Published in final edited form as:

Arch Phys Med Rehabil. 2012 April ; 93(4): 557–564. doi:10.1016/j.apmr.2011.10.027.

LEARNING TO RESIST GAIT-SLIP FALLS: LONG-TERM RETENTION IN COMMUNITY-DWELLING OLDER ADULTS

Tanvi Bhatt, PT, PhD, Feng Yang, PT, PhD, and Yi-Chung Pai, MPT, PhD

Department of Physical Therapy University of Illinois at Chicago, Chicago, IL 60612

Abstract

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—Forty-eight community-dwelling elderly (>65 years).

Intervention—Initial perturbation training applied to all subjects using low-friction platforms to induce, unannounced blocks of repeated right-side slips, interspersed with non-slips. The single-session group retested with only one slip 6-months later. The dual-session group received an additional slip at 3-month, post initial session, followed by a retest 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 to the first novel slip; although performance decay was evident in comparison to 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 the single-session group.

Conclusions—Motor memory could be retained for 6-months or longer following 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.

Keywords

stability; adaptation; memory; perturbation training; inoculation

Increasing susceptibility to falls with age¹ poses a health threat to older adults. Perturbation related falls (i.e. from trips or slips) are responsible for about 60% of outdoor falls among

Corresponding author: Yi-Chung Pai, MPT, PhD Department of Physical Therapy (MC 898) University of Illinois at Chicago 1919 W. Taylor Street, Fourth Floor Chicago, Illinois 60612 Tel: (312) 996-1507 Fax: (312) 996-4583 cpai@uic.edu.

Financial Disclosure: We certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on me or on any organization with which I am associated AND, if applicable, I certify that all financial and material support for this research (eg, NIH or NHS grants) and work are clearly identified in the title page of the manuscript.

Device Status Statement: The manuscript submitted does not contain information about medical device(s). Reprints will not be available from the authors

community-living adults aged 70 or older². Even the healthy older adults are not immune to devastating falls³. 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 (i.e. repeated slips) can be employed to achieve such objectives⁴⁻⁶. 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 theoretical 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 its stability limits for BLOB⁶⁻¹⁰.

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 vibrations¹¹. Recently, it was noted that adaptive skills acquired from a single session of repeated-slip exposure could be retained for several months in the young⁴⁻⁶. Nonetheless, the longer-term retention of the training effects from such support surface perturbations remains unclear among older adults, a population which is known for its general memory decay, and age-related sensorimotor deteriorations¹³, 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 training session could be retained for 6 months and enhanced by an intermediate ancillary session among 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 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 to the last slip of the training session¹⁴.

METHODS

Participants

Community-dwelling, healthy, older adults who gave written informed consent participated in this institutionally approved study after being screened for neurological, musculoskeletal, cardiopulmonary and other systemic disorders as assessed through a questionnaire, and were screened for selected drug usage (e.g. tranquilizers). Tests administered by the research staff further excluded older adults with osteopenia or osteoporosis (based on calcaneal ultrasound indicated by a T score of < -1.5 ¹⁵), cognitive impairment (score < 25 on the Folstein Mini Mental Status Exam¹⁶), poor mobility (> 13.5 s on the Timed-Up-and-Go test¹⁷), 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 two weeks prior, according to the participant's preference. Subjects were recruited from different senior exercise centers, other community exercise centers (e.g., YMCA's), 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 protocol⁶). To account for attrition and subject loss due to other reasons $n = 31$ and 16 were respectively assigned to the single and dual-session. Two subjects from the single-session group chose to discontinue the session after the first slip. 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 one slip) respectively (Figure 1).

Training Set-Ups

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 90 cm upon release of their locking mechanism. The platform was released when the corresponding foot contacted it, and detected by force plates (AMTI, Newton, MA) located below the platform. A harness, connected by shock-absorbing ropes to an overhead beam, was employed 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 (Figure 2a)⁶. The entire training paradigm, including the first trial, consists of a block of 8 repeated slips (S1-S8), a block of 3 non-slip trials (NS1-NS3), another block of 8 slips (S9-16), a second block of 3 non-slip trials (NS4-NS6), and a final block of 15 mixed trials. The sequence of the mixed block of trials was consistent for each subject⁶. The participants were expected to adapt implicitly to prevent falls or BLOB upon perturbation exposure. Participants were told only that, upon a slip, they should try to recover their balance and continue walking. The session lasted for approximately 60 minutes. All the repeated slips were firstly induced on the training (right) side. This paradigm was chosen based on the previous studies demonstrating significant motor learning using this protocol⁶. Previous studies have established that 5–8 repeated slips are sufficient for adaptive improvements in balance loss^{7, 9, 14}. The “overlearning” with the extra trials, consisting of a combination of blocked and random practice was designed to further enhance generalization¹⁸, as it had already proved effective in aiding retention⁶.

Ancillary training protocol and retention test

Subjects in the dual-session training group returned at a 3-month and 6-month interval post initial session, while the single-session group returned only once after 6-months. The test protocol for the retest sessions and the setup were identical to those of the initial session, with the only exception being that subjects were exposed to only one slip after 8–13 regular walking trials. The exact return date was within one week beyond or short of the estimated 3-month or 6-month retest date.

Data collection and processing

Full body kinematics was collected during walking at 120 Hz from 28 retro-reflective markers using an 8-camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA). Synchronously, load cell and force plate signals were recorded at 600 Hz. The COM kinematics were computed using sex- and age-dependent inertial parameters reported previously¹⁰.

To reduce and eliminate the impact of individual variance of body anthropometric parameters on stability calculation, the COM position and velocity were normalized. The anteroposterior position and velocity of the COM ($X_{COM/BOS}$ and $\dot{X}_{COM/BOS}$) were expressed relative to the rear of the BOS. The rear of the BOS was considered the heel of the most recent foot to touch down. The relative COM position to the BOS is calculated as the difference of the absolute anteroposterior position between the COM and the heel (i.e. $X_{COM} - X_{BOS}$). Then, such relative position ($X_{COM/BOS}$) was divided by foot length to get the normalized relative COM position¹⁹. For example, at right foot touchdown if the normalized COM position is -0.5 , the COM would be half foot length behind the right heel. When the normalized COM position is 0 , the COM is right above the right heel. If the normalized COM position is 1 , the COM locates right above the right toe. A similar nomenclature was used for normalizing the COM velocity. The BOS velocity, however, the velocity instead of the position of the heel was used and the relative velocity was normalized to a dimensionless variable ($\dot{X}_{COM/BOS}$) expressed as fractions of $\sqrt{g \times h}$,²⁰ where g is gravitational acceleration and h is body height.

Outcome measures

The present study included two direct outcome variables (fall and BLOB) and two *primary* mechanistic outcome variables (stability and limb support). A *fall* was identified if the peak load cell force during the slip trial exceeds 30% body weight²¹. A *recovery* was identified if the moving average force on the harness did not exceed 4.5% body weight over any 1-second period after slip onset²¹. Trials meeting neither the criterion of a fall nor a recovery were considered harness-assistance and excluded from analysis²¹. A BLOB occurred if a participant fell or his/her recovery/trailing limb heel landed posterior to the leading heel at recovery touchdown. No BLOB occurred when participants' trailing limb heel landed anterior to the slipping limb heel. Figure 2b–d respectively demonstrates the video sequence of fall, no BLOB, and BLOB from representative subjects.

Stability was calculated as the shortest distance from the COM state (i.e., $X_{COM/BOS}$ and $\dot{X}_{COM/BOS}$) to the model-derived threshold against BLOB under slip conditions²². The model predicts that BLOB must occur for COM states below the threshold (stability < 0) and should not occur for those above the threshold (stability > 0). Larger values indicate greater ability to resist BLOB^{23, 24}. Limb support provided by the stance limb(s) was quantified by the height of the midpoint of the two hip joint centers from the ground. Preslip stability (proactive control) was analyzed at the instant of preslip touchdown (initial contact) of the leading/slipping limb and postslip stability and hip height (reactive control) were both analyzed at liftoff of the trailing limb after slip onset. Three secondary variables were included in the analysis. Walking velocity was obtained as the COM velocity at the instant of right foot touchdown during the natural walking trial preceding the first slip trial. The slipping kinematics was calculated as the displacement and velocity of right heel at the instances of trailing limb liftoff.

Statistical analysis

Adaptation and long-term retention for the measured variables were analyzed using the first (S1) and last (S24) slips of the training session, and the 6-month (R-6mo) slip. A repeated

measure ANOVA was used for the *primary parametric variables* of stability and hip height with the same three trials (S1, S24 and R-6mo) as the within group factor and session (single versus dual) as the between group factor. Significant main effects and interactions were resolved with paired and independent t-tests correcting for multiple comparisons. Post-hoc t-tests were performed to examine changes in secondary variables of walking velocity, BOS displacement and velocity over trials. For the non parametric variables (fall and BLOB), a logistic regression was used with session (S1 vs. R-6mon) and group (dual- vs. single-session) as independent variable and slip outcome (fall vs. recovery, or BLOB vs. NLOB) as the dependent variable. Significant session by group interactions were resolved using post-hoc McNemar tests. The latter was also performed to test for differences between S24 and S1 and R-6mo. For between group effects the Mann Whitney test was performed for each trial of interest. Within subject tests were also performed on all variables for the dual-session group to examine differences between S1 and the 3-month slip (R-3mo), S24 and R-3mo and R-3mo and R-6mo. An independent t-test was performed on subject demographics between the two groups. A detailed analysis of trial-to-trial adaptation has been published previously¹⁰. All analyses were performed using SPSS 17 (Chicago, IL) with a significance level of 0.05.

RESULTS

Long-term retention

There was no group-related difference in subject demographics ($p > 0.05$, for all, Table 1). Older adults in the single-session group were able to reduce fall incidence from 44% to 0% with the perturbation training ($p < 0.01$, S1 vs. S24), and correspondingly reduce incidence of BLOB from 100% to 0% ($p < 0.001$). For the single-session group there was a significant decrease in falls from 44% on the S1 to 0% at the R-6mo slip ($p < 0.05$). Similarly subjects reduced their BLOB from 100% on S1 to 56% at R-6mo ($p < 0.05$). Although there was no difference in incidence of falls from S24 to the R-6mo ($p > 0.05$), there was a significant increase in incidence of BLOB between them ($p < 0.05$, Figure 3a and b).

The changes in mechanistic variables of stability and limb support paralleled those of the slip outcomes. There was a significant increase in preslip stability from S1 to R-6mo ($p < 0.001$), without any decrease from that of the S24 ($p > 0.05$). Although there was similar improvement in postslip stability from S1 to R-6mo ($p < 0.01$), there was a significant decrease in stability from S24 to R-6mo ($p < 0.01$, Figure 3c). Hip height was greater at R-6mo compared to S1 ($p < 0.01$), but it was significantly lower than that on S24 ($p < 0.05$, Figure 3d).

Effect of ancillary training

Overall, no between-groups difference was found in fall incidence at R-6mo (trial effect: $p = 0.006$, group effect: $p = 0.50$, trial by group interaction, $p = 0.998$). There was a significant trial by group interaction for the BLOB ($p = 0.02$; trial effect = 0.997, group effect: $p = 0.132$) with the dual-session group having a significantly lower incidence of BLOB on R-6mo than the single-session group ($p < 0.05$). Compared to their S1, BLOB was significantly lower at their R-3mo slip ($p < 0.05$). Although BLOB incidence increased from S24 to R-3mo ($p < 0.05$), it decreased from R-3mo to R-6mo ($p < 0.05$) resulting in no significant difference between the S24 and R-6mo slips in the dual-session group ($p > 0.05$) (Figure 3 a and b).

Although there was no between group difference at S1 and S24, the dual-session group had greater postslip stability at the R-6mo than the single-session group and significantly lower compared to its S1 (trial effect [$F(2, 72)=114.02$, $p < 0.001$]; trial by group interaction

[$F(2,72)=3.224$ $p = 0.04$]; no group effect, $p = 0.33$, Figure 3c) which was maintained at the S24 level ($p > 0.05$, S24 vs R-6mo). Although postslip stability was lower at R-3mo than on S24 ($p > 0.05$), it was greater than S1 ($p < 0.05$). There was a significant improvement in postslip stability between R-3m and R-6mo ($p < 0.05$). In contrast, no between-group differences were discovered in preslip stability [trial effect, $p < 0.001$, group effect, $p = 0.15$, trial $\times$ group interaction, $p = 0.26$] and in hip height [trial effect, $p < 0.001$, group effect, $p = 0.15$, trial by group interaction, $p = 0.26$] at R-6mo compared to single-session group (Figure 3d). There was no significant difference in walking velocity over trials and between groups ($p > 0.10$ for both, trial by group interaction, $p > 0.10$) (Table 2). There was a significant decrease in heel displacement and velocity at postslip liftoff of the trailing foot in both groups from S1 to S24 ($p < 0.001$) which was maintained at R-6mo ($p < 0.05$ between S1 and R-6mo, for both groups) (Table 2).

DISCUSSION

The present results support the primary hypothesis that the ability to retain fall-resisting skills from a single perturbation training session remains intact at older age. Subjects in this group showed a significant increase in both pre and postslip stability compared to the novel slip of the training session; explaining the ~50% success rate in prevention of BLOB⁷. The results indicated that these subjects did not resort to alter their regular walking velocity over trials during this learning process. This was noticeably different from the adaptive behavior observed in sit-to-stand-slip, where young and older adults' forward COM velocity at seat-off after the training was increased from their pre-training level of rising "as fast as possible"^{24, 25}. Instead, the subjects in the present study had learned to improve the control of the slip kinematics, such that a significant decrease in both slip displacement and its velocity led to the increase in the COM stability relative to its BOS. The significant increase in hip height further enhanced the success of recovery from slip by providing adequate limb support even under low friction conditions, enabling subjects to maintain natural progression in stepping with their contralateral limb.

Previous findings indicate that older adults have a greater fall incidence than younger adults on the first novel slip, however, the incidence of backward balance loss is comparable¹⁰. The difference in fall incidence dominantly arises probably from difference in ability to provide vertical limb support, rather than differences in stability and slip kinematics. Our preliminary data indicate no significant difference in slip displacement and velocity at postslip trailing limb liftoff between the young [0.1 (0.04) m and 1.18 (0.37) m/s, $n = 22$ ²⁶] and older adults [0.72 (0.03) m and 1.078 (0.46) m/s (combined dual and single groups, $n = 38$)]. However, with repeated slip exposure they are able to rapidly adapt similar to young and these differences disappear towards the end of training^{10, 26}, similar to that demonstrated here. Likewise our findings on retention were similar to previous results from young adults where a 60% retention in prevention of BLOB was demonstrated at 4-months after a similar single session of slip perturbation training²⁶. The positive findings indicate that there may not be a prominent age-specific decay in motor memory. The effects of perturbation training are definitely prone to a waning effect. There was a significant decrease in pre and postslip stability and hip height at the 6-month interval compared to the last training slip. This was accompanied by a 50% increase in incidence of BLOB. However, our previous findings suggested that such a deterioration was observed in the young adults as well, further enhancing the age-independency of motor memory decay^{4, 26}.

The limited retention in some individuals can be explained based on inter-individual differences, related to the process of consolidating the acquired internal representation of stability limits and limb support, and its subsequent recall. Following repeated slips, acquisition of adaptive improvements involve a possible shift from reliance on sensory feedback based error correction to a feedforward influenced, re-calibrated control that

regulates BOS perturbation kinematics and limb support ^{7, 14}. Such a shift would also result in developing an enhanced memory from the short-term labile state to a longer lasting stable state through the process of consolidation ^{27, 28}. Some subjects may not be able to sufficiently consolidate or recall the proactively acquired, feedforward commands for precisely altering COM state stability and gait pattern resulting in motor strategies ⁷, which in turn influence reactive control of BOS (or perturbation kinematics itself). Although retention was sufficient to significantly prevent fall incidence, it was insufficient to reduce these older adults' need of taking a backward step for balance recovery.

Similar to findings from our study, other researchers have demonstrated intact motor skill acquisition and longer-term retention in older adults without intervening rehearsals for voluntary skills, mainly using the upper extremity ^{29, 30}. There is emerging work in the elderly population, examining retention within locomotor-posture control system with an emphasis of developing efficient fall prevention protocols ^{31, 32}. Apart from the motorized nature of the perturbations, that may not be able to closely mimic real life situations, however, the perturbation intensity was low (i.e. small displacement, velocity and acceleration profiles), which may not be challenging enough to induce a true resistance against fall. Hence, the training effects for fall-prevention are yet to be verified ^{31, 32}.

It is not surprising that a single session could serve to induce such long-term benefits. Previous research has indicated that the acquisition of an adaptation response or motor skill is dependent upon the penalties imposed upon an inappropriate response by the CNS ³³. Fear conditioning studies in mice have demonstrated that a single acquisition session is sufficient for long-term retention of the acquired stimulus-response behavior within the CNS ³⁴. Similarly learning rate of certain life-survival skills like bicycling or swimming may be more dependent on the penalties encountered during learning (i.e. number of “falls” or “drowning” experience respectively).

Our results further suggest that motor memory decay could, however, be delayed, as it can be “primed” or refreshed *with merely minimal training stimulus*. The subjects receiving dual-session training with the single ancillary slip at the 3-month interval had significantly better stability control compared to the single-session group at 6 months, reflected in the lower BLOB incidence. Still, there was an outstanding individual in this group, who fell initially, then at 3 months, and again at 6 months – this 8% fall incidence at the 6 month interval was not statistically different than the single-session (training only) group (Figure 3a).

Based on the significant improvement in performance from 3 – 6 months, it is postulated that subjects could have started demonstrating a fading in motor memory, (unused memory getting stored away in subconscious areas) making it difficult to recall at about the 3 month mark. The single ancillary slip at this crucial time helps to serve as a “refresher” to enhance recall. It could have dually served to enhance memory consolidation from a labile to a more permanent consolidated stage and, as a primer to keep the consolidated memory within the recallable areas of motor memory.

The current findings could have clinical implications if they can be generalized to real-life setting and applied to a varied older adult population. Our recent findings have demonstrated that the effects of platform perturbation training could generalize to real-life floor slips in young adults ³⁵. Additionally, if ancillary slips serve to enhance motor memory, a customized program with low intensity (fewer slips) but high frequency (more sessions) could be designed for frail individuals who may not be able to tolerate a long session of 24 slips. Hence the clinical applicability of the proposed slip perturbation training for fall-prevention could be significant.

Study Limitations

The findings from the study of significant retention are very promising, although the findings are still pertinent to a laboratory setting the sample size is still relative small and its generalization to reduction of real-life fall incidence in everyday living still needs to be examined. Secondly, the study used a 2:1 randomization to validate its secondary hypothesis because of the expected “priming” effect from ancillary training. A 1:1 randomization could likely increase the power of the study.

Conclusion

The perturbation training developed in the current study is an emerging paradigm, which has shown to have considerable benefits in reducing fall incidence in the laboratory. The results of the present study provide a new benchmark for fall-prevention protocols, indicating that similar to the “learning from falling” observed in early childhood³⁶, through the experience of slipping and falling it may be possible to “inoculate” older adults to reduce falls.

Acknowledgments

Funding source: National Institutes of Health, 2R01-AG16727 and R01-AG029616 (awarded to Y.-C. Pai).

LIST OF ABBREVIATIONS

ANOVA	analysis of variance
BOS	base of support
BLOB	backward loss of balance
COM	center of mass
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
S1	first novel slip of training session
S24	twenty-fourth or last slip of training session
R-3mo	slip given at 3 months
R-6mo	slip given at 6 months

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Figure 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 > -1.5 and if mobility score quantified by the TUG was > 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.

Figure 2.

(a) Figure demonstrating the protocol for the two groups a) single-session and dual-session perturbation training. Note that both groups received similar initial session perturbation training at 0 week (0 wk). Both groups received a retest consisting of a single-slip at the 6-month interval. The dual-session group received the initial training followed by an ancillary session consisting of a single slip the 3-month interval. The perturbation training consisted of 24 slips total delivered in block and random fashion. Blocks of slip trials (S) are shown in gray, blocks of nonslip trials (NS) in white, and the block of mixed slip and nonslip trials in vertical lines. The sequence of trials comprised 10 initial non-slip (NS) trials, followed by a block of 8 slips, a block of 3 non-slip trials, a second block of 8 slips, a second block of 3 nonslip trials, then a mixed block of 8 slip and 7 nonslip trials. All trials were unannounced, and subjects were only aware that a slip “may or may not occur.” (b) Video sequence demonstration of an older subject who fell following a slip after stepping on the low-friction platform that was released unexpectedly during walking, shortly after right touchdown. The sequence was taken from the first slip of the initial training session on which the subject experienced a fall. (c) Video sequence of the same subject when he returned after a 6-month interval post-initial session. Note that the subject did not experience a fall or a balance loss but was able to successfully continue walking under slip conditions (i.e. platform released). (d) Video sequence of another subject on the first slip of training session demonstrating a backward loss of balance with a compensatory recovery step landing posterior to the slipping limb. Images in 1–3 correspond to events of right touch down preceding onset of slip, postslip liftoff and touchdown of contralateral limb. a1–4 corresponds to fall termination, b1–4 to slipping foot liftoff and c1–4 to trailing foot liftoff for d1–4.

Figure 3.

Incidence of a) falls and b) backward balance loss in percentage (%) c) postslip stability and (d) hip height (in means + SD), demonstrated on the first slip and last slips of the initial training session (S1 and S24 respectively) and the 6-month retest slip (R-6mo) for the two participating groups: Single-session (Training only, open squares) and dual-session (Training + Ancillary session; filled circles). These variables are also demonstrated for the dual-session group on the ancillary single slip at the 3-month interval. * indicates a significant level of $p < 0.05$ and ** a level of $p < 0.01$ for the independent and paired t-tests performed. Solid lines indicate comparisons within single-session group and dashed-lines within dual-session group.

Table 1

Means (standard deviations) of subject demographics for both single- and dual-session groups.

	Single-session (<i>n</i> = 25)	Dual-session (<i>n</i> = 13)	<i>p</i> value
Age (years)	73.42 (5.42)	70.13 (4.75)	0.13
Female	13	7	0.70
Body height (m)	1.69 (0.10)	1.71 (0.11)	0.66
Body mass (kg)	74.59 (12.57)	77.26 (12.76)	0.86
Past fall incidence ^a (%)	34	38	0.90

^aSubjective history of falls over 12 months prior to initial session

Table 2

Means (standard deviations) of walking velocity and slipping kinematics (displacement and velocity of the base of support, BOS) during the first (slip 1) and twenty-fourth (slip 24) in the initial session, and the 6-month retest slip (slip R-6mo) for both single- and dual-session groups.

Variable	Single-session (<i>n</i> = 25)			Dual-session (<i>n</i> = 13)		
	Slip 1	Slip 24	Slip R-6mo	Slip 1	Slip 24	Slip R-6mo
Walking velocity ^a (m/s)	1.02 (0.22)	1.01 (0.25)	0.97 (0.25)	1.06 (0.15)	1.03 (0.17)	1.02 (0.19)
BOS displacement ^b (m)	0.07 (0.02)	0.03 (0.04) ⁺	0.05 (0.03) ^{*,#}	0.08 (0.05)	0.04 (0.04) ⁺	0.04 (0.03) [*]
BOS velocity ^b (m/s)	1.11 (0.4)	0.31 (0.32)	0.47 (0.37)	1.09 (0.47)	0.27 (0.17)	0.36 (0.29)

^a: obtained at right foot touchdown during the natural walking trial preceding the first slip trial;

^b: obtained at the instant of the left (recovery) foot liftoff;

⁺: *p* < 0.05 between Slip 1 and slip 24;

^{*}: *p* < 0.05 between Slip 1 and slip R-6mo;

[#]: *p* < 0.05 between Slip 24 and Slip R-6mo.