167</td>
<td>1.28</td>
<td>1.16</td>
<td>0.013</td>
<td>0.002</td>
<td>0.285</td>
</tr>
<tr>
<td>peak horizontal velocity (m/s)</td>
<td>4.976</td>
<td>3.851</td>
<td>3.563</td>
<td>0.033</td>
<td>0.081</td>
<td>0.185</td>
</tr>
</tbody>
</table>

Figure 1: Ankle trajectories from (a) treadmill and (b) tripping activities in the sagittal plane, from left to right. In (b) the obstacle location is marked following the treadmill perturbation, respectively. Similarly, peak vertical velocities for the leading and trailing legs after the trip were 0.79±0.77 and 0.93±0.55 m/s faster than after the treadmill.

Foot state variables of the leading limb during the leaning task were not different than those measured during the treadmill task although they were significantly different compared to those of the trip (Table 1). Between-task comparisons of all three activities were limited to the leading limb variables in a subset of subjects (7 total), all of whom had the same maximum recoverable lean angle. MANOVA revealed that compared to the leaning task, tripping resulted in significantly larger leading leg step height, step length, and vertical velocity (p<0.013 for each measure). These