COMPARISON OF SLIP TRAINING IN VR ENVIRONMENT AND ON MOVEABLE PLATFORM

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ABSTRACT

Slip training is gaining popularity as an innovative fall intervention approach. The objective of this study was to compare the efficacy of two different slip training modalities (moveable platform and virtual reality) in reducing fall frequency and improving reactive recovery in older adults. Thirty-six healthy older adults were involved in a laboratory study, and were equally divided into the control group, the moveable platform training (MPT) group, and the virtual reality training (VRT) group. The MPT was achieved by inducing slips using a custom built sliding device consisting of a low friction, motorized moveable platform. The VRT was conducted by inducing visual perturbation in a head mounted display while subjects walked on a treadmill. All groups performed slip trials (kinematics, kinetics and EMG data were collected) on an actual slippery floor surface before and after a training session. The results indicated a significant reduction in fall frequency in both training groups. Between MPT and VRT groups, significant differences were also found in forward trunk rotations, peak knee angular velocity, ankle coactivity, and muscular activity in tibialis anterior. It was concluded that slip training in VR environment could produce comparable results in fall intervention.

Keywords: Elderly, Fall Prevention Training, Virtual Reality, Kinematics

INTRODUCTION

Fall accidents are a common and serious problem in older adults. Annually, one in three Americans over the age of 65 years experience a fall, and many of these falls are recurrent [1]. Among these, slip-induced falls account for 87% of all hip fractures, which often results in functional impairments and may require admission to a nursing home facility [2]. Because the prevalence of fall injuries is high among older adults, there is a need for prevention strategies that will help reduce the risks associated with falls. A training program that helps older adults learn movements directly related to recovery responses may improve their sensory and muscle co-ordination and thus their ability to recover from a slip-induced fall. A specific training regime that has a structural similarity with slip-induced fall is repeated perturbation training. Recently, Bhatt et al. [3] demonstrated improved recovery in young adults after repeated exposure to a simulated slip-perturbation. Similarly, Pai et al. [4] reported that older adults were able to reduce the incidence of backward loss of balance through adaptations to repeated slips induced during sit-to-stand. These findings suggest a potential application of repeated perturbation training as a slip recovery intervention for the elderly.

Slip perturbation training can be performed in various ways, one of which is to repeatedly perturb individuals using a motorized platform. The idea is to produce an overall sensory conflict (similar to a slip) by perturbing the somatosensory system via moving the platform/floor surface underneath the foot while walking. If the speed/acceleration of the motorized platform is matched to characterize an actual slip, participants may elicit similar muscle activations and stepping responses to recover from the perturbation.
An alternate perturbation training that may simulate the visual-vestibular conflict experienced when balance is challenged is through the use of an immersive virtual reality environment. A general training effect (i.e., less stepping response, improved ability to maintain balance) was observed in older adults through repeated exposures to the VR-induced sensory conflicts [5]. Based on these findings, it is reasonable to assume that a VR environment could induce repeated virtual slips via visual-vestibular conflict, causing individuals to elicit reactive recovery responses (i.e., increased muscle coactivity, head and neck motion, and trunk flexion) similar to an actual slip. Although studies have suggested that training with VR may induce goal-directed practice and thus be used in fall prevention programs [6-8], no current VR training is available that aims to improve recovery reactions in older adults. Additionally, the notion of whether learned responses associated with VR training can be translated to an actual slip needs to be investigated.

Therefore, the objective of this study was to compare the efficacy of two different training interventions (moveable platform and virtual reality) in reducing fall frequency and improving reactive recovery in older adults during unexpected slips. It was hypothesized that: 1) the moveable platform group and virtual reality group will have reduced slip severity and reduced fall frequency when exposed to a slippery surface, and 2) the reactive strategies employed (angular kinematics, muscle activations, co-activations) by the moveable platform and virtual reality training group will differ during the transfer of training trials.

**METHODS**

**Participants**

Thirty-six healthy older adults (> 65 years, 18 males and 18 females), were recruited for the study (Table 1). Informed consent approved by local Institutional Review Board (IRB) was obtained from the participants prior to data collection. Participants were equally divided into the control group, the moveable platform training group (MPT), and the virtual reality training group (VRT) using a stratified randomization that controls for age, gender, and body mass.

<table>
<thead>
<tr>
<th>Group (Mean ± SD)</th>
<th>MPT (n = 12)</th>
<th>VRT (n = 12)</th>
<th>Control (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>71.24 ± 6.82</td>
<td>70.54 ± 6.63</td>
<td>74.18 ± 5.82</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>68.24 ± 8.04</td>
<td>67.77 ± 8.04</td>
<td>69.63 ± 9.45</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>167.45 ± 11.52</td>
<td>167.13 ± 11.52</td>
<td>169.41 ± 9.16</td>
</tr>
</tbody>
</table>

**Apparatus**

The moveable platform training was conducted by inducing slips using a custom built sliding device consisting of a low friction, motorized moveable platform (40x120cm). Slips were induced by a computer-controlled program that moves the platform after the heel contact of the slipping foot, when the vertical ground reaction force of the trailing limb drops below a threshold (i.e., 40% of body weight was lifted off the force plate). Details of this set-up have been described elsewhere [9].

The virtual reality training was conducted on an instrumented treadmill (Nordick, T7 si, NY, USA). A head mounted display (Glasstron LDI–100B Sony, with a 28° horizontal field of view in each eye) was used to render the virtual reality scene. A regular downtown VR scene was generated with buildings, light poles, road, pavement, street signs, etc. The virtual slip consisted of perturbations (tilts) in the pitch plane of the VR scene at random intervals. Details of this set-up have been described elsewhere [10].
All groups performed slip trials on a slippery floor surface twice (Slip1 and Slip2), separated by a training session for the training groups, or a normal walking session for the control group. The slip trials were conducted on a walkway 15 m long. The walkway was embedded with two force plates, which was used to record gait characteristics and induce an actual slip. The slippery surface (i.e., top of one the force plates) was covered with a water and jelly mixture (1:1) to reduce the coefficient of friction (COF) (dynamic COF = 0.12) of the floor surface. Unexpected slips were induced while participants walked on the walkway. Details of this set-up have been described elsewhere [11].

**Measurement:** Full-body kinematics were recorded at 100 Hz using a six-camera motion capture system (Qualisys). Twenty- four reflective markers were attached to various bony landmarks of the body. The marker configuration was similar to previous studies [12]. Kinetic data were collected at 1000 Hz from the force plates. Eight-channel EMG telemetry Myosystem 2000 (Noraxon, USA), was used to record bilateral temporal activations of various muscles in the lower extremity during all the sessions. Bipolar Ag-AgCl surface electrodes was placed over vastus lateralis (VL), medial hamstring (MH), and tibialis anterior (TA) and medial gastrocnemius (MG) muscles of the lower extremity. The EMG data were sampled at 1000Hz. Uniform clothes and shoes were provided to all participants to minimize loose clothing and shoe-sole differences. Participants wore a full body fall-arresting harness throughout the experiment [12].

**Protocol**

The experiments were divided into three sessions: baseline measure, training acquisition, and transfer training, on three separate days. During the first session, all participants underwent a slip trial on a slippery floor surface as a baseline measure. After two weeks, the training groups performed the slip training and the control group performed normal walking trials. During the third session, all groups were exposed to a slippery floor surface similar to the baseline session.

The MPT group went through repeated simulated slips induced by moving a platform while the participants stepped on it. Participants were unaware of the position of the moveable platform. After collecting data from the walking trials, a simulated slip was induced by moving the platform 0.3 m at a speed of 1.2 m/s (acceleration at 20 m/s2). The training session consisted of 24 trials of slips and no slips (blocked and randomized). Details of this protocol have been described elsewhere [9].

The VRT group performed the training on a treadmill while wearing a HMD with a virtual scene displayed. Participants wore a head mounted display, and the moving scene was adjusted to their speed of walking on the treadmill. After being habituated to the VR, participants were told to look straight ahead and that a slip may or may not be induced. A sudden virtual slip was induced by tilting the environment 25 degrees in the pitch plane at 60o/s. The training session consisted of 24 trials of slips and no slips (blocked and randomized). Details of this protocol have been described elsewhere [10].

After the training groups performed training trials, and the control group performed normal walking trial, all groups came back for the transfer for training session on a slippery surface. The experimental protocol was similar to the baseline slip, and served as Slip2.

**Data Analysis**

The converted co-ordinate kinematic (marker data) and kinetic (force plate) data were low-pass filtered using a 4th order, zero lag, Butterworth filter at a cut off frequency of 7 Hz. The EMG data were digitally band pass filtered at 10-450 Hz following data collection [13], following which they were rectified and low-pass filtered using a fourth order, zero lag Butterworth filter with a 7 Hz cut off frequency to create a linear envelope [13]. All kinematic analyses were performed in the sagittal plane. For normal walking and slip recovery trials, the analyses were conducted for the stance phase (heel contact to toe off).
The dependent variables consisted of several slip severity measures, muscle activations, and angular kinematics during Slip1 and Slip2 trials.

1) Required coefficient of friction (RCOF), slip distances (SDI & SDII) and peak sliding heel velocity (PSHV) was used to describe the severity of slip according to published method [12].
2) Muscle activation onset and time to peak activation for all muscles was calculated using a threshold of two standard deviation above activity during a quiet period of gait cycle [14].
3) Knee and ankle coactivity (ratio of antagonist and agonist muscle pairs), and the time to peak activity was calculated using the method proposed by Rudolph et al. [15].
4) Angular kinematics including peak ankle flexion, knee flexion, hip flexion, and trunk extension angles after slip-start, along with angular velocities were calculated as described previously [9].

To examine any training induced proactive changes in participants several gait measures were included: 1) center-of-mass velocity at heel contact (COMvel), 2) transitional acceleration of the whole body center-of-mass (TA_COM), 3) ankle, knee, hip, and trunk angles at heel contact, 4) muscle onset and coactivity (ankle and knee) at heel contact. Details on these parameters can be found in our previous publication [9].

To examine effects of the two different training interventions (MPT, VRT) on reducing slip severity and improving recovery reactions, difference values were calculated between the two slips (Slip2 – Slip1), and a one-way analysis of variance (ANOVA), was conducted on each dependent measure between the two groups. The frequency of falls was analyzed between the two groups (control vs. training) for Slip1 and within the training group (Pre and Post) using the chi square (χ2) test statistic.

To determine if both groups had similar gait and slipping characteristics during Slip1, a one-way ANOVA was conducted on gait measures (COMvel, TA, and RCOF at heel contact), and slip measures (SDI, SDII and PSHV). All statistical analyses were conducted using SPSS 11.5.0 (Chicago, IL) with a significance level of p < 0.05 for all tests. In order to verify the assumptions of ANOVA, all of the data were evaluated for normality (using Shapiro-Wilk W test), and sphericity (using Bartlett’s sphericity test). The results indicated no significant violations of assumptions.

**RESULTS**

The fall frequency reduced significantly in the MPT (p = 0.001) and VRT (p = 0.003) compared to control group (Table 2). All groups were at a similar fall rate during the first unexpected slip, accounting for no group differences. Table 3 and 4 summarizes the various dependent variables related to proactive and reactive adaptations that were influenced by MPT and VRT.

<table>
<thead>
<tr>
<th></th>
<th>MPT (n=12)</th>
<th>VRT (n=12)</th>
<th>Control (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of falls (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slip1</td>
<td>41% (5)</td>
<td>0% (0)</td>
<td>50% (6)</td>
</tr>
<tr>
<td>Slip2</td>
<td></td>
<td></td>
<td>25% (2)</td>
</tr>
</tbody>
</table>

In terms of proactive adjustments, significant differences were found in TA (p = 0.04) between MPT and VRT groups. TA reduced more from Slip1 to Slip2 in the MPT group compared to the VRT group. No significant differences were observed in other proactive adjustments between MPT and VRT groups. In terms of reactive recovery, the one-way ANOVA between MPT and VRT group indicated significant differences in the peak trunk angular velocity (p = 0.01) and peak knee angular velocity (p = 0.001). The peak knee angular velocity decreased more from Slip1 to Slip2 in the MPT group compared to the VRT group.
group (Figure 2). The peak trunk angular velocity reduced more in the VRT group compared to the MPT group (Figure 2). No significant changes were found in the other peak angles and angular velocities.

### Table 3 – Statistical differences in proactive adjustments between groups

<table>
<thead>
<tr>
<th>Kinematics</th>
<th>EMG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Angles at heel contact</strong></td>
<td><strong>Activation Onset</strong></td>
</tr>
<tr>
<td>Ankle plantarflexion</td>
<td>MG (ankle plantflex)</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>TA (ankle dorsiflex)</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>MH (knee flex)</td>
</tr>
<tr>
<td>Trunk flexion</td>
<td>VL (knee ext)</td>
</tr>
</tbody>
</table>

### Table 4 Statistical differences in reactive recovery parameters between groups

<table>
<thead>
<tr>
<th>Slip measures</th>
<th>Kinematics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak angles</strong></td>
<td><strong>Activation Onset</strong></td>
</tr>
<tr>
<td>SDI</td>
<td>Ankle plantarflex</td>
</tr>
<tr>
<td>SDII</td>
<td>Knee flex</td>
</tr>
<tr>
<td>PSHV</td>
<td>Hip flex</td>
</tr>
<tr>
<td>EMG</td>
<td>Trunk ext</td>
</tr>
</tbody>
</table>

### Significant differences were found in the time to peak angle and angular velocities between the groups. The peak ankle coactivity reduced more in the MPT group (p = 0.001) compared to the VRT group (Figure 3). The knee coactivity decreased in both MPT and VRT group but no significant differences
were found (Figure 3). No significant differences were found in the onset of muscle activity (MG, TA, MH, and VL) between groups. However, time to peak TA muscle activity decreased more in the MPT group compared to the VRT group (p = 0.02). In terms of slip severity, both training groups reduced slip distances and peak sliding heel velocity, however no significant differences were observed between them.

DISCUSSION

The objective of the study was to compare efficacy of two different perturbation training (MPT and VRT) methods in reducing fall frequency and improving recovery mechanisms in older adults. Both training groups were able to reduce their fall frequency after training (MPT: 41% to 0%, VRT: 50% to 0%). Both training methods were able to reduce fall frequency via proactive and reactive adjustments after the training.

The comparison indicated a significant effect of VRT in reducing forward trunk rotations as compared to the MPT group. As indicated by Troy&Grabiner [16], reducing trunk rotations will have a significant effect in bringing the COM of the body within boundaries of stability. The VRT group had a significant effect on lower extremity angles and angular velocity; with a decreased peak knee flexion angle and angular velocity compared to the VRT group. Similar adaptations were observed in the MPT group during training, indicating a positive transfer may have occurred. In terms of proactive changes, MPT group had a significantly reduced TA. TA is important in assessing the forward momentum of the body during recovery from a backward loss of balance [12]. Both training methods had an effect on the neuromuscular characteristics (reduced knee coactivity, early activations of the muscles). However, ankle coactivity significantly reduced in the MPT group as compared to the VRT group.

In general, significant changes were observed in the lower extremity corrections to a slip in the MPT group, as compared to the upper body (i.e., trunk) corrections in the VRT group. This may be expected due to the differences in the perturbations used by each training method. The moveable platform created
a whole body perturbation by moving the foot over it. Due to this, participants may have initiated recovery reactions using their lower extremity (ankle and knee), and a secondary response by using their hip and trunk. In the VRT training, the visual perturbation induced an initial perturbation to the upper body (head, neck, arms, and trunk), followed by a secondary response by using the lower extremity. Similar results were reported by Bugnariu et al. [5], where older participants initiated balance reaction by activating their neck muscles first in response to a VR-induced sensory conflict while standing still, suggesting an excessive reliance on visual inputs. In this study, during the VRT training, participants did not experience more than 2-3 perturbations and thus it was difficult to generalize the changes to Slip2. Whereas in the MPT group, older participants modulated their proactive and reactive strategies during training, and reached a stable plateau by 6-7 training trials. This may be used as preliminary information on the time older adults required to refine and adapt their movements when experienced with slip perturbation.

In terms of feasibility, both training methods had their advantages and limitations. One of the limitations of the VRT trials was the inability to induce perturbations in older adults after 2-3 training trials. Participants adapted their walking to the VR and the visual perturbation. However, it required less space utilization (i.e., treadmill and the HMD), and has a potential to be used as a mobility tool for older adults with gait instability. Due to its portability, it may be beneficial to be used in community and care facilities. Additionally, older participants in the study were comfortable wearing the HMD and provided positive feedback on the VR environment experience. A few studies have shown a beneficial effect of VR in improving mobility in older adults [5, 17]. VR environments can be easily altered to create a desired scene, with perturbations in any direction. By using different intensities and types of visual tilts of the VR scene, VR environment can be made more rich and novel to the participants.

In the MPT training, the moveable platform was able to induce perturbation in participants in all the training trials. After the initial training trials, even if participants made significant proactive changes while approaching the platform, a slip was induced in them by moving the platform. Therefore, repeatability was an advantage in the MPT training. However, more space is required to create the whole set-up and significant cost may be involved (i.e., force plate, motorized unit, and track). Additionally, two participants reported anxiety while approaching the moveable platform due to the physical perturbation. Further studies may evaluate the dose-response relationship between different speeds, distance of movement, and biomechanical and neuromuscular changes.

**CONCLUSIONS**

In conclusion, both moveable platform and virtual reality training interventions have a potential to be used as slip-training methods for older adults. Future studies may test these interventions with a larger population sample, especially the fall prone individuals who are at the highest risk for injury. Additionally, future studies may evaluate the retention of the training effects. Furthermore, it would be beneficial to conduct a longitudinal study to report fall frequency in the participants post training.

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