ORIGINAL ARTICLE

Learning to Resist Gait-Slip Falls: Long-Term Retention in Community-Dwelling Older Adults

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ABSTRACT. Bhatt T, Yang F, Pai Y-C. Learning to resist gait-slip falls: long-term retention in community-dwelling older adults. Arch Phys Med Rehabil 2012;93:557-64.

Objectives: To determine whether the fall-resisting skills acquired from a single perturbation training session can be retained for 6 months or enhanced by an intermediate ancillary session.

Design: A randomized controlled trial.

Setting: Biomechanics research laboratory.

Participants: Community-dwelling elderly (N=48; age, >65y).

Interventions: Initial perturbation training applied to all subjects using low-friction platforms to induce unannounced blocks of repeated right-side slips, interspersed with nonslips. The single-session group retested with only 1 slip 6 months later. The dual-session group received an additional slip at 3 months after the initial session, followed by a retest of slips at 6 months.

Main Outcome Measures: Slip outcome (incidence of falls and balance loss), dynamic stability (based on the center-of-mass position and velocity), and vertical limb support (based on hip height).

Results: Subjects in both groups significantly reduced fall and balance loss incidence from first to last training slips, which resulted from improved stability and limb support control. Both groups demonstrated significant retention in all outcome measures at 6 months compared with the first novel slip, although performance decay was evident in comparison with the last training slip. The ancillary slip at 3 months led to significantly better control of stability and, hence, reduced balance loss outcome, in the dual-session group at 6 months than in the single-session group.

Conclusions: Motor memory could be retained for 6 months or longer after a single session of fall-resistance training, although a single "booster" slip could further impede its decay. Through the experience of slipping and falling, it may be possible to "inoculate" older adults against potentially life-threatening falls.

Key Words: Accidental falls; Memory; Postural balance; Rehabilitation; Retention.

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INCREASING SUSCEPTIBILITY to falls with age[1] poses a health threat to older adults. Perturbation-related falls (ie, from trips or slips) are responsible for about 60% of outdoor falls among community-living adults 70 years or older.[2] Even the healthy older adults are not immune to devastating falls.[3] It is therefore highly desirable to develop intervention paradigms that can prevent such falls in older adults.

It has recently been proposed that perturbation training induced via support surface translations (ie, repeated slips) can be used to achieve such objectives.[4-6] Such perturbation training involves altering the relationship between one's center of mass (COM) and the base of support (BOS), inducing a balance threat (such as a forward slip). The theoretic and empirical predictions underlying this training have demonstrated that the trial-error–induced practice stimulates adaptive changes within the central nervous system (CNS).[5] Strong evidence emerges that adaptation to perturbation can be rapidly developed by shifting from relying on pure feedback-controlled reactive responses to a more feedforward-controlled (proactive) motor strategy to prevent backward loss of balance (BLOB)—achieved possibly by modifying or updating the internal representation of the CNS's stability limits for BLOB.[6-10]

Yet, to achieve fall reduction objectives, the challenge is that the effect of such adaptation training must also be retainable. There is evidence of long-term (weeks or months) motor retention of adaptation induced from various types of perturbations, at least among young adults.[4-6,11,12] For instance, retention of adaptive effects in body sway was noted among those who underwent the "sensory organization test"[12] and calf vibrations.[11] Recently, it was noted that adaptive skills acquired from a single session of repeated-slip exposure could be retained for several months in the young.[4-6] Nonetheless, the longer term retention of the training effects from such support surface perturbations remains unclear among older adults, a population that is known for its general memory decay and age-related sensorimotor deteriorations,[13] as do the possible ways of improving such retention.

The purpose of this study was to determine whether the fall-resisting skills acquired from a single perturbation train-

List of Abbreviations

BLOB	backward loss of balance
BOS	base of support
CNS	central nervous system
COM	center of mass
R-3mo	3-month slip
R-6mo	6-month slip
S1	1st slip of training session
S24	last slip of training session
$X_{COM/BOS}$	anteroposterior position of the COM relative to the BOS
$\dot{X}_{COM/BOS}$	anteroposterior velocity of the COM relative to the BOS

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ing session could be retained for 6 months and enhanced by an intermediate ancillary session among the healthy elderly. The primary hypothesis was that improvements resulting from a single training session, in the control of stability and in generating fall-resisting limb support, would be retained, resulting in a lower incidence of BLOB and falls than that of their first novel slip 6 months ago. The secondary hypothesis was that the "priming" effect of a single slip delivered at 3 months could further delay the naturally occurring motor memory decay compared with the last slip of the training session.[14]

METHODS

Participants

Community-dwelling, healthy older adults who gave written informed consent participated in this institutionally approved study after being screened for neurologic, musculoskeletal, cardiopulmonary, and other systemic disorders as assessed through a questionnaire, and were screened for selected drug usage (eg, tranquilizers). Tests administered by the research staff further excluded older adults with osteopenia or osteoporosis (based on calcaneal ultrasound indicated by a T score <-1.5[15]), cognitive impairment (score <25 on the Folstein Mini-Mental State Exam[16]), poor mobility (>13.5s on the Timed Up and Go test[17]), or symptomatic postural hypotension. Participants' history of falls over the last 12 months was also collected using a questionnaire. These screening tests were performed in the same session as the gait/slip experiment, or up to 2 weeks prior, according to the participant's preference. Subjects were recruited from different senior exercise centers, other community exercise centers (eg, YMCAs), independent senior living facilities, and the Aging Research Registry of the Buehler Center on Aging at Northwestern University, and from affiliates of the Department on Aging, City of Chicago. A total of 48 subjects were recruited and assigned to either a single-session or dual-session group with a 2:1 randomization (respectively for the primary and secondary hypothesis testing). A minimum sample size of 12 was estimated to yield an 80% power for the smallest effect size variable for both between- and within-group comparisons at 6 months. This was based on power calculations from existing data on young adults (for similar protocol[6]). To account for attrition and subject loss because of other reasons, n=32 and 16 were respectively assigned to the single and dual sessions. Two subjects from the single-session group chose to discontinue the session after the first slip and one had missing data. Four of the 29 subjects in the single-session and 3 of the 16 subjects in the dual-session groups declined to come back. Hence, 38 subjects were included for data analysis, 25 in the single-session group and 13 in the dual-session group (the same perturbation training in the initial session plus an ancillary training with only 1 slip) (fig 1).

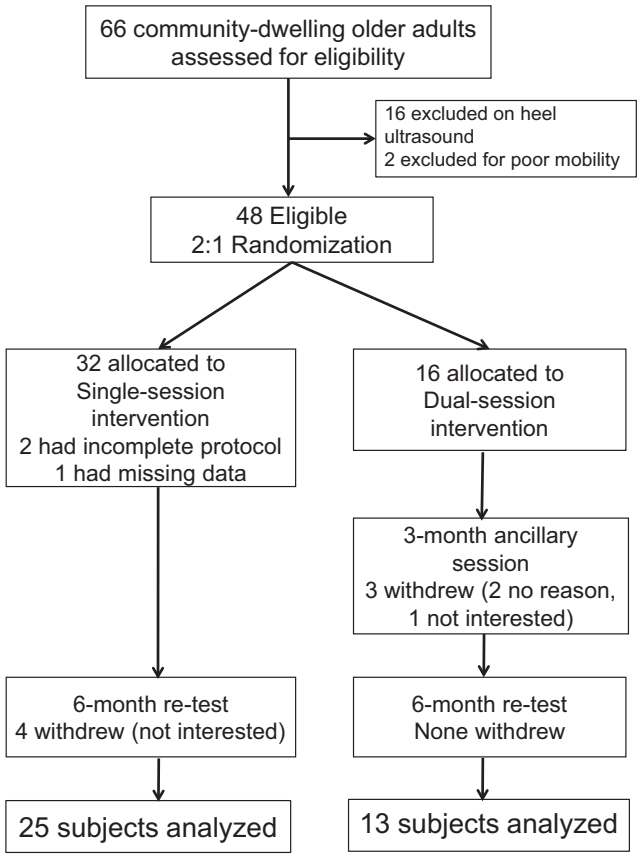

Fig 1. A flow diagram demonstrating subject recruitment and progress through the various phases of the study. Subjects were excluded if T score on calcaneal ultrasound was greater than −1.5 and if mobility score quantified by the Timed Up and Go test was greater than 13.5 seconds. Intervention consisted of the repeated slip-nonslip training protocol. Ancillary slip was a single slip given to subjects in the dual-session group.

Training Setups

Slips during walking were induced using a pair of side-by-side, low-friction, movable platforms embedded near the midpoint of a 7-m walkway. Platforms were free to slide forward up to 90cm on release of their locking mechanism. The platform was released when the corresponding foot contacted it, and detected by forceplates[a] located below the platform. A harness, connected by shock-absorbing ropes to an overhead beam, was used to protect subjects. A load cell measured the force exerted on the ropes.

Initial Training Protocol

The participants were instructed to walk with their preferred speed and manner. They were informed that they "may or may not be slipped" on any trial and that, if slipped, they should try to recover their balance and continue walking. After 10 trials of unperturbed walking, a slip was induced. Participants were unaware of when, where, and how they would slip. After the first slip, participants then underwent blocks of slips, nonslip trials, and a block of mixed slip and nonslip trials (fig 2A).[6] The entire training paradigm, including the first trial, consists of a block of 8 repeated slips (S1–S8), a block of 3 nonslip trials (NS1–NS3), another block of 8 slips (S9–16), a second block of 3 nonslip trials (NS4–NS6), and a final block of 15 mixed trials. The sequence of the mixed block of trials was consistent for each subject.[6] The participants were expected to adapt implicitly to prevent falls or BLOB on perturbation exposure. Participants were told only that, on a slip, they should try to recover their balance and continue walking. The session lasted for approximately 60 minutes. All the repeated slips were initially induced on the training (right) side. This paradigm was chosen based on the previous studies demon-

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