Task-specific training reduces trip-related fall risk in women

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Conflict of Interest declarations:

University of Illinois at Chicago: Owns a patent on some of the technology used in the ActiveStep system and consequently there is an institutional conflict of interest.

Mark D. Grabiner M.D. Grabiner is an inventor of the ActiveStep system but has no conflicts of interest to declare with regard to the present study.

Mary Lou Bareither: Has no conflicts of interest to declare with regard to the present study.

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Abstract

Purpose: The potential of task-specific training as a fall-prevention intervention was studied. The primary purpose of the study was to determine the extent to which a task-specific training protocol decreased the number of falls by middle age and older women following a laboratory-induced trip. Secondary purposes were to explore the ability of trunk kinematics during the initial recovery step and the length of the initial recovery step to correctly classify the trip outcome, and to quantify the extent to which the training protocol affected these variables.

Methods**:** Healthy community dwelling women (n=52) were assigned to either a training group or control group that received no training. Training group women participated in an individually tailored, task-specific training protocol during which forward-directed stepping responses were necessary to avoid a fall following treadmill-delivered postural disturbances. Following the protocol, the ability to avoid a fall following a laboratory-induced trip was assessed. The primary outcome variable was the success (recover) or failure (fall) of the post-trip stepping response.

Results: Compared to the control group, there were fewer falls by the trained women following the laboratory-induced trip ($p<0.001$; odds ratio = 0.13). Using logistic regression, falls and recoveries following the trip were sensitively classified by trunk flexion angle at the completion of the initial recovery step and the length of the initial recovery step (sensitivity = 0.67, specificity =0.98), the former of which improved as a result of the task-specific training protocol.

Conclusions: The task-specific training protocol significantly reduced the number of falls following a laboratory-induced trip. Prospective study is required to determine if this task-specific training reduces falls in the community and, consequently, may complement currently used exercise-based fall prevention intervention methods.

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Introduction

Paragraph Number 1 Exercise demonstrably reduces falls by older adults (3). However, it may be possible to improve effectiveness of fall prevention interventions by the inclusion of task-specific perturbation-based balance training (6). Conceptually, task-specific training that involves practicing the actual motor skill of avoiding a fall following loss of balance will possess greater specificity to falls that occur in the community. The potential of this form of task-specific training to reduce trip-related falls was studied in healthy older adults who performed stepping responses to avoid falling following treadmill delivered postural disturbances (7). Subjects successfully modified their stepping responses after only a single exposure to the postural disturbance. Two key modifications were the reversal of trunk flexion velocity to an extension velocity at the instant of initial recovery step completion, referred to hereafter as recovery step completion, and the length of the initial recovery step. Other investigators have shown that this type of task-specific training can reduce falls by frail older adults (13) and Parkinson's disease patients (11). Collectively, these studies suggest that practicing the actual motor skill of avoiding a fall following a large postural disturbance may decrease fall risk.

Paragraph Number 2 The relationships between the outcome of laboratory-induced trips and trip recovery kinematics have been established in young subjects (4,5) and healthy older adults (8, 9,10). The post-trip trunk flexion angle of healthy older adults was about 33 percent larger than that of younger adults, yet, these older adults avoided falling. However, the post-trip trunk flexion angle of healthy older adults who fell was about 80 percent and 71 percent larger than younger adults and healthy older adults who did not fall, respectively. In these studies, trunk flexion velocity at recovery step completion characterized older adults who fell, whereas those who recovered were characterized by a trunk extension velocity.

Paragraph Number 3 The primary purpose of this study was to determine the extent to which a task-specific training protocol decreased the number of falls by middle age and older women following a laboratory-induced trip. We hypothesized that, compared to the control group, there would be significantly fewer falls by trained women. Secondary purposes were to explore the ability of trunk kinematics during the initial recovery step as well as the length of the initial recovery step, to correctly classify the trip outcome, and to quantify the extent to which the training protocol affected these variables. We expected that successful recoveries following the induced trip would be sensitively classified by trunk kinematics during the initial recovery step and the length of the initial recovery step length. Further, we expected these variables to be significantly improved following the training protocol.

Methods

Paragraph Number 4 All procedures were approved by the Institutional Review Board of the University of Illinois at Chicago. A medical history acquired during an initial telephone interview, excluded subject with cardiovascular, neurological, musculoskeletal and other systemic disorders. Subsequently, 87 independent community-dwelling women provided written informed consent and were examined by a physician. Exclusion factors included a history of lower extremity fracture/surgery, vertebral fracture/ surgery, noticeably impaired gait and dizziness (8) and proximal femur bone mineral density <65 g/cm^2, assessed by DEXA (Hologic, Inc, Bedford, MA). Twenty-one women who were consented failed the physical or DEXA exam. Sixty-six women were alternately assigned to the training or control group. Three experimental group women self-dropped before study completion; one reporting that the protocol caused her to become anxious, and two citing the inconvenience of traveling to the laboratory. Ambiguity about the outcome of the trip arose because of the difficulty in distinguishing a subject who engaged the safety harness system during recovery but may have recovered if she had not been limited by the length of the harness rope from a subject who would have fallen if she had not been restrained by the harness ropes (9). Therefore, the ambiguous outcomes of the trips for three control group women and eight trained women were not included in the analyses. Complete data sets were available for 22 trained women (age: 65.9±7.8 years, height:1.61±0.07 m, weight:69.9±12.4 kg) and 30 control group women (age: 58.8±4.7 years, height: 1.58±0.07 m, mass: 70.2±14.9 kg).

Paragraph Number 5. Fourteen women participated in four training sessions, each consisting of up to 30 postural disturbances, over four weeks. Six women participated in eight training sessions consisting of up to 15 postural disturbances over four weeks. The weekly sessions were administered on a Monday-Wednesday, Tuesday-Thursday, or Wednesday-Friday schedule. Two women participated ten training sessions consisting of up to 15 postural disturbances, over 3.5 weeks. Training sessions were terminated when the subject completed the planned number of trials or if the subject self-terminated the session, which occurred when the subject reported "feeling tired" or "not feeling well". The average total number of trials for four, eight and ten training sessions was 120±0, 120±0, and 142.5±10.6, respectively. The treadmill post-test and the laboratory-induced tripping protocol were conducted 8±6 days (range=4 to 30, median: 5, interquartile range: 3) after training protocol completion. One subject, for whom the time between the training protocol completion and post-test was 30 days, accounted for the large variability. Without this subject, the range was 7±3 (median: 5, interquartile range: 1.38).

Paragraph Number 6 Postural disturbances were delivered by a microprocessor-controlled, stepper motor-driven treadmill (Simbex, Lebanon, NH). Each training session began with treadmill walking for 30 seconds at 0.67 m/s, followed by 30 seconds at 0.89 m/s, and finally, 30 seconds at 1.11 m/s. The training protocol consisted of postural disturbances that simulated a trip (7) caused by motion of the treadmill belts that resulted in forward-directed rotation of the subject. The disturbances, which were delivered while the subject stood upright, hands at her side, feet a self-selected distance apart and heels aligned, were sufficient to cause a fall if the stepping response was inadequate. A 5 cm high foam obstacle, placed about two inches in front of the subject's shoes and intended to increase the height of the step, could not interfere with the recovery step if contacted (15). A safety harness system allowed the subject to fall but precluded contact of the hands and knees with the treadmill.

Paragraph Number 7 Disturbances were characterized by three phases, the parameters of which altered the difficulty of the recovery task. During the initial acceleration phase, which established the initial rotational ("falling") velocity of the subject relative to the treadmill, the treadmill belt velocity changed from 0.0 m/s to a selected peak velocity (range = 1.0 to 1.44 m/s). During the constant velocity phase the selected peak treadmill belt velocity was maintained (range = 0 to 4 seconds), with longer durations requiring multiple recovery steps. During the deceleration phase, the treadmill belt velocity decreased to zero (range = 0.1 to 2.0 seconds), with shorter durations being more destabilizing because of the suddenness of the stop. Before each trial, the subjects were asked if they were "ready" and the disturbance occurred after a variable delay between one and five seconds. Disturbances eliciting backwards-directed steps were randomly placed in the disturbance sequence to reduce anticipation of the disturbance by the subject (three disturbances for training sessions having 15 trials, six disturbances for training sessions having 30 trials). Following the warm-up on the first training day, but before the training disturbances, a "pre-test" disturbance having an initial acceleration phase of 0.0 to 1 m/s in 175 ms (5.7 m/s^2), a constant velocity phase: five seconds, and a deceleration phase: 2.0 seconds, was delivered.

Paragraph Number 8 The sequence of postural disturbance magnitudes was tailored to each subject's day-to-day and trial-to-trial performance, which was evaluated by the investigator (initial accelerations: 4.2 m/s^2, 5 m/s^2, or 7.5 m/s^2,constant velocity phase: 0, 0.1, 0.2, 0.35, 0.5, 2.0 or 4.0 seconds; deceleration phase: 0.1,0.26 or 0.4 seconds). Successful recovery was generally followed by an increase in the difficulty of the subsequent disturbance. Multiple failures generally resulted in the return to a disturbance that had been previously successfully performed.

Paragraph Number 9 The order in which the treadmill post-test and the laboratory-induced trip was administered was balanced across subjects. The post-test disturbance was identical to the pre-test disturbance.

Paragraph Number 10 During the tripping protocol the subject performed over-ground walking trials at a self-selected speed, first without and then with the safety harness. As in previous work, subjects were tripped only once. Subjects did not know how or during which trial the trip would occur. Before the beginning of the trial immediately after the subject donned the safety harness, and in full view of the subject, a rope was laid across the gait pathway and about which nothing was said. The rope was intended to mislead the subject about both the location and the mechanism of the trip. Trips were induced by a concealed obstacle about 3.0 m from the rope and that rose approximately five centimeters from the floor when activated.

Paragraph Number 11 Trips were categorized as a fall, rope assist, miss or recovery (11). Subjects who fell were unambiguously supported by the safety harness. The category "rope-assist" was assigned when unambiguous determination of the extent to which the safety harness supported the subject could not be made. A "miss" occurred when the subject's foot was not completely obstructed by the obstacle. Rope-assists and misses were excluded from the data analyses. Outcomes not characterized as a fall, rope-assist or miss were a "recovery".

Paragraph Number 12 During the initial training, the pre-test, and the post-test sessions, the three dimensional positions of 23 reflective markers were tracked using motion capture (Motion Analysis Corporation, Santa Rosa, CA) operating at 60 Hz. The markers were used to construct 13 segment model of the body from which kinematics were computed (16).

Paragraph Number 13 To determine the extent to which the task-specific training protocol decreased the number of falls following the laboratory-induced trip, a comparison between the occurrences of falls and recoveries by control group and trained women was conducted using a chi square test. Stepwise logistic regression (forward conditional) was used to explore the ability of the variables for which significant between-group difference were found (Bonferroni-adjusted, independent t-tests) to correctly classify the trip outcome. The cutoff value for the logistic regression analysis was determined using the receiver operator characteristic (ROC). The extent to which the training protocol affected trunk kinematics and recovery step length following treadmill disturbances was determined using paired t-tests to compare the pre-test and post-test values. Statistics were conducted using IBM SPSS V19.0 (IBM SPSS, Armonk, NY) and threshold for significance of $p \leq 0.05$.

Results

Paragraph Number 14 Fewer trained women fell after the trip than control group women. In control group women, of 30 successful trips, there were eight falls for which the outcomes were unambiguous (26.6 percent). For the trained women, of 22 successful trips having unambiguous outcomes there was one fall (4.5 percent). The chi square analysis revealed that the between-group difference was significant ($p=0.043$). Overall, there was a 22.2 percent absolute risk reduction and an 83.2 percent relative risk reduction in the trained group compared to the control group (odds ratio = 0.13).

Paragraph Number 15 The trunk kinematics of the nine women who fell after the trip were different from those of the 43 women who did not fall At recovery step completion the trunk flexion angle of the women who fell was 37±5 degrees and the trunk velocity was 40±41 degrees/second (flexion). In contrast, the trunk flexion angle of the women who did not fall was 22±13 degrees and the trunk flexion velocity was -13±44 degrees/second (extension). The between-group differences for trunk flexion angle and velocity were significant (p=0.001 and 0.002, respectively). The recovery step length of women who fell was significantly shorter than that of women who did not fall (28.4±19.3 percent body height versus 58.2±16.9 percent body height, respectively, p<0.001).

Paragraph Number 16 The final stepwise logistic regression function included recovery step length (ExpB = 0.87; 95% CI =0.78-0.98, p=0.019) and trunk flexion angle (ExpB = 1.19; 95% CI =1.03 -1.37, p=0.018). The area under the receiver operator curve was 0.895 and, using a cutpoint of 0.5, yielded a sensitivity and specificity of 0.67 and 0.98, respectively. The total correct classification of falls and recoveries was 92.3 percent.

Paragraph Number 17 The training protocol improved trunk flexion angle and trunk velocity at recovery step completion. After training, the trunk flexion angle decreased 43 percent from 30±13 degrees to 17±8 degrees (p<0.001). After training, the trunk velocity increased over four-fold from -13±55 degrees/second (extension) to -60±19 degrees/second (extension). This change was significant (p=0.002). After training, the normalized recovery step length increased only four percent, from 36.0±16 to 40.2±8 percent body height (p>0.05).

Discussion

Paragraph Number 18 The results demonstrated that task-specific training decreased the number of falls by middle age and older women following a laboratory-induced trip. The ability to avoid falling after the trip was characterized by the smaller trunk flexion angles during the longer, initial recovery step after the trip, thereby confirming previous results (8). The ability to limit trunk flexion following the post-test treadmill disturbance was beneficially influenced by the training protocol.

Paragraph Number 19 The decreased number of falls following the trip and the changes of trip-recovery kinematics are consistent with results from previous studies of healthy older adults (1,7) and studies of task-specific training and fall risk of older adults with physical impairments. In one study, frail older adults completed a six-month training protocol consisting of postural disturbances delivered during treadmill walking (13). During the six month follow-up period there were 21 percent fewer falls, in addition to fewer total falls and a longer time to first fall compared to control subjects. The differences, however, did not achieve significance. In another study, men with idiopathic Parkinson's disease completed a two month protocol consisting of multidirection, treadmill-delivered postural disturbances (11). During a two week follow-up period, the trained men had 50 percent fewer falls than the control subjects although the difference did not achieve significance. Nevertheless, these studies, combined with the present results, provide consistent, preliminary support for the potential of task-specific training as a fall prevention intervention.

Paragraph Number 20 The number of middle age women who fell after the trip is notable and may have practical value. The 24 percent of the middle age control group women who fell is close to the 21.9% of untrained women 65+ years of age who fell after a laboratory-induced trip (10). In the US, middle age women have fewer fall-related hospitalizations and fewer non-hospitalized injuries than women 65+ years of age. However, in 2000, women between 45-64 years of age registered more than 1.9 million non-hospitalized, fall-related injuries (2); only 5.4 percent smaller than that of women older than 65. A history of falls is one of the strongest predictors for falling; having odds ratios and relative risk values ranging between 1.5 and 6.7 (14). Consequently, identifying middle-age women who are at risk for falls and candidates for early targeted intervention may reduce the overall rate of falls, particularly injurious falls, that becomes manifest at around age 65 years.

Paragraph Number 21 The present results extend those of Bieryla (2007) who reported that a single session of treadmill-delivered disturbances improved the ability to control trunk kinematics following a laboratory-induced trip. These results are clinically important. Compared to the duration of conventional, exercise-based fall-prevention interventions such as strength training, balance training and tai chi, the present results were achieved with a relatively short protocol considering the number of sessions and the overall duration of the intervention. Identifying the clinically-modifiable mechanism(s) through which task-specific training reduces fall risk, and defining the protocol design parameters that maximize the clinical outcomes, are important direction for further study.

Paragraph Number 22 There are limitations of the present work that merit consideration. First, the middle age and older women studied were healthy and not representative of the population of older women most likely to fall. However, the success of the protocol justifies the question of the extent to which people with musculoskeletal and/or neuromuscular conditions may benefit from a task-specific training. The results of the previously mentioned studies (11,13) suggest that there is a benefit. However, it is likely that the extent to which underlying conditions affect mobility will exert an influence on the time required to elicit a reduction in fall risk and, possibly, the maximum attainable improvement in fall risk. Further systematic investigation may determine the minimum mobility level that is required for a task-specific protocol to achieve an attractive cost:benefit ratio. Secondly, the static conditions from which the postural disturbances were initiated in the present study differ from the dynamic conditions of locomotion. Although the treadmill used in the present study allows disturbances to be delivered to a walking subject, the apparent effectiveness of the protocol in its present form raises the legitimate, and testable, question of whether disturbances initiated during walking would further decrease in fall risk.

Paragraph Number 23 In summary, a short-term, task-specific training protocol significantly reduced the number of falls following a laboratory-induced trip by middle age and older women. The smaller number of falls was associated with training-induced changes in biomechanical variables that have been consistently demonstrated to be of central importance to avoiding a fall following a trip. Nevertheless, a prospective study design is required to determine if the task-specific training reduces falls in the community and, as a result, if task-specific training can contribute to current exercise-based fall prevention intervention methods.

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Strawberry Gatts**	Is deceased.
Jane Marone:	Has no conflicts of interest to declare with regard to the present study.
Karen L. Troy:	Has no conflicts of interest to declare with regard to the present study.

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