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Original Research

The Effects of a 4-Week Perturbation-Based Training on Functional Outcomes in Community-Dwelling Older Adults

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Abstract

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Falls are a leading cause of injury and functional decline in older adults. Traditional fall prevention programs often focus on improving strength and balance through predictable movement patterns that may not reflect real-world scenarios. Perturbation-based balance training (PBT) has emerged as a promising intervention to improve reactive balance; however, evidence supporting short-term, clinically feasible protocols remains limited. This study evaluated the effects of a 4-week PBT program on functional mobility in community-dwelling older adults. Thirty participants (67.71 ± 8.16 years) completed eight training sessions over four weeks using a perturbation treadmill (ActiveStep™). Sessions included progressive slips and trips under dual-task conditions. Functional performance was assessed before and after the intervention using the 30-second Sit-to-Stand (STS) and 8-Foot Up-and-Go (8UG) tests. Paired *t*-tests and Cohen's *d* effect sizes were calculated. STS performance improved by 2.27 ± 3.99 repetitions ($t(29) = 3.11$, $p = 0.0042$, ES = 0.528), 8UG time decreased by 0.49 ± 1.10 seconds ($t(29) = -2.434$, $p = 0.0213$, ES = -0.370), and trip perturbation level increased significantly (0.87 ± 1.17; $t(29) = 4.069$, $p < 0.001$, ES = 0.766). Changes in slip perturbation level were not significant (0.5 ± 1.38; $t(29) = 1.980$, $p = 0.0573$, ES = 0.416). These findings demonstrate that even a brief PBT program can improve functional strength, mobility, and trip recovery performance in healthy older adults, supporting its potential as a practical fall-prevention intervention.

Keywords: Fall risk, aging, treadmill, intervention

Introduction

Falls are the leading cause of injury and injury-related death among adults aged 65 years and older in the United States, with approximately one in four older adults experiencing a fall each year.[1,2] Beyond immediate physical injury, falls often initiate a cycle of negative outcomes including reduced physical activity, loss of independence, fear of falling, and increased risk of dementia and mortality.[3-6] Mortality risk after a fall has been reported as 9.6% during the first 30 days and 33% after one year.[7] These findings highlight the need for research focused on maintaining mobility and preventing fall-related decline in older populations.

Functional mobility and lower extremity strength are key contributors to fall risk and independence in older adults. Falls typically result from a failure to predictively or reactively adapt to unexpected environmental disturbances.[8] Successfully recovering from these perturbations requires rapid neuromuscular responses and the ability to generate stabilizing

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steps, which are key indicators of functional mobility. Clinical assessments such as the 8-foot up-and-go (8UG) and 30-second Sit-to-Stand (STS) tests are used to evaluate functional mobility and fall risk in older adults.[9-14] The 8-foot up-and-go (8UG) is a standardized clinical assessment developed specifically for use in older adults to evaluate functional mobility, dynamic balance, and walking ability, with slower completion times strongly associated with an increased risk of falls. [9-12] STS evaluates lower extremity strength and functional performance, both of which are essential for activities of daily living such as standing, walking, and transferring between positions.[11-14] Poorer STS performance has also been linked to greater fall risk and reduced functional independence, and established age- and sex-specific normative values further support its clinical utility. [11-14] Although these assessments do not directly measure an individual's ability to respond to unexpected perturbations, they provide standardized, clinically accepted measures of mobility and lower extremity function that are routinely used to evaluate fall risk. As such, they serve as useful outcome measures for determining whether improvements following the perturbation-based balance training (PBT) protocol translate to broader functional performance. Together, the 8UG and STS provide complementary assessments of strength, mobility, balance, and functional capacity, making them clinically relevant outcome measures for evaluating interventions designed to reduce fall risk.

Traditional fall-prevention programs focus on improving muscular strength, balance, and functional mobility through resistance training, balance exercises, and task-based rehabilitation.[15,16] While these approaches can reduce fall incidence, they typically emphasize predictable, controlled movement patterns rather than the reactive balance responses required to recover from unexpected trips and slips. PBT has emerged as an approach that replicates real-world trips and slips in a controlled setting.[17-19] By repeatedly exposing individuals to unexpected perturbations, PBT may enhance reactive balance responses and the ability to stabilize after a loss of balance.[20,21] Previous studies have demonstrated that these reactive balance adaptations can be retained for 6–12 months, and in some cases beyond one year, following the initial intervention. [22-29] Collectively, these findings suggest that while perturbation-induced motor learning is relatively durable, periodic booster sessions may help preserve functional performance and maximize long-term fall protection. Despite previous research, standardized PBT protocols and clinically practical training prescriptions remain limited. Short-term interventions are particularly attractive because they reduce patient burden, require fewer clinical resources, and can be more easily integrated into outpatient rehabilitation and community-based programs. Demonstrating meaningful improvements following a brief intervention may therefore increase the feasibility of implementing PBT as a routine fall-prevention strategy.

An additional advantage of PBT is that these improvements are thought to arise primarily through rapid, task-specific motor learning and neuromuscular adaptations, allowing meaningful functional gains to occur within a relatively short training period. Consequently, brief PBT protocols may be more feasible to integrate into outpatient care and in community-based fall prevention. Despite these advantages, relatively few studies have evaluated standardized, short-duration PBT protocols using clinically relevant functional outcome measures. Therefore, further research is needed to determine whether brief PBT interventions can produce meaningful improvements in functional mobility. The present study aimed to evaluate the effects of a 4-week PBT protocol using pre- and post-intervention functional mobility assessments. Specifically, the 8UG and STS tests were used to determine whether this protocol produces measurable changes in functional performance. Participants in this study were community-dwelling individuals representative of the general older adult population rather than individuals already classified as high fall-risk.[2]

Establishing the functional effects of this protocol in a representative population may help support its future use as a standardized training approach for mobility and fall prevention.

Thus, the purpose of this study was to evaluate the effects of a 4-week PBT protocol on functional mobility, lower extremity strength, and perturbation tolerance in community-dwelling older adults. It was hypothesized that following the 4-week PBT intervention, participants would demonstrate significant improvements in functional performance, characterized by reduced completion time on the 8UG test and an increased number of repetitions on the STS test. Additionally, we hypothesized that participants would demonstrate a significant increase in maximum perturbation tolerance.

Methods

Participants

This study employed a longitudinal, repeated-measures design over a 4-week intervention period. A total of 30 healthy older adults (67.71 ± 8.16yr) were recruited from the Northfield community. Healthy older adults were operationally defined as community-dwelling adults over the age of 55 who were able to walk independently for at least 15 minutes and who reported no neurological, musculoskeletal, or cardiovascular conditions that would interfere with safe participation in the intervention. Fear of falling was assessed at baseline using the Falls Efficacy Scale–International (FES-I), a validated questionnaire that measures concern about falling during a range of everyday activities. Scores range from 16 to 64, with higher scores indicating greater concern about falling.[30] Additionally, subjects were asked to report any falls 3 months prior to their initial visit. They were then contacted between 10-36 months after their final visit to report any falls in detail. A within-subject repeated-measures design was selected because each participant's pre-intervention performance served as their own baseline for comparison. This approach reduces variability due to individual differences and increases sensitivity for detecting changes following the intervention. The findings from this study are intended to inform the design and sample size considerations of future randomized controlled trials. This research design is appropriate in evaluating the intervention and informing future controlled studies. All participants provided written informed consent prior to participation. The study protocol was approved by the St. Olaf College Institutional Review Board. Because pilot data was not available, and prior studies using comparable interventions have demonstrated substantial pre-post changes in the primary outcome, a large effect size (Cohen's dz = 0.8) was assumed for the a priori power analysis.[31,32] Based on a two-tailed paired t-test with an alpha level of 0.05 and 80% statistical power, the estimated required sample size was 15 participants. This research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*.[33]

Protocol

Treadmill Protocol. The four-week intervention consisted of two sessions per week, for a total of eight perturbation training sessions, conducted using the ActiveStep™ treadmill (Simbex, New Hampshire). The initial and final sessions lasted an hour due to pre- and post-functional assessments, whereas normal training sessions lasted 30 minutes. The treadmill system includes five levels of difficulty, with increasing levels corresponding to greater magnitudes of perturbation. Participants were secured in an overhead harness during all sessions to prevent injury in the event of a fall. An accelerometer was attached to the posterior of the harness throughout each session.

Each session included a warm-up followed by a series of perturbation tasks: Trunk Stability, Forward Step Stability, Lateral Step Stability, Backward Step Stability, Continuous Trips, and Continuous Slips. The Trunk Stability and Step Stability tasks assessed participant progression using a binary pass/fail system. The Continuous Trips and Slips tasks were employed as training modalities, exposing participants to repeated perturbations while walking.

Participants began each session with a two-minute warm-up at a self-selected walking speed. Walking speed, along with the selected level of difficulty, determined the magnitude of the perturbations in subsequent tasks. Perturbations were then delivered without warning for each task, and a designated "distractor" engaged participants in conversation to achieve dual tasking.

During the Trunk Stability task, a forward perturbation was delivered while participants were instructed to maintain balance without stepping or relying on the harness. During the Step Stability task, participants were instructed to take only one step in response to perturbations while facing forward, left, right, and backward. Participants then completed the Continuous Trips and Continuous Slips at the highest level achieved during the forward Step Stability task for that session. During these tasks, participants walked at their normal walking speed while random perturbations were administered. Participants were instructed to maintain their balance and continue walking. Participants performed 10 continuous perturbations per task during sessions 1-4 and 15 perturbations during sessions 5-8.

Progression through perturbation levels was based on performance. A failure was defined as placing greater than 30% body weight into the harness[34], stepping during the Trunk Stability task, or taking more than one step during Step Stability tasks. Participants advanced to the next level if they passed on their first attempt. If a failure occurred, three additional trials were performed at that same level. Tasks were terminated if two or more failures occurred at a given level. At Level 5, four trials were always completed. Pass/fail outcomes were not recorded during continuous tasks.

Statistical Analysis

Primary outcome measures included the 30-second STS and 8UG test performed before and after the intervention. Participant performance was also categorized relative to published age- and sex-specific normative values.[11,12] Because normative values for the STS and 8UG are available beginning at 60 years of age, the five participants younger than 60 years were classified using the nearest available age group (60–64 years). Secondary outcome measures included the highest perturbation level achieved during the Continuous Trips and Continuous Slips tasks, recorded during the first and final intervention sessions.

Statistical analyses and summary statistics were performed using R version 4.4.1 (2024-06-14). Paired *t*-tests were used to evaluate pre- to post-intervention changes in continuous outcome measures. Confidence intervals (95%) and Cohen's *d* effect sizes were calculated for the mean differences. Changes in the proportion of participants classified as below normative values for the STS and 8UG were assessed using McNemar's exact test. Statistical significance was set at $p < 0.05$.

Results

Functional assessments were performed prior to session 1 and immediately following completion of session 8. STS performance improved following the intervention, increasing by an average of

2.27 ± 3.99 repetitions ($t(29) = 3.11$, $p = 0.0042$, ES = 0.528), indicating a moderate effect. Similarly, 8UG completion time decreased by 0.49 ± 1.10 seconds post intervention ($t(29) = -2.434$, $p = 0.0213$, ES = -0.370), representing a small-to-moderate effect. In addition to improvement in functional scores, the proportion of participants performing below age- and sex-specific normative values[11,12] on the STS decreased significantly from 56.7% (17/30) at baseline to 33.3% (10/30) following the intervention (exact McNemar's test, $p = 0.039$). For the 8UG, the proportion of participants classified as below normative values decreased from 36.7% (11/30) to 20.0% (6/30); however, this change was not statistically significant (exact McNemar's test, $p = 0.063$). Furthermore, improvements were seen in the highest level achieved during continuous trip tasks, which increased by 0.87 ± 1.17 levels ($t(29) = 4.069$, $p < 0.001$, ES = 0.766), reflecting a moderate-to-large effect. Continuous slips performance increased by 0.50 ± 1.38 levels; however, this change did not reach statistical significance ($t(29) = 1.980$, $p = 0.0573$, ES = 0.416). Participant characteristics are summarized in Table 1. The study included 30 healthy community-dwelling older adults (67.71 ± 8.16 years; 20 women, 10 men). Baseline participant characteristics, including BMI, fear of falling (FES-I), and fall history, are reported in Table 1. Descriptive statistics for all outcome measures are presented in Table 2.

Table 1. Participant Demographics.

Age	67.71 ± 8.16
Sex	20 F / 10 M
BMI	28.59 ± 6.78
Race	29 Caucasian / 1 Black
Baseline FES-I Score	20.87 ± 3.87
Fallen in last 3 months	8 / 30 (26.67%)

Table 2. Summary Statistics of Outcome Measures.

	p value	95% CI Lower	95% CI Upper	Paired Cohen's d	*t* value	Degrees of Freedom	Average Pre ± SD	Average Post ± SD	Average Post - Pre ± SD
STS	0.0042*	0.776	3.757	0.528	3.11	29	14.43 ± 3.43	16.7 ± 4.77	2.27 ± 3.99
8UG	0.0213*	-0.899	-0.078	-0.370	-2.434	29	5.99 ± 1.39	5.5 ± 1.22	-0.49 ± 1.1
Level Trips	0.0003*	0.431	1.302	0.766	4.069	29	3.47 ± 1.25	4.33 ± 0.96	0.87 ± 1.17
Level Slips	0.0573	-0.017	1.017	0.416	1.980	29	2.9 ± 1.18	3.4 ± 1.22	0.5 ± 1.38

Note: "*" indicates statistical significance. Paired Cohen's d provides effect sizes abbreviated as ES.

Discussion

The present study aimed to evaluate the effects of a 4-week PBT protocol using the ActiveStep™ system on functional mobility in healthy older adults, as assessed by the STS and 8UG. While PBT specifically targets reactive balance control during unexpected disturbances, the STS and 8UG assess broader aspects of lower-extremity strength, mobility, and functional performance that are routinely evaluated in clinical practice.[9,12] Therefore, these measures provide insight into whether improvements gained through PBT translate to meaningful changes in overall functional mobility. Following the intervention, participants demonstrated improvements in both assessments. STS performance increased by an average of 2.27 ± 3.99 repetitions, indicating improved lower body functional performance, while 8UG completion time decreased by an average of 0.49 ± 1.10 seconds, reflecting enhanced dynamic balance and mobility. One possible explanation for these improvements is that repeated exposure to unexpected perturbations enhances reactive neuromuscular control through rapid, task-specific motor learning. Unlike traditional resistance and balance training programs, which often require several weeks or months before measurable

physiological adaptations occur, PBT primarily targets improvements in reactive stepping, trunk stabilization, and limb coordination through repeated exposure to unexpected balance disturbances.[20] These neuromuscular adaptations may explain how meaningful improvements in functional mobility can occur within a relatively short training period, making the four-week timeline observed in the present study biologically possible. Improved reactive motor control and coordination may have facilitated more effective performance during functional tasks requiring dynamic balance and rapid postural adjustments, such as rising from a chair, turning, and walking, thereby contributing to the observed improvements in STS performance and 8UG completion time.

When comparing these results to the broader literature, the magnitude of functional improvements observed in this study stands out. A comprehensive meta-analysis of 25 randomized controlled trials found that while PBT substantially improves reactive balance, reducing laboratory-induced falls by 58%, it yields no statistically significant pooled effects on generalized fall risk factors such as generic muscular strength or global mobility metrics like the Timed Up-and-Go (TUG) test.[32] This lack of transfer to traditional clinical tests is frequently reported in the literature due to the high task-specificity of reactive motor adaptations.[26, 32] For example, in a trial evaluating a short-term PBT intervention in community-dwelling older adults, researchers observed no significant changes in traditional physical performance scales, despite generating minor improvements in dual-task gait speed (0.05 m/s).[35] In contrast to these trends, our 4-week protocol yielded statistically significant, moderate improvements in both non-specific functional measures. Specifically, our participants increased their 30-second STS performance by 2.27 ± 3.99 repetitions (p = 0.0042, d = 0.528) and decreased their 8UG duration by -0.49 ± 1.10 seconds (p = 0.0213, d = 0.370). The divergence in our findings may be explained by the structure of our training protocol. Unlike single-session protocols or low-dose interventions that average 2.5 hours of exposure across 3 to 6 sessions,[31] our protocol used 8 progressive sessions spread over 4 weeks to total around 5 hours in a dual-task environment. Furthermore, our treadmill protocol incorporated multi-directional tasks (forward, lateral, and backward step stability), which require rapid, voluntary lower-limb repositioning and multi-directional force generation. This progressive and multi-directional motor task likely stimulated broader adaptations in rapid lower-extremity force production and dynamic stability, resulting in a successful transfer to the STS and 8UG tests that lower-dose or single-direction PBT protocols may not achieve.

Beyond modest improvements in functional measures, perturbation-based balance training also shifted participants toward age- and sex-specific normative functional classifications. The proportion of participants performing below normative values [11,12] on the STS decreased significantly from 56.7% to 33.3%, while the proportion classified below normative values on the 8UG decreased from 36.7% to 20.0%. Although the reduction in below normative 8UG classifications did not reach statistical significance, both findings suggest that the intervention produced clinically meaningful improvements in functional performance. Importantly, these results indicate that the observed gains were not limited to changes in mean performance but were sufficient to move several participants into normative functional ranges. These findings suggest that the intervention produced changes extending beyond improvements in group mean performance, enabling several participants to transition into age- and sex-appropriate functional ranges. Such transitions may be clinically meaningful, as poorer performance on chair-rise and functional mobility assessments has been associated with reduced functional independence and an increased risk of falls in older adults.[9, 36]

Over the course of the intervention, participants also reached higher perturbation levels in the continuous trips task, with an average increase of 0.87 ± 1.17 levels from the first to last session. A similar trend was observed in the continuous slips task, with an average increase of 0.5 ± 1.38 levels. Participants' progression to higher perturbation levels reflects the progressive nature of the intervention and indicates improved tolerance to balance disturbances and reactive balance capacity.

This study contributes to the growing body of literature supporting PBT as a promising approach to reducing fall risk. Previous trials on healthy, community-dwelling older adults have demonstrated that treadmill and overground perturbation training can achieve long-term retention of fall-resisting skills and significantly reduce laboratory-induced fall rates.[22,27] However, these studies primarily evaluated outcomes using specialized laboratory measures, such as mechanical slip outcomes, center-of-mass stability, or fall occurrence following the intervention.[22,27] In contrast, this study demonstrates that PBT also produces measurable benefits on non-specific, clinically accessible functional outcomes, like the STS and 8UG tests. This distinction is important for clinical translation as these assessments are routinely used in rehabilitation and community settings to evaluate functional mobility and monitor patient progress. Our findings suggest that meaningful improvements can be detected over the course of an eight-session PBT program using tools that are readily available in clinical practice.

Together, these findings provide preliminary evidence that an eight-session PBT protocol can improve factors associated with fall risk in healthy older adults. Notably, meaningful improvements in functional mobility and balance were observed over a relatively brief course of training, suggesting that clinically relevant changes can be achieved without prolonged intervention. This practical training model may provide a feasible framework for future clinical implementation and investigation in outpatient rehabilitation, community wellness programs, and aging services where time and resources are limited.

The clinical impact of this study is in defining an efficient "minimum effective dose" for perturbation training. Traditional fall-prevention programs typically require 2 to 3 hours of weekly training for up to 12 months to achieve a 23% reduction in falls,[15,16] which often leads to poor patient compliance. In contrast, our protocol demonstrates that just 5 hours of total training (8 sessions over 4 weeks) is sufficient to significantly improve core functional mobility and perturbation tolerance ($p < 0.05$). This highly compressed timeline offers a scalable, resource-efficient model that can be easily integrated into standard outpatient physical therapy or community wellness programs.

Although our primary protocol did not originally include a prospective longitudinal design, existing literature outlines potential for a translational pathway from these functional improvements to actual fall reductions. PBT works by driving rapid neural adaptation, rewriting the central nervous system's predictive motor loops to execute faster, more effective compensatory stepping and trunk stabilization during a loss of balance.[19,20] Meta-analytic data shows that PBT programs exceeding a 2.5-hour threshold successfully reduce real-world fall rates by 33%.[32] By exposing participants to progressive, multi-directional perturbations under dual-task conditions, our brief 4-week program directly targets these neuromuscular failures. To preliminarily evaluate this translation, we conducted an exploratory follow-up (10 to 36 months post-training; 90% response rate). While limited by retrospective recall, these observational self-reports revealed that real-world falls dropped from 26% (in the 3 months prior to enrollment) to 14% across the entire post-

intervention period, with only a single pre-trial faller experiencing a recurrent fall. Crucially, all post-training falls occurred at least two years after completion under environmental challenges (e.g., ice, heavy loads), and none resulted in injury or required medical care. Furthermore, 73% of participants explicitly reported successfully recovering from a slip or trip in daily life, suggesting that the rapid motor adaptations acquired during PBT may confer durable, long-term protection against everyday hazards. Although this investigation into the long-term translation of PBT into real life is exploratory, this data prompts the need for further, more exhaustive investigation.

Several limitations should be considered when interpreting these findings. The long-term fall outcomes must be interpreted with caution due to the retrospective, self-reported nature of the follow-up data. Because participant contact occurred between 10 and 36 months post-training, the data are susceptible to recall bias and memory decay regarding non-injurious events over extended time horizons. Future trials should incorporate prospective fall calendars and frequent, scheduled check-ins to rigorously confirm the durability of these perturbation-based adaptations. The absence of a control group limits the ability to attribute observed improvements solely to the intervention. A within-subject design was selected for this investigation to evaluate feasibility and preliminary efficacy. However, future randomized controlled trials are needed to establish the comparative effectiveness of perturbation-based treadmill training relative to existing interventions. The sample size was modest, and participants were primarily healthy, community-dwelling older adults who generally exhibited a moderate concern about falling at baseline (FES-I 20.87 ± 3.87) and were not considered to be at high risk of falls. As a result, the magnitude of observable change may have been limited, and findings may not generalize to higher-risk populations or those with greater functional impairments. Furthermore, the cohort skewed toward the younger range of older adulthood, which may further limit generalizability to more vulnerable populations. Future research should address these limitations by incorporating larger, more diverse samples and including individuals at higher risk for falls. Tracking fall incidence in daily life is needed as well to establish the real-world impact of perturbation-based interventions, beyond functional assessments. Mechanistic investigations, such as the use of electromyography (EMG), may help understand the neuromuscular adaptations underlying improvements in reactive balance. Additionally, because participants wore an overhead safety harness throughout training, movement behavior may have differed from real-world situations. Although the harness improves participant safety and allows higher perturbation exposure, it may reduce fear of falling and slightly alter natural balance responses. Finally, given known disparities in access to care in rural populations, [37-39] future work should explore how this intervention can be implemented in community-based settings while addressing barriers such as transportation, cost, and accessibility.

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Conflict of Interest/Financial Disclosure

None declared

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"We stand on the homelands of the Wahpekute Band of the Dakota Nation. We honor with gratitude the people who have stewarded the land throughout the generations and their ongoing contributions to this region. We acknowledge the ongoing injustices that we have committed against the Dakota Nation, and we wish to interrupt this legacy, beginning with acts of healing and honest storytelling about this place."

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