A PRELIMINARY STUDY OF TRIP RECOVERY TRAINING IN OLDER ADULTS FOR USE AS A FALL PREVENTION INTERVENTION

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(ABSTRACT)

Falls are a leading cause of injury and death in older adults. Numerous exercise interventions have been explored for fall prevention with their effectiveness being inconsistent. An alternative intervention based on motor learning concepts has potential to help prevent falls. Two separate studies are reported in this thesis. The purpose of the first study was to investigate if older adults exhibit short-term performance adaptation and long-term motor learning with repeated exposures to a simulated trip. While in a safety harness, participants stood on a treadmill that was quickly accelerated to simulate a trip. Improvements in trip recovery performance due to repeated exposures of a simulated trip included arresting the forward rotation of the trunk more quickly, reacting to the perturbation more quickly, and decreasing agonist/antagonist co-contraction. Overall, the results provide evidence for both short-term performance adaptation and motor learning. The purpose of the second study was to investigate if skills obtained from repeated exposure to a simulated trip transfer to recovery from an actual trip. Participants were randomly assigned to either an experimental or control group performing one trip before and after an intervention. The intervention for the experimental group consisted of trip recovery training on a treadmill while the intervention for the control group was walking on a treadmill. Overall, the results suggested beneficial effects of trip recovery training on actual trip recovery. These beneficial effects included decreasing maximum trunk angle, decreasing the time to reach maximum trunk angle, and raising minimum hip height during the initial recovery step.

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CHAPTER 1 – INTRODUCTION

STATISTICS AND IMPORTANCE

Falls are a leading cause of injury and death in adults aged 65 and older (65+). In 2004, approximately 5070 older adults were treated everyday in hospital emergency rooms for fall-related injuries, and 37 older adults died due to fall-related injuries (1). One of the most serious fall-related injuries is a hip fracture. Falls were the cause of 89% of hip fractures from 1990-1991 (2), and these fractures can decrease the long-term mobility of a person, including the ability to dress independently, walk independently, and climb a flight of stairs (3). Moreover, one half of adults aged 75 and older who sustain a hip fracture will die within one year (4). The population of adults 65+ in the United States is projected to increase from 35.1 million in 2000 to 86.7 million in 2050 (5). With this increase in population, the number of fall related injuries and deaths will also continue to grow.

In addition to injury and death, falls can have a large impact on society in terms of total cost, and quality of life of older individuals. It has been estimated that the 14 million falls that occurred in 1995 resulted in an total cost of $64 billion (6). With the projected increase of falls, the total cost of falls for the year 2020 is expected to exceed $85 billion (6). The ability to complete everyday tasks such as dressing oneself, climbing stairs, or walking independently can be drastically reduced due to a fall (7). Falls can also induce a fear of falling in older adults, which has been shown to limit social interactions, lower self esteem, and hinder mobility (8).

Falls can be the result of many different factors that have been categorized as intrinsic or extrinsic factors (7,9,10). Lord et al. (7) subdivided the category of intrinsic factors into psychosocial and demographic factors, postural stability factors, sensory and neuromuscular factors, medical factors, and medication factors. Based on published studies, Lord et al. (7) rated the amount of evidence in the literature supporting the contribution of each type of risk factor to falls. A risk factor rated as strong evidence was consistently found in prior research to be associated with falls. Psychosocial and demographic factors that had strong evidence were history of falls, advanced age, and activities of daily living limitations. Postural stability factors that had strong evidence were impaired gait and mobility, impaired ability in standing up, and impaired ability with transfers. Sensory and neuromuscular factors that had strong evidence were poor reaction time, muscle weakness, reduced peripheral sensation, and visual contrast sensitivity. Medical factors that had strong evidence were impaired cognition, stroke, and

Parkinson's disease. Finally, medication factors that had strong evidence were psychoactive medication use and the use of four or more medications (7). Extrinsic factors that may cause falls include poor lighting, loose carpets, slippery surfaces, cords and wires on the floor, and sidewalk cracks among others(9,10). Any factor alone may cause a fall to occur, but most often falls are caused by the interaction of multiple factors.

TRIPS

Fifty-three percent of falls can be attributed to tripping (11). A trip typically occurs during gait when a person's swing foot is unexpectedly disturbed by an obstacle or change in elevation. This disturbance results in the center of mass translating and rotating forward beyond the base of support. If a person is unable to retard the forward rotation of the trunk and re-establish a base of support which contains the center of mass, a fall may occur.

Trips and falls have been examined by many researchers in an experimental setting which allows the investigators to gain insight into the multifactor nature of trips. The most common way to elicit a trip in a research setting is to use an obstacle to obstruct the leg during the swing phase of gait. As described earlier, epidemiological studies have identified risk factors and/or characteristics of fallers. While these studies are helpful in identifying factors that contribute to falls, they are unable to distinguish between factors that directly contribute to falls and those that may simply vary with risk of falls. As such, biomechanical studies of falls are necessary to identify factors that directly contribute to falls (12-19).

Grabiner et al. (12) induced trips during walking with the purpose of obtaining information on the basic motion patterns associated with recovery from a trip, concentrating on the kinematics of the trunk and lower extremity. Participants walked along a walkway and six trips were elicited using an obstacle to obstruct the swing leg during random trials. All participants were able to recover from the disturbance. The main finding of this study was that arresting forward rotation of the trunk was important to a successful recovery from a trip. This study was the first to describe recovery kinematics after a trip and was the basis for other researchers to expand work on trips.

Eng et al. (13) identified two main strategies used to recover from a trip. The elevating strategy occurs when the obstructed limb was used to step over the obstacle in one continuous motion to complete the initial recovery step. This was seen primarily in early swing perturbations. The lowering strategy occurs when the obstructed limb is first placed on the ground before the obstacle and the contralateral leg steps over the obstacle to complete the initial recovery step. This was seen primarily in late swing perturbations.

Pavol et al. (14-16) were the first to publish biomechanical studies of trips in older adults. These studies aimed to determine if gait characteristics (14), age (15), or gender (15) influenced the probability of falling from a trip, and to determine the mechanisms associated with a fall from a trip (16). Seventy-nine older adults participated in the study. A trip was induced during walking using a pneumatically-driven obstacle that rose from the floor in approximately 170 ms. Participants wore a full-body harness at all times during the experiment to prevent a fall to the ground. Sixty-one participants were successfully tripped with nine failures occurring. A trip was considered a failure if the participant was fully supported by the safety harness. In regards to gait characteristics, participants who failed tended to have a higher gait speed than those who were able to recover from the trip (14). In regards to gender, 5% of the men fell while approximately 22% of women fell (15). In regards to the mechanisms of failure from a trip, three were identified. Participants who used the lowering strategy and fell within the initial recovery step had a faster gait speed and a delay in loading of the support limb compared to those participants who recovered. Participants who used the lowering strategy and fell after the initial recovery step had a more anterior center of mass of their head-arms-trunk segment at the time of trip and excessive lumbar flexion after the start of the trip. Finally, one participant who fell using the elevating strategy had a quicker walking time and greater lumbar flexion after trip initiation (16).

Pijnappels et al. (17-19) examined the role of the support limb during recovery from a trip in both young and older adults (the recovery limb is the leg which initially steps over the obstacle, and the support limb is the stance limb during the initial step over the obstacle). Trips were again induced during gait using an obstacle to obstruct the swing leg. It was shown in young adults the support limb plays an important role in trip recovery at push-off (time from contact of the obstacle to support limb toe-off) by allowing enough time for proper placement of the recovery limb and helping to reduce angular momentum of the trunk (17). Based on these results, it was hypothesized that a slower reaction of the support limb may discriminate between fallers and non-fallers in older adults. A follow up study addressed this hypothesis and showed older participants who fell were unable to sufficiently reduce their angular momentum during push-off of the support limb (18). EMG recorded from the support limb muscles showed significantly lower magnitudes and slower rates of development in older adults as compared to young adults. The authors suggest that the slower rate of development may cause a reduction in the ability to quickly generate forces in the response recovery, in turn leading to a lesser ability to recover from a fall (19).

FALL PREVENTION INTERVENTIONS

Numerous exercise interventions have been proposed to help prevent falls in older adults. They can usually be classified as endurance training, strength training, balance training, or some combination thereof (20-22). The results of the exercise studies vary. Some show no beneficial effects on falls (22,23) while others show an increase of falls (24). Despite this, exercise is generally considered to have a beneficial effect on falls (9) yet the most effective type, frequency, duration, and intensity has yet to be determined (25).

An alternative intervention involves applying motor learning concepts to skills related to fall prevention. Motor learning is a well-developed concept that has been applied to a myriad of fine and gross motor skills, but to our knowledge has not been applied in the context of preventing falls in older adults. It is this application of motor learning to fall prevention that is the focus of this thesis.

MOTOR LEARNING

Motor learning can be defined as "a set of processes associated with practice or experience leading to relatively permanent changes in skilled behavior" (26). Retention can be defined as the ability to recall a skill at a later instance in time. A small number of studies have demonstrated varying levels of motor learning for tasks related to fall prevention in young adults. Bhatt and Pai (27) exposed eight young adults to a slip during walking that was elicited by a sliding force platform. Participants were exposed to five slips in the first session, and five slips in a second session one year later. All participants failed to recover on the first slip in both testing sessions. Participants were able to significantly reduce balance instability by the third slip in session one and by the second slip in session two. Although these results show that long-term retention of recovery skills did not occur because all participants failed on the first slip in the second session, participants were able to obtain stability quicker in session two. The authors considered this a partial retention. The authors also note that a single session of five trials may not have been enough for motor learning.

Orrell et al. (28) investigated motor learning during a balancing task. Forty-two young adults took part in the study that consisted of two testing sessions separated by two weeks. The participants stood on a platform that was mounted to freely pivot along the horizontal axis in the frontal plane. Participants stood on the platform and were instructed to maintain the platform parallel to the floor. Each participant completed an acquisition session involving 16 balance trials each lasting 60 seconds followed by 15 minutes rest before the beginning of the first testing session During each trial, the root-mean-square error (RMSE) of the platform angular position with respect to horizontal was used to quantify performance. After the acquisition session, there was no significant change in the RMSE, which the authors suggest indicates participants learned the balancing task. There was also no difference in RMSE after the two week periods, indicating there was motor learning and retention of the acquired balance skill.

Rodrigue et al. (29) examined the effect of age on long-term retention of an upper extremity fine-motor skill over five years. Participants were tested on three consecutive days, each day completing five blocks of five trials. The motor task consisted of tracing a six-pointed star from a mirror image. Five years later, participants returned to the laboratory and the same protocol was repeated. The number of errors (times the star boundary was crossed) and speed of completion were recorded. As the number of trials performed increased, both the rate of errors and speed of completion decreased. Additionally, older adults were able to show partial retention of accuracy in tracing the star five years after the initial testing. These results concluded long-term retention of a motor skill decreases with increasing age. Although this motor learning is not related to fall prevention, it is important to note that motor learning of a skilled task could be seen in older adults. This indicates that motor learning of a task related to fall prevention is possible in older adults.

Smith et al. (30) investigated motor learning of fine motor skills of the hand in older adults. The purpose of the study was three-fold: 1) to determine if performance times of completing a motor task diminished with increasing age, 2) to determine if motor learning decreased with age, and 3) to determine if older adults would retain the skill after two years of non-exposure. Hand fine motor performance times were measured using a human movement analysis panel on 121 older adults. The testing session consisted of four tasks where participants had to remove a bolt from an object with varying difficulty. Five trials for both the right and left hand were collected at each level of difficulty. The final task was used to compare the first testing session to the second testing session which occurred on average two years later. During the initial testing session, older adults were able to decrease the time to complete the trials, though not as much as young participants. After two years, the mean first trial time was lower than the final trial time two years prior, and performance time continued to improve through the five trials. The results concluded performance time and motor learning decreased with increasing age. Older adults were able to retain the skill from the motor task and continued to improve performance time after two years of non-exposure.

ADAPTATION STUDIES

Although motor learning of a task related to fall prevention has not been shown in older adults, short-term performance adaptations from postural perturbations have been shown. For the purpose of the present study, performance adaptations can be defined as a set of processes associated with practice or experience leading to temporary changes in skilled behavior. Many factors can influence performance adaptations including learning, motivation, fatigue, anxiety, or medication (31). The difference between motor learning and adaptation is that motor learning results in a relatively permanent change in performance while adaptation results in only a temporary change in performance.

A study conducted by Owings et al. (32) showed short-term performance adaptations upon repeated exposure to postural disturbances on a treadmill. The purpose of this study was to determine if failed recoveries from a simulated trip on a treadmill used similar mechanisms as failed recoveries from an actual trip. A secondary goal was to determine if participants who failed initially would be able to modify their strategy to recover on subsequent trials. Seventy-nine older adults participated in the study. Participants stood on an inactivated treadmill that accelerated to 0.89 m/s in about 150 ms. Upon activation of the treadmill, participants were instructed to simply take steps to recover their balance and continue walking. A safety harness was worn by all subjects for all trials to prevent a fall to the ground. The perturbation on the treadmill displaced the feet posteriorly so that the body center-of-mass was anterior to the base of support (similar to what one would experience in an actual trip). Five trials were collected. A trial was considered a failure if the participant's hand touched the treadmill or they were completely supported by the safety harness. Twenty-three participants failed on their initial attempt. Participants who failed had a slower reaction time and took a shorter recovery step than those that recovered. Within four attempts, 18 of the original 23 fallers were able to recovery by having a faster reaction time and taking a longer recovery step. Failed recoveries on the treadmill were associated with the same mechanisms of failure from an actual trip, including increased trunk flexion, slower reaction times, and greater trunk velocity. The authors suggest that this protocol could be used in the future as a tool for trip recovery. The results of this study showed performance adaptations due to repeated exposures of a treadmill trip, but were not able to confirm motor learning due to its experimental design.

Pavol et al. (33,34) also showed performance adaptations upon repeated exposure to a slipping perturbation. Slips were induced in 41 older adults using a sit-to-stand sliding platform protocol. The experimental protocol consisted of five slipping trials followed by three to five non slipping trials and then two more slipping trials. Seventy-three percent of older adults failed to recover on the first trial. All but one subject was able to recover within five attempts. After the non-slipping trials, only 20% of older adults failed upon re-exposure to the slip. Recovery from the slips consisted of both proactive and reactive responses (34). Proactive responses included adjusting the COM anterior position and velocity at seat off. Reactive responses included changing placement of the stepping leg and lowering hip height at heel contact from recovery step. This study showed that older adults have the ability to improve recovery due to repeated exposures of a postural perturbation. Additionally, the authors state both proactive and reactive responses should be taken into consideration when planning a fall intervention.

SUMMARY AND PURPOSE

To summarize, falls are a leading cause of injury and death in older adults. Numerous exercise interventions have been explored for fall prevention with their effectiveness being inconsistent. An alternative intervention based on motor learning concepts has potential to help prevent falls. Although short-term performance adaptations during skills related to fall prevention have been shown in older adults, little is known about motor learning of skills related to fall prevention in older adults. The long-term goal of this research is to develop a fall prevention intervention based on motor learning concepts.

This thesis consists of two separate studies. The purpose of the first study (Chapter 2) was to investigate if older adults exhibit short-term performance adaptation and long-term motor learning with repeated exposures to a simulated trip. The purpose of the second study (Chapter 3) was to investigate if skills obtained from repeated exposure to a simulated trip transfer to recovery from an actual trip. Both of these issues are necessary in the development of a fall prevention intervention based on motor learning.

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Chapter 2 – Short-term performance adaptation and motor learning of trip recovery due to repeated exposures of a simulated trip

Abstract

Falls are a leading cause of injury and death in older adults. Motor learning is a concept that can be used to improve numerous motor skills, and could conceivably be applied to skills related to preventing falls. The purpose of this study was to determine if repeatedly exposing older adults to a simulated trip would result in motor learning. Participants were randomly assigned to either an experimental or control group performing one trip before and after an intervention. The intervention for the experimental group consisted of trip recovery training on a treadmill while the intervention for the control group was walking on a treadmill. Trip recovery performance was quantified using several measures derived from the kinematic and EMG data. Improvements included, in a general sense, arresting the forward rotation of the trunk more quickly, reacting to the perturbation more quickly, and decreasing agonist/antagonist co-contraction. The results of this study support the continued study of motor learning as an intervention for fall prevention

INTRODUCTION

Falls are a leading cause of injury and death in older adults. Everyday, approximately 5000 adults aged 65 and over (65+) are treated in hospital emergency rooms for fall-related injuries (1). In addition, approximately 37 will die everyday from fall-related injuries (1). The population of adults 65+ in the United States is projected to increase from 35.1 million in 2000 to 86.7 million in 2050 (2). With this increase in the population of older adults, the number of injuries and deaths related to falls is expected to increase as well.

Numerous exercise interventions have been proposed to help prevent falls in older adults. Some of these exercise interventions include resistance training, endurance training, balance training, or a combination thereof (3-6). Although several studies show exercise has no beneficial effect on fall rates (5,7), it is becoming generally accepted that exercise can help reduce the risk of falls (8). However the most effective type, duration, intensity, and frequency of exercise to help prevent falls has not been determined (9).

Motor learning is a concept that can be used to improve numerous motor skills, and could conceivably be applied to skills related to preventing falls. Motor learning is defined as "a set of processes associated with practice or experience leading to relatively permanent changes in skilled behavior" (10). These relatively permanent changes in skilled behavior are thought to result from the improvement of motor programs through practice and optimizing neural pathways (10,11). Little is known about motor learning in older adults.

Evidence of motor learning of a skill related to fall prevention has been shown in younger adults (12). Participants were exposed to five slips initialized by a sliding force platform in the first session, and five slips in a second session one year later. All participants failed to recover on the first slip in both testing sessions. Participants were able to significantly reduce balance instability by the third slip in session one and by the second slip in session two, indicating a partial retention of skills were obtained. Additionally, older adults were able to show motor learning of a skill, albeit not related to balance, from an upper extremity mirror tracing task after five years (13).

Although motor learning of a task related to fall prevention has not been shown in older adults, short-term performance adaptations from postural perturbations have been shown. Performance adaptations can occur due to many factors including motivation, fatigue, anxiety, or learning (14). A study conducted by Owings and colleagues demonstrated that older adults who failed to recover from a postural perturbation from a treadmill could successfully recover on a second attempt by modifying their recovery strategy (15). Participants who initially failed were able to decrease their reaction time, increase step length, and decrease trunk flexion and trunk velocity at toe off of the recovery foot on their subsequent attempts. Performance adaptations in older adults were also seen with repeated exposures to a slipping perturbation using a sit-to-stand moving platform protocol (16). Seventy three percent of older adults failed to recover on their initial attempt. All but one participant learned to recover within five attempts and after minimal non-exposure time, only twenty percent of the participants fell upon re-exposure to the perturbation. The results of these studies were unable to confirm "relatively permanent" changes in performance that is associated with motor learning, but they do not discount it either. They provide support for the continued application of motor learning toward fall prevention in older adults.

The purpose of this study was to determine if repeatedly exposing older adults to a simulated trip would result in motor learning. Trips were the focus because they are responsible for approximately 53% of falls (17). It was hypothesized that older adults would demonstrate both short-term and long-term performance adaptations that were consistent with an improvement in trip recovery performance and motor learning.

METHODS

Six community-dwelling, older adults (three men and three women, mean age 71.6, SD 5.5) participated in the study. A medical screening was performed to exclude participants with neurological, cardiac, respiratory, otological, or musculoskeletal disorders, or a history of multiple falls within the past year. In addition, a minimum bone mineral density of 0.65 g/cm^2 of the femoral neck using dual-energy x-ray absorptiometry (Norland Medical Systems., Fort Atkinson, WI) was required to be included in the study (18). The study was approved by the Institutional Review Board of Virginia Tech, and written consent was obtained from all participants prior to participation.

The experiment consisted of two identical testing sessions separated by one week. During each session, participants were exposed to twenty simulated trips using a modified treadmill as described below. Trip recovery performance was determined from recovery kinematics and muscle activation patterns during the trip. Changes in trip recovery performance during each session were considered short-term performance adaptations, and changes in trip recovery performances between the two sessions were considered motor learning.

Participants stood quietly on a treadmill while looking straight ahead (Figure 1) and were warned that it would be activated shortly.

Figure 1: Trip recovery training experimental setup. Participant stood on an inactivated treadmill with an obstacle in front of their feet. Upon activation, the perturbation displaced the feet posteriorly so that the body center-of-mass was anterior to the base of support (similar to what one would experience in an actual trip).

Once activated, the treadmill accelerated to 0.89 m/s (2.0 mph) in approximately 190 ms. A 7.6 cm (3 in) high obstacle was placed in front of the participants feet to elicit an initial step that more closely resembled the initial step over an object after an actual trip (19). During all trials, participants wore a full body harness suspended from the ceiling. The length of the harness was adjusted so that the participants' fingers were approximately two inches from the ground when bent at the waist. Participants were instructed to step over the obstacle and continue walking upon treadmill activation. After the first two trials, the treadmill speed was either increased or decreased by 0.089 m/s (0.2 mph) based on whether the investigator thought the participant successfully recovered from the trip or not. The decrease in speed after two consecutive failed recoveries provided a better opportunity for a successful recovery, which can improve motor learning (11). The increase in speed after two consecutive successful recoveries provided a greater challenge, which can also improve motor learning (11). Participants were instructed to take their first step over the obstacle with their right foot during the first 10 trials and with their left foot during the second ten trials. This study focuses only on the right foot recovery trials. The last two trials for each foot were also collected with the treadmill accelerating to 0.89 m/s for all participants to facilitate comparisons of trip recovery performance between the first two and last two trials of session 1 and session 2.

Whole body kinematics, lower extremity electromyograms (EMG) and force applied to the harness were recorded during all trials. Nineteen reflective markers were placed bilaterally over selected anatomical landmarks on the head, arms, trunk, and lower extremities. Marker position was 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 (2nd order zero-phase-shift Butterworth filter). EMG electrodes were Ag/AgCl disc electrodes with 1 cm diameter (Vermed, Inc., Bellows Falls, VT). EMGs were sampled at 1000 Hz bilaterally from the tibialis anterior (TA), medial gastrocnemius (MG), vastus lateralis (VL), and medial hamstring (MH). EMGs were subsequently bandpass filtered 20-500 Hz, full wave rectified, and low pass filtered at 25 Hz (2nd order zero-phase-shift Butterworth filter) to create a linear envelope of the EMG signal. All EMG signals were normalized to maximum values obtained during five strides of a walking trial (20). Force applied to the harness (Cooper Instruments & Systems, Warrenton, VA), was sampled at 1000 Hz and used during data analysis to determine the outcome of the trial. If the force on the load cell exceeded 200 N during a trial, the trial was classified as a failure (21). All kinematic measures were limited to the sagittal plane. The onset of a simulated trip was determined from the start of anterior-posterior movement of a marker placed on the obstacle. Toe off of the initial recovery step was determined from the start of vertical motion of the 5th metatarsal marker. Foot contact of the first step over the obstacle was determined from the end of vertical motion of the 5th metatarsal marker or calcaneous marker, whichever occurred first. Full body center of mass (COM) was estimated from anthropometric measurements (22) and trunk angle was defined as the angle between the shoulder and the L3L4 joint center relative to vertical.

Trip recovery performance was quantified using several measures derived from the kinematic and EMG data. Kinematic measures included: 1) COM-to-foot distance at toe off (TO) of initial recovery step expressed as a percentage of body height (bh), 2) COM-to-foot distance at foot contact (FC) of initial recovery step expressed as a percentage of body height, 3) trunk angle at toe off of initial recovery step, 4) trunk angle at foot contact of initial recovery step, 5) maximum trunk angle over the first two steps after treadmill activation, 6) time to maximum trunk angle, 7) maximum trunk angular velocity over the first two steps after treadmill activation, 8) time to maximum trunk angular velocity, 9) step length, defined as the change in relative position of the marker on the treadmill obstacle and ankle marker of the recovery foot from treadmill onset to foot contact (15) expressed as a percentage of body height, and 10) step time, defined as the time from toe off of initial recovery step to foot contact. EMG measures (Figure 2) included: 1) onset time, determined visually (23) as the time from treadmill activation to the onset of the muscle activity, 2) rise time, defined as the time from onset of the muscle activity to 90% of peak amplitude, 3) agonist/antagonist co-contraction of the ankle dorsiflexors and plantar flexors (TA and MG) and knee flexors and extensors (MH and VL), calculated as the area under the EMG curve when both muscles were activated over the initial recovery step and normalized to step time , and 4) peak EMG amplitude, calculated over the initial recovery step. EMG measures were calculated for the swing (SW) leg (initial recovery step leg) and the stance (ST) leg (follow through leg).

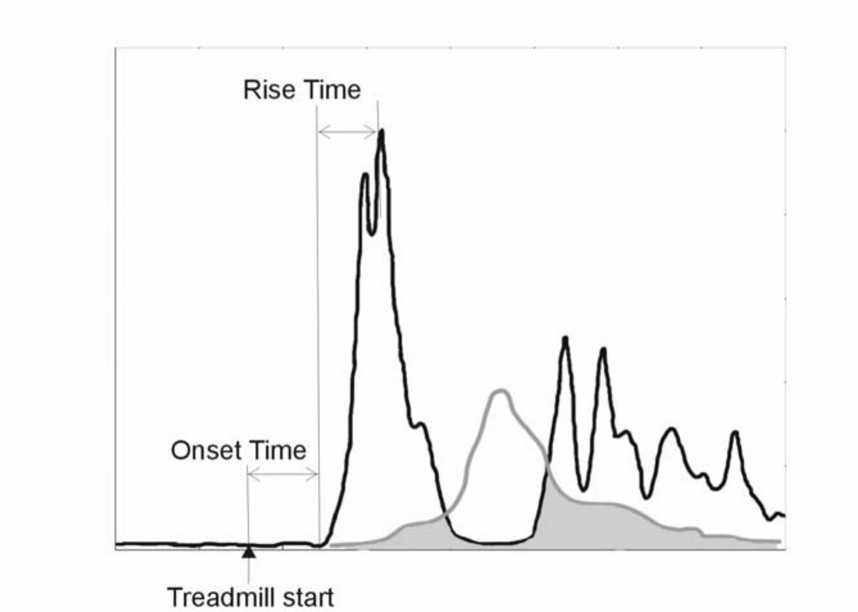

Figure 2: Representative picture of EMG, showing performance measures. The shaded gray area represents the area of co-contraction of the muscles.

Prior to statistical analysis, all trials deemed to be failures were removed, and the first two trials and last two trials from each session were averaged together. A two-way repeated measures ANOVA was conducted on each dependent measure with trial (first two or last two) and session (1 or 2) as independent measures. A main trial effect indicated short-term performance adaptation within a session, and a main session effect indicated motor learning across sessions. Data transforms were performed on trunk angle and trunk velocity to achieve distributions that did not deviate significantly from normal. All statistical analysis was completed in JMP 5.1.2 (Cary, NC) with $p \leq 0.05$ indicating statistical significance. Due to the pilot nature of this study, statistical trends approaching significance ($p<0.10$) were also noted.

RESULTS

Five of six participants successfully recovered during all trials of both sessions. The sixth participant failed during the first and ninth trials of session 1 and recovered during all trials of session 2.

Several measures of trip recovery performance showed a main effect of trial, which indicated short-term performance adaptation. Mean changes in kinematic measures from the first to last trials (Table 1) included a 9.8 deg decrease in maximum trunk angle ($p<0.001$), a 26 ms decrease in time to reach maximum trunk angle ($p=0.004$), a 7.1 deg decrease in trunk angle at foot contact ($p<0.001$), a 18.4 deg/s decrease in maximum trunk angular velocity ($p=0.002$), and a 13 ms decrease in time to reach maximum trunk velocity ($p=.040$).

Table 1: A comparison of kinematic measures of trip recovery performance between the first and last trials (mean ± sd).

Measure	First Trials	Last Trials	
COM-to-foot distance TO (%bh)	12.2 ± 2.9	12.1 ± 2.5	
COM-to-foot distance FC (%bh)	5.2 ± 2.4	5.7 ± 2.6	
Max. trunk angle (deg)	31.7 ± 13.0	21.9 ± 9.7	∗
Time to max. trunk angle (ms)	86.0 ± 18.1	59.7 ± 24.7	∗
Trunk angle TO (deg)	3.4 ± 5.7	1.6 ± 4.1	
Trunk angle FC (deg)	19.3 ± 12.8	12.2 ± 11.9	∗
Max. trunk angular velocity (deg/s)	129.4 ± 31.5	111.0 ± 31.4	∗
Time to max. trunk angular velocity (ms)	40 ± 18	27 ± 5	∗
Step length (%bh)	42.8 ± 7.1	42.5 ± 4.8	
Step time (ms)	384 ± 37	383 ± 19	

∗ indicates a significant difference between first and last trials which suggests a short-term performance adaptation

Mean changes in EMG measures from the first trials to last trials (Figure 3) included a decrease in onset time of the SW TA (33.8 ms; $p=0.011$), the SW VL (51.4 ms; $p=0.010$), and the SW MH (14.9 ms; $p=0.002$).

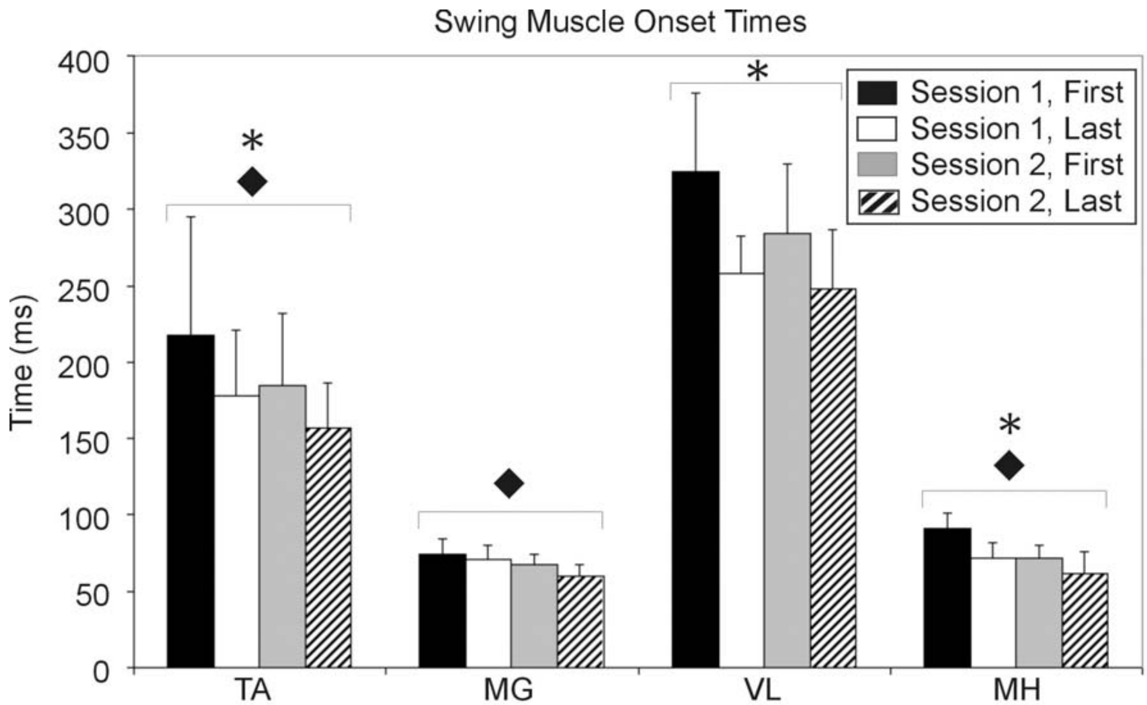

Figure 3: Onset times of the swing leg muscles. Diamonds represent significance between sessions, indicative of motor learning, star represent significance between first and last trials, indicative of adaptation

In addition, onset time tended to decrease in the SW MG (5.4 ms; p=0.086) and the ST MH (7 ms; p=0.077). A decrease in co-contraction of the ankle dorsiflexors and plantar flexors of the stance leg (0.16; p=0.009), and co-contraction of the knee flexors and extensors of the swing leg (0.16; p=0.029) occurred between the first and last trials. Furthermore, co-contraction of the knee flexors and extensors of the stance leg tended to decrease between the first and last trials (0.26; p=0.087).

Several measures of trip recovery performance showed a main effect of session, which indicated motor learning. Mean changes in kinematic measures from session 1 to session 2 (Table 2) included a 1.7 %bh increase in COM-to-foot distance at TO (p=0.029), a 1.6 deg increase in trunk angle at TO (p=0.038), and a 4.1 %bh decrease in step length (p=0.004).

Table 2: A comparison of kinematic measures of trip recovery performance between session 1 and session 2 (mean ± sd).

Measure	Session 1	Session 2	
COM-to-foot distance TO (%bh)	12.9 ± 2.4	11.3 ± 2.7	∗
COM-to-foot distance FC (%bh)	5.7 ± 2.6	5.2 ± 2.5	
Max. trunk angle (deg)	27.9 ± 14.1	25.7 ± 10.6	
Time to max. trunk angle (ms)	77 ± 26	69 ± 24	
Trunk angle TO (deg)	1.7 ± 5.8	3.4 ± 4.0	∗
Trunk angle FC (deg)	16.3 ± 12.9	15.2 ± 12.9	
Max. trunk angular velocity (deg/s)	116.5 ± 31.5	123.9 ± 33.8	
Time to max. trunk angular velocity (ms)	34 ± 15	32 ± 15	
Step length (%bh)	44.7 ± 6.8	40.6 ± 4.9	∗
Step time (ms)	393 ± 34	374 ± 18	

∗ indicates a significant difference between session 1 and session 2 which suggests motor learning

In addition, step time tended to decrease (19 ms; p=0.072). Changes in EMG measures from session 1 to session 2 (Figures 3 & 4) included a decrease in onset time of the SW TA (27.3 ms; p=0.034), the SW MG (8.7 ms; p=0.009), the SW MH (14.8 ms; p=0.003), the ST MG (8 ms; p=0.026), and the ST MH (13.9 ms; p=0.002).

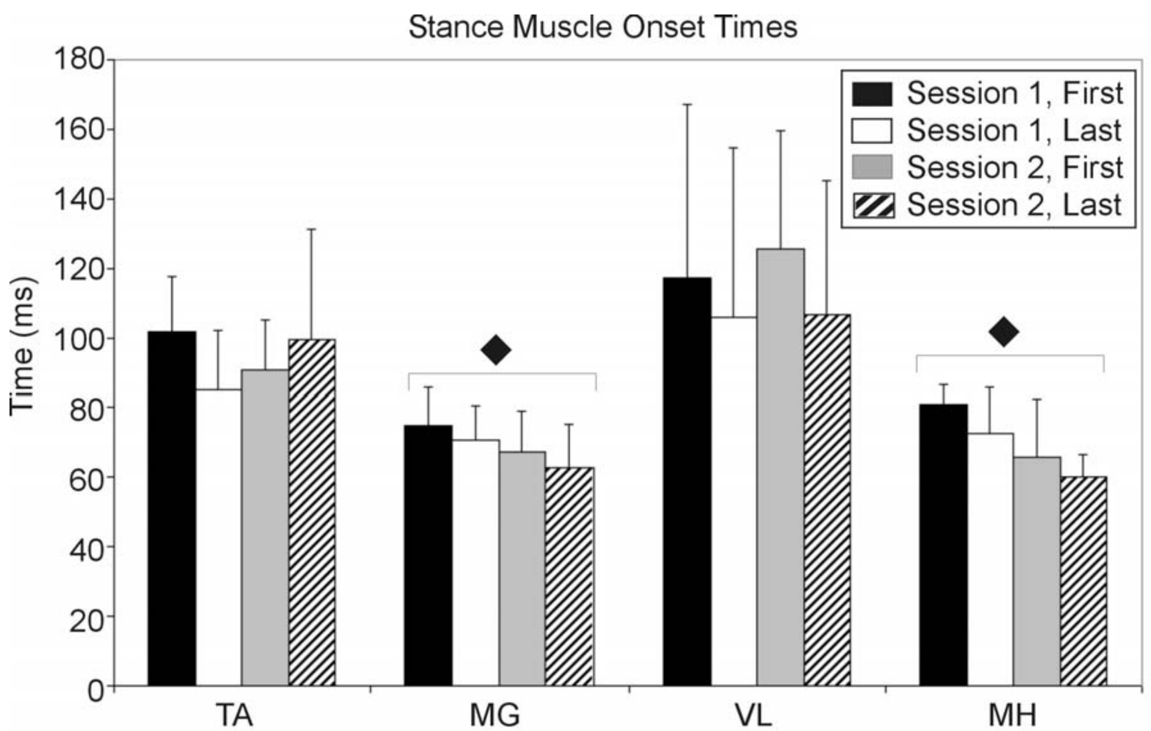

Figure 4: Onset times of the stance leg muscles. Diamonds represent significance between sessions, indicative of motor learning

Similarly, rise time tended to decrease in the SW TA (18.8 ms; p=0.054), the SW MH (11 ms; p=0.099), and the ST VL (40.2 ms; p=0.099). In addition, knee flexors and extensors of the swing leg tended to decrease from session 1 to session 2 (0.13; p=0.069).

DISCUSSION

The purpose of this study was to determine if repeatedly exposing older adults to a simulated trip would result in motor learning. Overall, the results provide evidence for both short-term performance adaptation and motor learning. Although no feedback was provided to participants in regards to how to improve trip recovery performance, the changes in recovery kinematics and muscle recruitment patterns due to performance adaptations and motor learning were consistent with an improvement in trip recovery performance. These improvements included, in a general sense, arresting the forward rotation of the trunk more quickly, reacting to the perturbation more quickly, and decreasing agonist/antagonist co-contraction.

Arresting the forward rotation of the trunk is a key factor in recovering from a trip (24,25). When the COM translates anterior to the base of support, a moment is created about the base of support that accelerates the trunk forward. To arrest this acceleration and decelerate anterior trunk movement, the anterior limit of the base of support must be placed anterior to the COM via stepping. Assuming sufficient muscle strength, the ground reaction force from this leg can reverse this moment and effectively decelerate the anterior movement of the trunk. Our results show that trunk deceleration was performed more quickly with practice. One can reason that a longer initial recovery step would be beneficial to accomplish this deceleration (15). However, we observed a decrease in initial recovery step length. This may be due to improved ability of the stance leg to contribute to trunk deceleration. It has been shown in young adults the stance leg plays an important role in trip recovery at push-off (time from contact of the obstacle to support limb toe-off) by allowing enough time for proper placement of the recovery limb and helping to reduce angular momentum of the trunk (26). Due to the declaration of the trunk, a large step may not be necessary for recovery. Additionally, older participants who fell were unable to sufficiently reduce their angular momentum during push-off of the stance leg (21) suggesting that control of the trunk and step length are important factors for a successful trip recovery.

Reacting more quickly to the perturbation is another improvement in trip recovery performance. The quicker response in the muscles may have led to quicker movement control after the perturbation, in turn leading to better overall balance. This may also hold true for a trip. Quicker reaction in the muscles allows a quicker overall response time to recover from the disturbance. The gastrocnemius provides a force to plantar flex the foot, allowing for push off of the foot. Next, the medial hamstrings allow extension of the hip and flexion of the knee during the swing phase of the stepping movement. The tibialis anterior provides dorsiflexion of the foot while the vastus lateralis extends the knee during the swing phase. The faster responses of the muscle can lead to faster generation of the necessary steps required to successfully recovery from a trip. Studies have demonstrated the ability to decrease reaction time via motor learning. Experienced Tai Chi practitioners of one year had significantly quicker onset times of the hamstrings and gastrocnemius during a anterior-posterior perturbation test than those adults with little or no Tai Chi experience (27).

A decrease in lower extremity agonist/antagonist co-contraction can also be viewed as a beneficial effect of trip recovery performance (28). By lowering the amounts of coactivation, the muscle torques generated about a joint can increase (29). This increase in torque may lead to a better ability to recover from a trip. An increase in torque can assist at reducing the buckling of the stepping leg, which is necessary for successful recovery. Furthermore, the increase could help decelerate body rotation about an obstacle (30).

Several limitations of this study warrant discussion. This study used healthy community dwelling older adults. It is unclear whether the results would be the same with a different population. In addition, there may not have been enough trips in a session to obtain motor learning in all trip recovery performance measures. Future studies should increase the number of trials in a session to optimize the ability to retain the adaptations that were made. The small number of participants may limit the generalizability of the results, but the results here warrant further investigation of the use of this protocol as a fall prevention intervention. Additionally, it is unclear if improvements in recovery from a simulated trip on a treadmill transfer to recovery from an actual trip.

In conclusion, older adults were able to improve their ability to recover from a simulated trip, and these improvements can be attributed, at least in part, to motor learning. The results of this study support the continued study of motor learning as an intervention for fall prevention despite the small number of participants and the relatively few numbers of training trials used. Future studies should optimize training to maximize learning effects, and investigate how long improvements in recovery are retained.

ACKNOWLEDGEMENTS

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CHAPTER 3 – PRACTICING RECOVERY FROM A SIMULATED TRIP IMPROVES RECOVERY KINEMATICS AFTER AN ACTUAL TRIP

ABSTRACT

Numerous exercise interventions have been proposed to help prevent falls in older adults. An alternative intervention to help prevent falls may be to take advantage of motor learning principles by allowing individuals to practice movements directly related to fall prevention. 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 participated in the study. Participants were randomly assigned to either a control or experimental group. Each group performed one trip before and one trip after an intervention. The intervention for the experimental group consisted of trip recovery training on a modified treadmill while the intervention for the control group was walking on a treadmill for 15 minutes. After the intervention, the experimental group significantly decreased maximum trunk angle ($p=0.027$), decreased time to maximum trunk angle ($p=0.043$), and increased minimum hip height ($p=0.020$) more than the control group. Additionally, trunk angle at foot contact of the initial recovery step tended to decrease in the experimental group more than the control group ($p=0.056$). Overall, the results suggested beneficial effects of trip recovery training on actual trip recovery. Future studies should further examine the ability to retain improvements over extended periods of non-exposure to a trip, and optimize the training to maximize the beneficial effects.

INTRODUCTION

Falls are a major cause of injury and death in adults aged 65 and older (65+). Over 1.85 million people aged 65+ were treated in the emergency room for fall-related injuries in 2004, which is equivalent to over 5,000 being treated every day (1). In addition, approximately 37 adults aged 65+ die every day from a fall-related injury (1). The number of adults aged 65+ 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). Most of these can be categorized as resistance training, endurance training, balance training, or some combination thereof. Despite some exercise interventions showing no beneficial effect on fall rates (3,6), and some even reporting an increase in falls (7), it is becoming generally accepted that exercise has a prophylactic effect on the risk of falls (8). However, the most effective type, intensity, frequency, and duration of exercise in preventing falls has yet to be identified (9,10).

An alternative intervention may involve taking advantage of motor learning principles by allowing individuals to practice movements directly related to fall prevention in a safe, controlled setting. 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. These researchers also suggested that many older adults possess the motor performance and sensory abilities necessary to recover from a trip, but that appropriate integration and coordination of these abilities may erode with age and hinder their ability to enact the quick, effective steps that are required. Practicing trip recovery may allow older adults to effectively “re-learn” appropriate sensory integration and muscle coordination, and improve their ability to recover from an actual trip without falling. Using a similar idea, Pavol et al. (12) demonstrated an improvement in slip recovery following repeated exposures to a slipping perturbation.

The results of Owings et al. (11) justify further investigation of “trip recovery training” as a fall prevention intervention. Further investigation must address two fundamental questions. First, do repeated exposures to simulated trip result in motor learning? The short-term adaptations in performance documented by Owings et al. are encouraging, but do not necessarily indicate a “relatively permanent” change in motor performance that is associated with motor learning (13). Motor learning is necessary in order for any improvements in trip recovery performance to be retained over extended periods of time. Second, do improvements in stepping responses to a simulated trip transfer to improvements in recovery from an actual trip? In order for trip recovery training to be an effective fall prevention intervention, participants must be able to transfer the 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. It is this second research question that is the focus of this study.

The goal of this preliminary study was to determine if trip recovery training improves the ability of older adults to recover from an actual trip. It was hypothesized that repeated exposures to a simulated trip on a treadmill would improve recovery kinematics from an actual trip.

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 walking on a treadmill. The general hypothesis tested was that the experimental group would exhibit a greater improvement in trip recovery performance from Trip 1 to Trip 2 compared to the control group.

To start the experiment, participants walked repeatedly along a 9 m walkway at a self-selected pace while looking straight ahead (Figure 1). They were informed that a trip may occur in any trial.

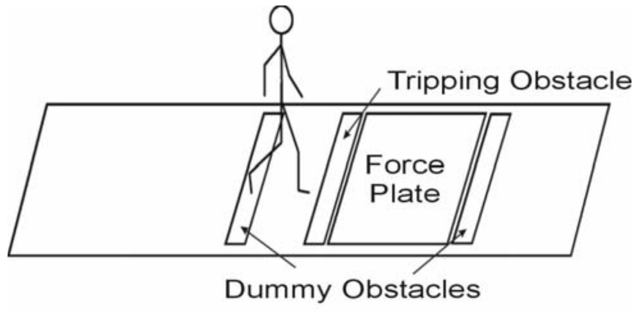

Figure 1: A schematic of the experimental set up. The functional tripping obstacle was positioned between two non-functional dummy obstacles. Although participants were not informed of how a trip would occur, dummy obstacles were used so the participants would be unaware of where a trip may occur. A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

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 a participant reached for the ground, there was approximately two inches between the fingertips and ground.

After Trip 1, the experimental group performed trip recovery training on a modified treadmill. Participants stood quietly on the treadmill while looking straight ahead, and were warned that it would be activated shortly. Once activated, the treadmill accelerated to 0.89 m/s (2.0 mph) in approximately 190 ms. A 7.6 cm high obstacle was placed in front of the participant's feet to require an initial step that resembled the initial step over an object after tripping (15). Participants were instructed to, upon treadmill activation, step over the obstacle and continue walking. 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, 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 (as determined visually). Increasing the speed after a successful recovery provided a greater challenge to participants, which can improve motor learning (16). Decreasing the speed after a failed recovery provided a better opportunity for a successful recovery, which can also improve motor learning (16). The last two trials were performed with the treadmill accelerating to 0.89 m/s to evaluate changes in performance between the beginning and end of the trip recovery training (focus of a separate study). The control group walked on the treadmill at 0.89 m/s for 15 minutes (the approximate time it took to complete the trip recovery training). 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 Trip 1 and Trip 2. Nineteen reflective markers were placed bilaterally over selected anatomical landmarks on the head, arms, trunk, and lower extremities. Marker data was 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 (2nd 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 (17).

Trip recovery performance was quantified using several measures derived from the kinematic data. These measures were based on whole body center of mass (COM) estimated from anthropometric measurements (18), 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 using the perpendicular distance from the obstacle to the stance position of the obstructed foot, and expressed as a percentage of the previous stride. Finally, 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 (19).

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 and body kinematics at trip onset differed between trips or groups, a two-way analysis of variance was used to determine the effects of trip, group, and their interaction on gait speed, step height, step length, and step time. One control subject was excluded from 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.

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 elevating, two lowering), and seven participants used different strategies after the two trips (two used lowering then elevating, and five used elevating then lowering). Recovery strategy did not affect any of the trip recovery performance measures ($p>0.05$). Trips were initiated at 61.3 ± 5.7 % (mean ± SD) 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 compared to the control group (Figure 2).

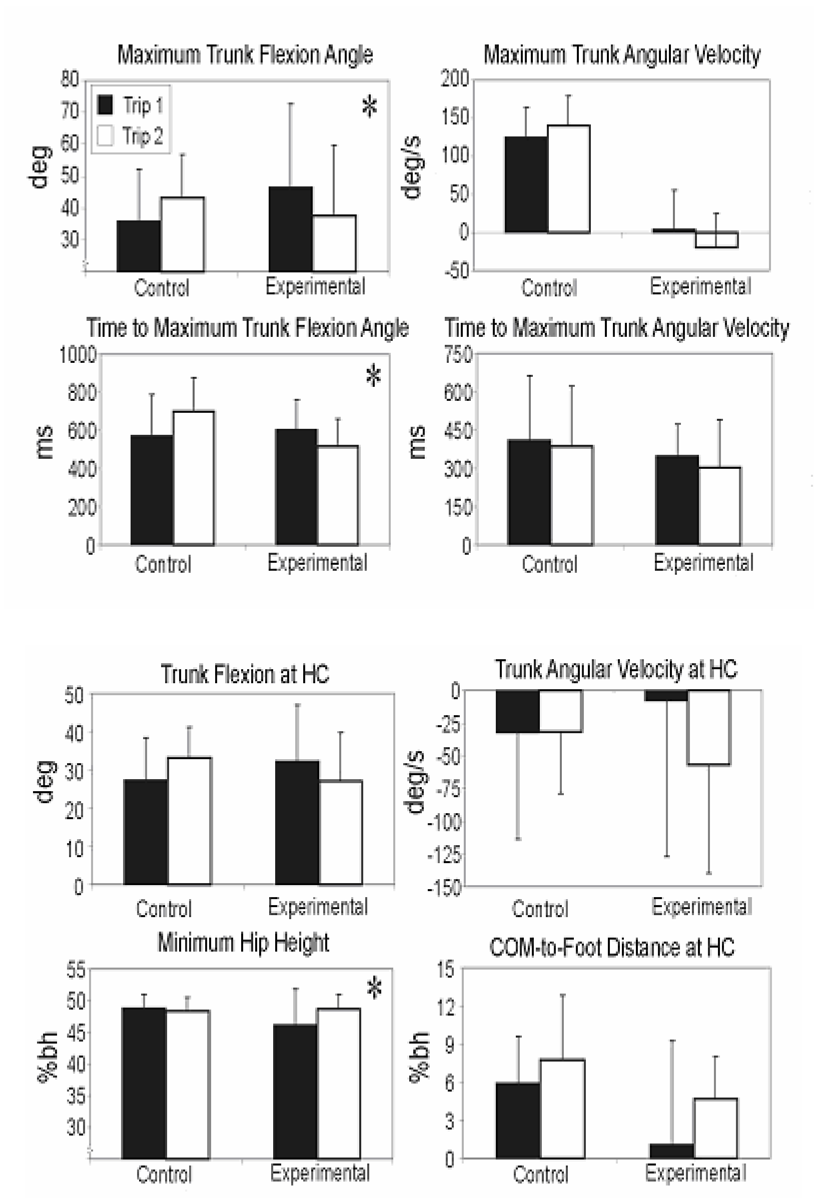

*Figure 2: Mean values of control and experimental groups for Trip 1 and Trip 2. Error bars represent standard deviations and * represents significance in difference values between groups.*

Maximum trunk angle decreased 8.8 ± 12.8 deg in the experimental group and increased 7.2 ± 3.8 deg 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=0.020). In addition, trunk angle at foot contact of the initial recovery step showed a trend (p=0.056), decreasing 5.2 ± 9.7 deg in the experimental group and increasing 5.6 ± 6.5 deg in the control group. No other variables of trip recovery performance were different between groups.

Gait characteristics before tripping and body kinematics at trip onset showed minor differences between Trip 1 and Trip 2. Gait speed increased from 1.14 ± 0.18 m/s before Trip 1 to 1.18 ± 0.18 m/s before Trip 2 (p=0.006), step height increased from 16.1 ± 0.8 %bh to 16.3 ± 0.8 %bh (p=0.008), step length increased from 37.6 ± 3.6 %bh to 38.3 ± 3.3 %bh (p=0.015), and step time decreased from 0.55 ± 0.05 s to 0.54 ± 0.05 s (p=0.011). Although these differences were statistically significant, they were deemed to be practically not important. There was also a significant group x trip interaction effect on step height (p=0.002) and step length (p=0.012). 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 with the exception of a group x trip interaction for step time (p=0.017). This suggested that this participant had a disproportionate influence on the statistical results regarding gait characteristics. Body kinematics at the time of contact with the obstacle (i.e. COM-to-foot distance, trunk angle, trunk angular velocity, and hip height) showed no effects of trip, group, or their interaction.

DISCUSSION

The goal of this preliminary study was to determine if trip recovery training improved the ability of older adults to recover from an actual trip. Overall, the results suggested beneficial effects of trip recovery training on actual trip recovery. These beneficial effects included decreasing maximum trunk angle, decreasing the time to reach maximum trunk angle, and raising 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 (20,21), and raising the minimum hip height improves the chances of the initial recovery step clearing the obstacle for a successful recovery (22).

The beneficial effects of trip recovery training may be due to changes in "neural factors" elicited by motor learning. For example, older adults subjected to involuntary postural perturbations have been observed to over-activate muscles not necessary for balance stabilization and activate muscles in sequences different from those used by healthy young adults (23,24). This suggests that muscle activation levels and muscle activation sequences need to be modified in older adults to help prevent falls. Trip recovery training may allow such modifications to occur via motor learning. In fact, studies of motor learning have demonstrated changes in several neural factors including modifying the recruitment and discharge pattern of motor units (25), reducing levels of agonist-antagonist coactivation (26), altering synergist muscle activity (26,27), and improving muscle coordination involved in a specific task (28). Future studies should employ electromyography to investigate these changes.

Inspecting individual participant data (Figure 3) can provide additional information that is not apparent from mean data (Figure 2), and lead to the development of additional research ideas and/or hypotheses.

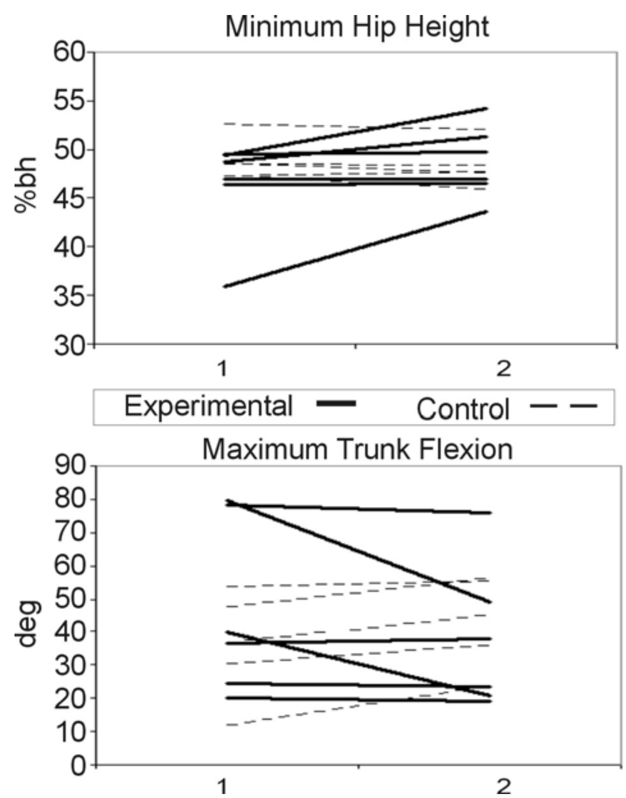

Figure 3: Minimum hip height and maximum trunk flexion for Trip 1 and Trip 2. These figures illustrate the often large inter-subject variability as well as overall trends for these measures in the control and experimental groups.

However, one should exercise caution before making strong conclusions from individual data. Maximum trunk angle decreased substantially in some participants of the experimental group, and decreased to a lesser degree in others. Similarly, minimum hip height increased substantially in some participants in the experimental group and increased 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.

Two potential limitations of this study warrant discussion. Seven of 11 participants used a different recovery strategy between Trips 1 and 2, and these different strategies could conceivably have contributed to some differences in trip recovery performance between Trips 1 and 2. However, 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 our investigation. It also possible that a change in strategy was a beneficial effect of training, but this was difficult to discern because the mean phase of stride when trips occurred (61.3% of stride) could elicit either strategy and be appropriate. Another limitation of this study is that it is unclear if the results from the study will transfer to trips outside the laboratory. However, the work here was a necessary step to determine if further investigation of trip recovery training is warranted.

In conclusion, practicing trip recovery from a simulated trip on a treadmill improved recovery from an actual trip. From a basic science standpoint, this provides evidence for the positive transfer of gross motor skill learned during training on a treadmill to recovery from an actual trip. From an applied science standpoint, 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 optimize the training to maximize the beneficial effects.

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Vita

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Kathleen Bieryla was born in Wilkes-Barre, Pennsylvania on August 5, 1982. She attended James M. Coughlin High School in Wilkes-Barre, Pennsylvania and was honored as Valedictorian. She completed a Bachelor of Science in Bioengineering, graduating Summa Cum Laude from the University of Pittsburgh in 2004. She obtained a Master of Science Degree in Mechanical Engineering with a Biomedical Engineering option from Virginia Polytechnic Institute and State University. Her research was conducted in the Virginia Tech Musculoskeletal Biomechanics Laboratory on the topic of trip recovery training in older adults and has been published in conference proceedings. She will continue with her graduate work with the intent of obtaining a Ph.D. Kathleen has two loving parents, Dennis and Molly, as well as an older brother Dennis. In her free time she enjoys reading, hanging out with friends, playing sports, and traveling.

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