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Practicing recovery from a simulated trip improves recovery kinematics after an actual trip

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Abstract

The goal of this study was to determine if practicing recovery from a simulated trip improved the ability of older adults to recover from an actual trip. Twelve healthy older adults ranging in age from 63 to 83 years were randomly assigned to either a control or an experimental group. Each group performed one trip before and one trip after an intervention. The experimental group received trip recovery training on a modified treadmill while the control group walked on a treadmill for 15 min. Compared to the control group, the experimental group showed greater reduction in maximum trunk angle ($p = 0.027$) and time to maximum trunk angle ($p = 0.043$), as well as increased minimum hip height ($p = 0.020$). Although the results showed beneficial effects of trip recovery training on actual trip recovery, future studies should explore the ability to retain improvements over extended periods.

Keywords: Falls; Older adults; Intervention

1. Introduction

Falls are a major cause of injury and death in adults aged 65 and older (65+ years). Over 1.85 million people in the United States aged 65+ years were treated in the emergency room for fall-related injuries in 2004, which amounts to over 5000 being treated every day [1]. Approximately 37 adults aged 65+ years die every day from a fall-related injury [1]. The number of adults in the United States aged 65+ years is expected to increase by 51.6 million between now and 2050 [2]. Based on these projections, the prevalence of fall-related injuries and death is expected to grow substantially.

Numerous exercise interventions have been proposed to help prevent falls in older adults [3–5]. These include resistance training, endurance training, balance training, and other therapies. Although it is generally accepted that exercise has a prophylactic effect on the risk of falls [6], some exercise interventions show no beneficial effect on fall rates [3,7], and others have been associated with an increase in falls [8]. The most effective type, intensity, frequency, and duration of exercise in preventing falls have yet to be identified [9,10].

An alternative approach is to apply motor learning principles to fall prevention. The premise is that falls can be prevented by practicing (and learning) movements directly related to fall prevention in a safe, controlled setting. Many older adults are thought to have the motor and sensory abilities necessary to recover from a large postural perturbation without falling [11]. Nevertheless, integration and coordination of these abilities may decline with advancing age and compromise their ability to enact stepping responses required for balance recovery. Practicing movements related to balance recovery may allow older adults to effectively "re-learn" appropriate sensory integration and muscle coordination, and improve their ability to recover from a large postural

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perturbation without falling. For example, Owings et al. [11] reported adaptations of stepping responses after repeated exposures to a simulated trip that were consistent with an improvement in trip recovery ability. Similarly, Pavol et al. [12] demonstrated an improvement in slip recovery following repeated exposures to a slipping perturbation. These findings justify further investigation of ‘‘trip recovery training’’ as a fall prevention intervention.

Trip recovery training can be performed in a variety of ways, one of which is to trip individuals while walking over ground. If this intervention is ever to be applied clinically, the physical space required for such a setup would be considerable. As such, the approach employed here uses a treadmill modified to accelerate quickly from zero to a comfortable walking velocity. The quick acceleration displaces the feet posteriorly to bring the body center of mass (COM) anterior to the base of support, as would occur in an actual trip. The stepping response after this ‘‘simulated trip’’ on the treadmill is qualitatively similar to the stepping response after an actual trip [11]. Placing an obstacle in front of the feet prior to accelerating the treadmill requires an initial recovery step over the obstacle that resembles the initial recovery step over an obstacle after an actual trip [13]. Although participants do not actually trip during this simulation, the goal of the training is to allow participants to practice the response required to step over an obstacle, as would be required after an actual trip.

Motor learning is necessary in order for any improvements in motor performance during trip recovery training to be retained over extended periods of time. Moreover, in order for trip recovery training to be an effective fall prevention intervention, participants must be able to transfer the motor performance skills learned during training to recovery from an actual trip. Little is known about the ability of older adults to transfer a learned skill related to postural control between tasks. Therefore, the main aim of this preliminary study was to determine if trip recovery training improves the ability of older adults to recover their balance after an actual trip. It was predicted that repeated exposures to a simulated trip on a treadmill would improve recovery kinematics after an actual trip.

2. Methods

Twelve healthy, community-dwelling older adults (six men and six women) ranging in age from 63 to 83 years participated in the study. A medical screening was performed to exclude participants with any neurological, cardiac, respiratory, otological, or musculoskeletal disorders, or a history of multiple falls within the past year. Participants were also required to have a minimum bone mineral density of 0.65 g/cm^2 in the femoral neck as assessed by dual-energy X-ray absorptiometry (Norland Medical Systems, Fort Atkinson, WI) [14]. The study was approved by the Virginia Tech Institutional Review Board, and written consent was obtained from all participants.

The experiment employed a two-group pretest–posttest design. Participants were randomly assigned to either an experimental or control group while maintaining three males and three females in each group. There was no difference in height ($p = 0.795$) or body mass ($p = 0.571$) between groups. Each group performed one trip before (Trip 1) and one trip after (Trip 2) an intervention. The intervention for the experimental group was trip recovery training on a treadmill while the intervention for the control group was simply walking on a treadmill. It was predicted that the experimental group would exhibit a greater improvement in trip recovery performance from Trip 1 to Trip 2 compared to the control group. A single investigator who was not blinded to each participant's group conducted all data collections.

To start the experiment, participants walked repeatedly along a 9 m walkway at a self-selected pace while looking straight ahead (Fig. 1). They were informed that a trip might occur in any trial. Participants were instructed to, upon tripping, simply regain their balance and continue walking. After a minimum of 20 walking trials, a 7.6 cm (3 in.) high pneumatically driven obstacle embedded in the floor was triggered manually to elicit a trip. The obstacle rose in approximately 160 ms from time of activation. Two non-functional dummy obstacles, which appeared to be identical to the tripping obstacle prior to activation, were placed in the walkway so that participants were unaware of where the trip would occur. Using this setup, trips were induced in the mid-to-late swing phase of gait. Participants wore a full body harness for the duration of the experiment to prevent a fall to the ground in the event of an unsuccessful trip recovery. The length of the lanyard connecting the harness to a ceiling-mounted support track was adjusted so that when participants reached for the ground, there was approximately 2 in. between the fingertips and ground.

After Trip 1, the experimental group performed trip recovery training on a modified treadmill. Participants stood quietly on the inactivated treadmill while looking straight ahead, and a 7.6 cm high obstacle was placed approximately 5.0 cm in front of the participants' feet. Upon activation, the treadmill accelerated to 0.89 m/s (2.0 mph) in approximately

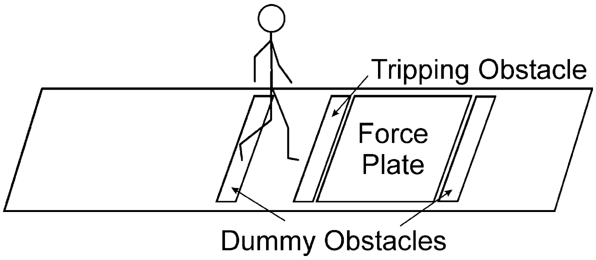

Fig. 1. A schematic of the experimental set up. The functional tripping obstacle was positioned between two non-functional dummy obstacles. Although participants were not informed of how a trip would occur, dummy obstacles were used so the participants would be unaware of where a trip may occur. A force plate recorded ground reaction forces after the trip.

190 ms, and participants attempted to step over the obstacle and continue walking. The goal of the training was to allow participants to practice the stepping movements required to step over an obstacle and recover their balance after a simulated trip. The obstacle was used to require an initial recovery step that resembled the initial recovery step after tripping [13]. After recovering their balance and establishing a stable gait pattern, the treadmill was slowly decelerated to zero velocity, and participants were provided a short (20 s) rest.

A total of 20 trials were performed, 10 while stepping initially with the right leg and 10 while stepping initially with the left leg. After the first two trials of each leg, the treadmill speed was either increased or decreased by 0.089 m/s (0.2 mph) depending on whether the participant succeeded or failed in recovery (a trial was deemed a failure if the participant visually appeared to use the harness for support). Increasing the speed after a successful recovery provided a greater challenge to participants, which can improve motor learning [15]. Decreasing the speed after a failed recovery provided a better opportunity for a successful recovery, which can also improve motor learning [15]. The last two trials of each leg were performed with the treadmill accelerating to the same speed used in the initial two trials (0.89 m/s) to evaluate changes in performance and motor learning during trip recovery training itself (focus of a separate study). The entire trip recovery training protocol lasted approximately 15 min. The intervention for the control group involved walking on the treadmill at 0.89 m/s for 15 min. After their respective interventions, both the control and experimental groups were tripped again while walking after a minimum of 20 walking trials.

Whole body kinematics, ground reaction forces, and force applied to the harness were recorded during randomly selected walking trials as well as during Trips 1 and 2. Nineteen reflective markers were placed bilaterally over selected anatomical landmarks on the head, arms, trunk, and lower extremities. Marker data were sampled at 100 Hz using a Vicon 460 motion analysis system (Vicon Motion Systems Inc., Lake Forest, CA) and low-pass filtered at 7 Hz (second order zero-phase-shift Butterworth filter). Ground reaction forces were sampled at 1000 Hz using a force platform (Bertec Corporation, Columbus, OH) and were used to determine the time of foot contact after the trip. Force applied to the harness was sampled at 1000 Hz using an inline load cell (Cooper Instruments & Systems, Warrenton, VA) and was used to determine the outcome of the trial. A trial was classified as a failed recovery if the force exerted on the load cell exceeded 200 N [16].

Trip recovery performance was quantified using several measures derived from the kinematics data that have previously been shown to differ between successful and failed trip recoveries [17]. These measures focused mainly on the importance of controlling the trunk segment after tripping in order to prevent a fall [18,19], and were based on whole body COM estimated from anthropometric measurements [20], trunk angle defined as the angle between the trunk segment (mid-point of the shoulders to the L3L4 joint) and vertical, and trunk angular velocity calculated as the time derivative of trunk angle. These measures included: (1) anterior–posterior distance between the COM and stepping leg's ankle marker at the instant of foot contact of the first step over the obstacle; (2) trunk angle at the instant of foot contact of the first step over the obstacle; (3) trunk angular velocity at the instant of foot contact of the first step over the obstacle; (4) maximum (forward) trunk angle over the first two recovery steps; (5) maximum trunk angular velocity over the first two recovery steps; (6) minimum hip height over the first two recovery steps determined from the average height of markers on the greater trochanters and normalized to percent body height (BH); (7) time to maximum trunk angle from trip onset; and (8) time to maximum trunk angular velocity from trip onset. The phase of gait at which the trip occurred was calculated as the anterior–posterior distance from the obstacle to the previous stance position of the obstructed foot, and was expressed as a percentage of the previous stride. Recoveries were classified as either a lowering strategy where the participant immediately placed the obstructed foot on the ground and stepped over the obstacle with the contralateral leg, or an elevating strategy where the participant stepped over the obstacle with the obstructed leg [21].

To determine the effect of the trip recovery training on trip recovery performance, difference values were calculated between the two trips (Trip 2 − Trip 1), and a *t*-test was performed between the two groups for each measure. To determine if gait characteristics prior to tripping differed between trips or groups, a mixed two-way analysis of variance (ANOVA) was used to determine the effects of trip, group, and their interaction on gait speed, step height, step length, and step time. To determine if body kinematics at trip onset differed between trips or groups, a mixed two-way ANOVA was used to determine the effects of trip, group, and their interaction on the phase of gait at which trips occurred, and trunk angle and trunk angular velocity at trip onset. To determine if trip recovery performance differed between recovery strategies (lowering and elevating), a *t*-test was performed between the two strategies for each measure using data from both trips. One control subject was excluded from the trip recovery performance analysis because a second trip was not obtained. All statistical analysis was conducted using JMP IN 5.1.2 (Cary, NC) with a significance level of $p \leq 0.05$ for all tests.

3. Results

Nine of 11 participants successfully recovered their balance after both trips, one participant failed only after Trip 1 and one participant failed after both trips. Four participants used the same recovery strategy after both trips (two used the elevating strategy and two used the lowering strategy), and seven participants used different strategies after the two trips

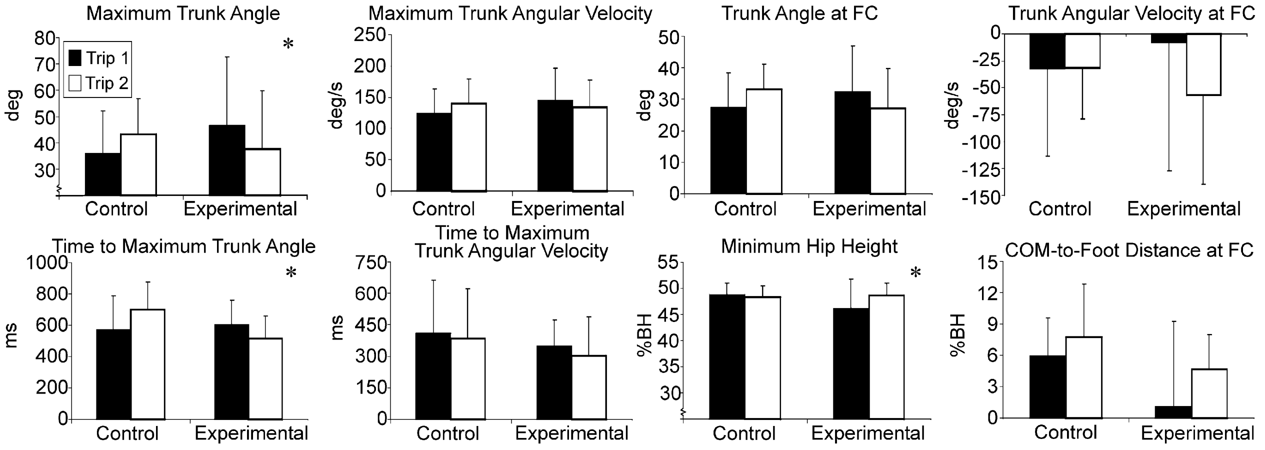

Fig. 2. Mean values of control and experimental groups for Trips 1 and 2. Error bars represent standard deviations; *significance in difference values between groups.

(two used lowering then elevating strategy, and five used elevating then lowering strategy). Recovery strategy did not affect any of the trip recovery performance measures ($p > 0.05$). Trips were initiated at 61.3 ± 5.7% (mean ± S.D.) of stride, and this phase of stride was not affected by group ($p = 0.718$), trip ($p = 0.762$), or their interaction ($p = 0.732$).

Several measures of trip recovery performance exhibited changes from Trip 1 to Trip 2 that were consistent with greater improvements in the experimental group (Figs. 2 and 3). Maximum trunk angle decreased 8.8 ± 12.8° in the experimental group and increased 7.2 ± 3.8° in the control group ($p = 0.027$). The time to maximum trunk angle decreased 80 ± 120 ms in the experimental group and increased 130 ± 160 ms in the control group ($p = 0.043$). Minimum hip height increased 2.5 ± 3.1% BH in the experimental group and decreased 0.5 ± 0.7% BH in the control group ($p = 0.02$). Trunk angle at foot contact of the initial recovery step showed a trend ($p = 0.056$), decreasing 5.2 ± 9.7° in the experimental group and increasing 5.6 ± 6.5° in the control group. No other variables of trip recovery performance were different between the groups.

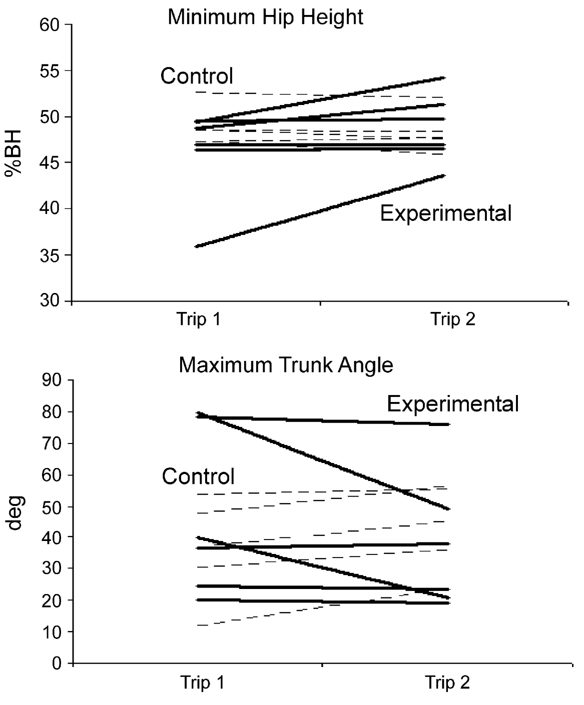

Fig. 3. Minimum hip height and maximum trunk angle for Trips 1 and 2. These figures illustrate the often large inter-subject variability as well as overall trends for these measures in the control and experimental groups.

Gait characteristics before tripping and body kinematics at trip onset showed minor differences between Trips 1 and 2. Gait speed increased from 1.14 ± 0.18 m/s before Trip 1 to 1.19 ± 0.17 m/s before Trip 2 ($p = 0.002$), step height increased from 16.3 ± 0.9% BH to 16.4 ± 0.8% BH ($p = 0.016$), step length increased from 37.9 ± 3.7% BH to 38.6 ± 3.3% BH ($p = 0.009$), and step time decreased from 0.56 ± 0.05 to 0.54 ± 0.04 s ($p = 0.002$). Although these differences were statistically significant, the effect sizes were small and not clinically significant. There was also a group × trip interaction for gait speed ($p = 0.022$), step height ($p = 0.004$), and step length ($p = 0.007$). Upon further inspection of the data, the gait characteristics of a single participant before Trip 2 appeared to differ substantially from all other trials. With the removal of this participant from analysis, all statistical differences for gait characteristics before tripping were eliminated. This suggested that this participant had a disproportionate influence on the gait characteristics results. Trunk angle and trunk angular velocity showed no effects of trip, group, or their interaction.

4. Discussion

This preliminary study examined whether trip recovery training improved the ability of older adults to recover from an actual trip. Overall, the results showed beneficial effects, including decreased maximum trunk angle, decreased the time to reach maximum trunk angle, and increased minimum hip height during the initial step over the obstacle.

Arresting the forward rotation of the trunk has been shown to be a key factor in successfully recovering from a trip [18,19], and raising the minimum hip height improves the chances of the initial recovery step clearing the obstacle for a successful recovery [17].

It could be speculated that the beneficial effects of trip recovery training may be due to changes in neural factors elicited by motor learning. Such changes could initiate the modification of recruitment and discharge patterns of motor units [22], reduced levels of agonist–antagonist coactivation [23], altered synergist muscle activity [23,24], and improved muscle coordination for a specific task [25]. Older adults subjected to postural perturbations exhibit differences in some neural factors compared to young adults (e.g. overactivate muscles not necessary for balance stabilization and activate muscles in different sequences) [26,27]. The age-related differences in these neural factors may contribute to falls in older adults.

Inspecting individual participant data (Fig. 3) can provide additional information that is not apparent from mean data (Fig. 2). However, one should exercise caution before making strong conclusions from individual data. Maximum trunk angle decreased substantially in some participants in the experimental group, and to a lesser degree in others. Similarly, minimum hip height increased substantially in some participants in the experimental group and to a lesser degree in others. Participants who had larger improvements from Trip 1 to Trip 2 may have been more able to adapt their trip recovery performance or transfer trip recovery skill from the treadmill to actual trip recovery. Conversely, those participants that did not improve as much may require substantially more training on the treadmill to improve their performance. This raises a benefit of using a treadmill for trip recovery training. Training protocols can be easily tailored for individuals in terms of the number of perturbations and magnitude of perturbations, in order to optimize the beneficial effects on actual trip recovery. Inspection of the individual data also suggests no ‘‘ceiling effect’’ in these data which would have been apparent if participants who performed poorly during Trip 1 had larger improvements, and the participants who performed well during Trip 1 had smaller improvements. This suggests, at least in the cohort used here, that large improvements in trip recovery performance are possible regardless of trip recovery capabilities prior to trip recovery training.

Several limitations of this study warrant discussion. First, 7 of 11 participants used a different recovery strategy between Trips 1 and 2, and these differences could have contributed to differences in trip recovery performance. There appeared to be no systematic changes in strategy between the experimental and control groups, and the lack of an effect of recovery strategy on any trip recovery performance measure suggests that the use of different strategies after the two trips did not confound the results. Second, only healthy older adults were used in this preliminary study for safety concerns, and it is unclear how these results will extrapolate to other populations. Third, the sample size was small, which limits generalization of the results to healthy older adults. Fourth, the number and magnitude of simulated trips during trip recovery training were selected arbitrarily for this preliminary study due to the lack of previous work in this area, and may not represent the optimal parameters for motor learning and transfer. Fifth, it is unclear if the results from the study transfer to trips outside the laboratory.

In conclusion, practicing trip recovery from a simulated trip on a treadmill improved recovery from an actual trip. This provides preliminary evidence for the positive transfer of gross motor skills learned during training on a treadmill to recovery from an actual trip. These results support the continued investigation of trip recovery training as a fall prevention intervention. Future studies should examine the ability to retain improvements in trip recovery performance over extended periods without training or non-exposure to a trip, and how to optimize the training content and schedule to maximize its effectiveness.

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