Published in final edited form as:

Gait Posture. 2016 March ; 45: 51–55. doi:10.1016/j.gaitpost.2016.01.007.

Influence of non-spatial working memory demands on reach-grasp responses to loss of balance: Effects of age and fall risk

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Abstract

Reactive balance recovery strategies following an unexpected loss of balance are crucial to the prevention of falls, head trauma and other major injuries in older adults. While a longstanding focus has been on understanding lower limb recovery responses, the upper limbs also play a critical role. However, when a fall occurs, little is known about the role of memory and attention shifting on the reach to grasp recovery strategy and what factors determine the speed and precision of this response beyond simple reaction time. The objective of this study was to compare response time and accuracy of a stabilizing grasp following a balance perturbation in older adult fallers compared to non-fallers and younger adults while loading the processing demands of non-spatial, verbal working memory. Working memory was engaged with a progressively challenging verb-generation task that was interrupted by an unexpected sideways platform perturbation and a pre-instructed reach to grasp response. Results revealed that the older adults, particularly those at high fall risk, demonstrated significantly increased movement time to handrail contact and grasping errors during conditions in which non-spatial memory was actively engaged. These findings provide preliminary evidence of the cognitive deficit in attention shifting away from an ongoing working memory task that underlies delayed and inaccurate protective reach to grasp responses in older adult fallers.

Keywords

Aging; Falls; Grasp; Reach; Balance; Postural perturbation

Introduction

One fundamental issue in balance rehabilitation concerns the extent to which individuals can dedicate cognitive resources to meet postural demands. The widespread use of dual task

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Conflict of Interest:

None

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paradigms, in which postural and cognitive tasks are performed simultaneously, has revealed interference effects demonstrating the importance of cognition to balance and gait control [1-6]. However, such dual task paradigms, although useful in testing the cognitive capacity for divided attention, do not address the integrative role of executive cognitive control in reactive balance tasks. Moreover, since most of our daily thoughts are spontaneous in nature and appear to tax non-spatial executive resources, it is essential that non-spatial demands be incorporated into cognitive studies of reactive balance control.

In light of these considerations, the rapid reach to grasp stabilizing response to a sudden loss of balance brings forth particular challenges to executive cognitive function that has not yet been fully explored. Although older adults are more likely to use the reach to grasp strategy, they also demonstrate more errors in their grasping attempts compared to younger adults [7-9]. The known visuospatial working memory demands of an efficient grasp response [7] highlight the potential importance of shifting attention from the ongoing internally directed thoughts that occupy a majority of our mental processes. Therefore, known age-related declines in attention shifting between working memory processes [10,11] may underlie reduced grasp accuracy in older adults who are at risk of falling.

The objective of this study was to compare response time and accuracy of a stabilizing grasp following perturbation in older adult fallers compared to non-fallers and young adults while loading non-spatial working memory. It was hypothesized that, compared to older non-fallers and young adults, older fallers would demonstrate differences in reaction time and time to handrail contact while non-spatial working memory was actively engaged. Secondly, we hypothesized that older fallers would demonstrate increased frequency of grasping error and variability in reaching direction.

Methods

A total of 33 participants were divided into the following three groups: (1) 12 healthy older adult fallers (70 +/- 5 yrs), (2) 11 healthy age-matched older non-fallers (69 +/- 4 yrs), and (3) 10 healthy young adults (25 +/- 2 yrs). All participants were recruited from a sample of convenience and older adults were classified as a 'faller' if they had experienced a minimum of one unintended fall within the prior 12 months. A fall was defined as "unintentionally coming to the ground or some lower level other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure" [12]. Exclusion criteria included significant musculoskeletal, vestibular, or neurological impairments, and a Mini-Mental State Exam (MMSE) score <24, suggestive of dementia [13]. Demographic data for all participants are reported in Table 1. This study was approved by the University Institutional Review Board (IRB) and all participants provided written informed consent prior to participation.

The ActiveStep Simbex (Simbex Inc.) was used to conduct all laboratory balance tests. Participants were asked to stand laterally on the belt in a comfortable, quiet standing position with eyes focused straight ahead on a large red 'X'. A 40x40 cm restraint box was lined with foam and secured around each participant's feet to prevent stepping. One handrail was placed to the right and another to the left at a distance of 30% of each subject's height

from midline. Handrails were 89 cm high, which is within the Occupational Safety and Health Administration (OSHA) standards of 76-94 cm (Section 1926.1052). An overhead safety harness was used to reduce the risk of falling, but did not restrict movement during the perturbations.

Using custom profiles of the ActiveStep, an individualized perceived loss of balance threshold was assessed for each participant. Thus, we could identify the perturbation necessary for a true reactive arm response as opposed to a voluntary response cued by platform movement. The acceleration of the initial platform perturbation (i.e. level 1) was 1.5 m/s^2 for a distance of 0.06 m. Higher levels of perturbation were achieved by acceleration increases of 2 m/s^2 to the point at which the participant was observed to naturally grasp the handrail to restore balance. The response was confirmed over 3 trials and testing level was set 2 levels above threshold.

Four different perturbation conditions were administered, with 8 trials for each condition. Instructions were as follows: “As soon as you feel the platform begin to move, quickly grab the one rail that will help you recover your balance most effectively. Do not take a step”. Conditions were as follows: (1) *Predictable*: non-random order of right or left perturbations; (2) *Unpredictable*: random order of right and left perturbations; (3) *Unpredictable with verb generation*: a verb generation task was interrupted by a random order of right or left perturbations. A member of the study team read concrete nouns aloud at 2s intervals to which the subject was to generate an associated verb as quickly as possible; (4) *Unpredictable with 1-back verb generation*: a 1-back verb generation task was interrupted by a random order of right or left perturbations. Participants generated a verb for the noun stated 1-prior to the current noun as quickly as possible. Practice trials were provided without perturbation prior to conditions 3 and 4 until 5 verbs were generated without error. Instructions to prioritize one task over the other (i.e. balance vs. cognitive) once the perturbation occurred were not provided. Also, in this initial investigation, the progression from least to most cognitively challenging conditions was blocked and not random to avoid possible confusion from alternating different cognitive task demands. The possibility of habituation was ruled out by comparing the first and last two trials under each condition.

Reach responses were analyzed as reaction time, movement time, and grasp accuracy (Figure 1). *Reaction time* was defined as the time from the onset of platform perturbation to time of initial arm response (defined as EMG onset of anterior or middle deltoid). *Movement time* was calculated as the latency from initial arm response to handrail contact that resulted in a stabilizing grasp. Handrail contact was measured using an attached custom contact sensor. Raw EMG data was collected using six wireless dual electrodes (Noraxon U.S.A., Inc) taped onto bilateral anterior deltoid (AD) and middle deltoid (MD) muscles, parallel to muscle fiber alignment. Data was collected at a set sampling rate of 1,500 Hz for seven seconds with 100 ms analog output time and 10-500 Hz Butterworth band pass filtering for cut-off frequency. EMG onset time was determined using a customized Matlab program (Mathworks, Inc) that identified the time at which the EMG signal rose three standard deviations above baseline, maintained for at least 25 ms. Since data was collected for both middle and anterior deltoid, the faster of the two muscles per trial for each participant was used. Moreover, since we were interested in responses related to the direction of

perturbation, movement time analyses only included opposite and same side responses (defined below).

Grasp error frequency and direction of reach to grasps were also determined. A *grasp error* was defined as a collision, overshoot, or undershoot of the handrail. A *stabilizing grasp* was either a full grasp (five digit grasp) or a partial grasp (less than five digits grasp). Pictorial classifications were used to determine grasp type using video captured during the balance task. Three members of the research team independently confirmed each trial classification. Grasp error frequency was calculated as the percent of total trials for each subject. For the direction of grasp, the following reach classifications were used: (1) *Opposite side* represents reach in the direction of the fall, which was opposite to the direction of perturbation (e.g. platform moves right, reach to left); (2) *Same side* represents reach in the opposite direction to the fall, which was to same direction of perturbation (e.g. platform moves right, reach to right); (3) *Bilateral* represents a reach to both sides; (4) *No change across trials* represents a reach to only one side regardless of the direction of platform movement.

Statistical tests were performed using IBM SPSS, version 22 (IBM Corp. Armonk, NY). The experimental design was 3 (groups) $\times$ 4 (conditions). Individual and group averages were calculated as the arithmetic means between trials and individuals, respectively. Parametric or nonparametric methods were used depending on adherence to commonly accepted data distribution assumptions. Parametric tests for reaction and movement time were performed using a 2-way repeated measures ANOVA with condition as the repeated factor and Tukey-Kramer post-hoc tests. Nonparametric tests for grasp error frequency and direction of grasp were performed using Kruskal-Wallis and Dunn's multiple comparison post-hoc tests. Significance was established at $\alpha=0.05$.

Results

Prior to reaction and movement time analysis, trials were analyzed for differences in reaching arm and errors in verb generation. Since there were no significant differences between left and right-sided reach reaction ($F(1, 32)=0.002, p=0.961$) and movement times ($F(1, 32)=0.183, p=0.672$) across all experimental conditions, these trials were collapsed for all subsequent analyses. Similarly, no significant differences were identified between "opposite" versus "same side" reach responses with respect to platform perturbation direction across all conditions (Reaction: $F(1, 25)=0.416, p=0.525$; Movement: $F(1, 21)=3.357, p=0.081$). Therefore, opposite and same side reaches were combined for further analyses. The influence of self-reported hand dominance on the frequency of the side of reach was also analyzed and revealed no differences between groups or across conditions ($0.100 \leq p \leq 0.999$). Finally, there were no differences between groups or across conditions in the number of verb generation errors within conditions 3 and 4 ($0.302 \leq p \leq 0.843$).

Against our hypothesis, there were no significant between- ($F(2, 22)=0.456, p=0.639$) or within-group ($F(1, 22)=1.855, p=0.187$) differences in *reaction time* for any perturbation

condition (combined group mean $\pm$ SE, Predictable: 102 $\pm$ 17ms; Unpredictable: 101 $\pm$ 15ms; Verb Generation: 102 $\pm$ 17ms; 1-back: 105 $\pm$ 18ms). See Figure 2a for individual group means.

In line with our hypothesis, there was a significant main effect for between group responses ($F(2,18) = 6.107, p = 0.001$) in *movement time* (opposite and same side reaches). A subsequent post hoc one-way ANOVA revealed that the group differences only occurred for the two working memory conditions (Verb Generation: $F(2, 23) = 3.397, p = 0.050$; 1-back: $F(2, 23) = 3.597, p = 0.044$). Older adult fallers demonstrated significantly increased movement times (Verb Generation: 228.5 $\pm$ 39.2 ms; 1-Back: 268.9 $\pm$ 77.9 ms) than young adults (Verb Generation: 202.4 $\pm$ 49.2 ms; 1-Back: 216.9 $\pm$ 51.1 ms) under these two conditions (Verb Generation: $p = 0.052$; 1-Back: $p = 0.041$) (Figure 2b). Moreover, there was an increase in movement time under the two working memory conditions for fallers (Verb Generation: 228.5 $\pm$ 39.2 ms; 1-Back: 268.9 $\pm$ 77.9 ms) compared to non-fallers (Verb Generation: 208.6 $\pm$ 44.0ms; 1-Back: 221.6 $\pm$ 41.6ms), though neither was significantly different (Verb Generation: $p = 0.161$; 1-Back: $p = 0.187$). No significant within-group differences for movement times were identified across the four conditions or between the first and last two trials of each condition (Reaction: $F(1, 30) = .044, p = 0.834$; Movement: $F(1, 29) = 1.305, p = 0.263$), thereby ruling out habituation effects across the series of blocked conditions. See Figure 2b for individual group means.

A main effect of grasp error (i.e. collision, overshoot, or undershoot of the handrail) was identified only under the two cognitive conditions (Verb Generation: $\chi^2(2) = 13.6, p = 0.001$; 1-Back: $\chi^2(2) = 14.7, p = 0.001$) (Figure 3). In particular, significant differences were found between older adult fallers (percent of error: Verb Generation= 13.2%; 1-Back: 16.1%) and younger adults (percent of error: Verb Generation= 1.3%; 1-Back= 0%) (Verb Generation: $t(19) = 13.13, p = 0.001$; 1-Back: $t(19) = 12.5, p = 0.001$). Significant differences were also identified between older adult fallers (percent of error: Verb Generation= 13.2%; 1-Back: 16.1%) and non-fallers (percent of error: Verb Generation= 4.5%; 1-Back= 3.4%) (Verb Generation: $t(21) = 9.31, p = 0.030$; 1-Back: $t(21) = 9.64, p = 0.013$). All errors were observed during opposite reaches with the exception of one same side reach from a subject in the older adult faller group. Moreover, no consistent pattern in the number of errors between the first and last two trials of each condition for all subject groups, thereby again ruling out habituation effects across the series of blocked conditions.

Results of the selected direction of reach with respect to platform perturbation revealed general aging effects in both groups of older adults compared to younger adults (Figure 3). A main effect of group was noted in the percentage of trials in which the rail opposite to the platform perturbation direction was grasped (Predictable: $\chi^2(2) = 12.6, p = 0.002$; Unpredictable: $\chi^2(2) = 6.8, p = 0.033$; 1-back $\chi^2(2) = 7.1, p = 0.028$). Although post hoc analysis revealed no significant differences between the older groups, age-related differences were noted between older adult non-fallers and younger adults on 2 conditions (Predictable: $t(20) = 12.09, p = 0.007$; Unpredictable: $t(20) = 10.04, p = 0.045$) and between older fallers and younger adults on 2 conditions (Predictable: $t(19) = 12.29, p = 0.005$; 1-back: $t(19) = 10.03, p = 0.034$).

Discussion

This study is possibly the first to examine the effects of varied cognitive demands related to reach-to-grasp responses following postural perturbations in older adult fallers and non-fallers and healthy younger adults. The main findings were that as processing challenges to non-spatial working memory were added, older adult fallers demonstrated increased movement time compared to younger adults and a greater percentage of grasping errors compared to non-fallers and younger adults. Moreover, a generalized aging effect was observed in the selected side of reach with respect to perturbation direction. Whereas younger adults nearly always reached towards the rail that was opposite to the direction of platform perturbation, the older adults grasped both rails together or consistently used the same rail in approximately 20-40% of trials within the two working memory conditions.

In contrast to our hypothesis, reaction times were equivalent across the three groups and four conditions, suggesting that any differences in movement time and grasp accuracy were not attributable to initial muscle response timing differences. The early onset latencies were consistent with seated arm reaction times to a loud auditory stimulus [14], pointing to a generalized startle response that may have interacted or overlapped with the initiation of a directed reach. Our lack of within group differences, even once the cognitive challenges were added, supports the subcortical underpinnings of this response as reported by others [15]. Further research is warranted to tease these findings apart and better understand the influence of startle on directed balance responses.

Following the initial reaction, increased movement time and increased grasp errors in older fallers were only identified once the cognitive challenges were added. From a neural perspective, the compensatory activation of cognitive brain regions during motor tasks of older adults generally supports successful performance, even if these regions remain inactive in younger adults [16]. Our findings indicate that when these cognitive resources become overloaded or impaired, the result is unsuccessful performance. While movement times in older non-fallers are comparable to previous reports of reach to grasp responses [7,17], the increased movement time and markedly increased grasp error frequency in the older fallers, suggest deficits in cognitive shifting ability from working memory source to another, beyond that which is observed in healthy aging. The slowed time to handrail contact appeared to partially compensate for this deficit as demonstrated by a stabilizing grasp in approximately 85% of all trials (see Figure 3). However, the remaining 15% of trials resulted in grasping errors, despite having only two possible choices of rails and multiple reaching attempts. Since no differences in movement time were observed between stable grasp trials and trials with grasp errors in older fallers, the increased number of grasping errors may be attributable to a speed- accuracy trade off. While recognizing the urgency in which the reach response needed to be completed, it was at the expense of grasp accuracy even at the relatively slower movement speeds compared to younger adults.

A general aging effect was observed in the decreased frequency with which the upper extremity reach was generated towards the direction of the fall. Whereas this directed reach strategy was observed in nearly all trials in the younger group, it was found in just over half of all trials for both older groups (see Figure 4). The remaining trials in the older groups

progressed from always grasping the same rail on predictable trials, regardless of fall direction, to grasping both rails under the more challenging cognitive trials. Both of these strategies appeared to represent “default” responses in which sensory feedback regarding the direction of fall was not necessarily integrated. We speculate that the older adults were more likely to preplan the reaching movement, thereby defaulting to a non-specific response to the perturbation. In doing so, they effectively avoided the timing delays inherent to the integration of the directional sensory cue with spatial memory of the rail [18]. Alternatively, these results may reflect a reduced reliance on online-sensory processing about the evolving state of instability due to diminished sensorimotor function, especially when increased cognitive challenges are present [19].

A few limitations to this study should be mentioned. First, although retrospective fall data is a strong predictor of future falls [20], prospective fall information may have provided additional confidence in the predictive nature of our data. Second, a lateral reach response induced from stationary standing may not be consistent with reach responses during dynamic walking with perturbations from multiple directions. However, by controlling the perturbation direction and forcing an upper extremity response, we could effectively isolate differences in reaching dynamics and strategies in all groups.

Conclusions

Results of this study demonstrated increased movement time and decreased grasp accuracy in older fallers only under conditions in which non-spatial working memory was engaged. Moreover, the greater percentage of non-specific responses under these conditions represent one possible compensatory strategy to restore balance in both older groups. Together, these findings suggest that evaluating and facilitating attention shifting towards the integration of balance related sensory cues and visuospatial working memory could be an important factor in the rehabilitation of protective reach-to-grasp responses in older fallers.

Acknowledgments

This work was supported by a Claude D. Pepper Older Americans Independence Center Pilot Grant to KW (NIA P30 2P30AG028747).

References

1. Brauer SG, Woollacott M, Shumway-Cook A. The interacting effects of cognitive demand and recovery of postural stability in balance-impaired elderly persons. *J Gerontol A Biol Sci Med Sci*. 2001; 56:M489–96. [PubMed: 11487601]
2. Shumway-Cook A, Woollacott M, Kerns KA, Baldwin M. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *J Gerontol A Biol Sci Med Sci*. 1997; 52:M232–40. [PubMed: 9224435]
3. Lajoie Y, Teasdale N, Bard C, Fleury M. Attentional demands for static and dynamic equilibrium. *Exp Brain Res*. 1993; 97:139–44. [PubMed: 8131825]
4. Persad CC, Giordani B, Chen HC, Ashton-Miller JA, Alexander NB, Wilson CS, et al. Neuropsychological predictors of complex obstacle avoidance in healthy older adults. *J Gerontol B Psychol Sci Soc Sci*. 1995; 50:272–7.

5. Hausdorff JM, Yogev G, Springer S, Simon ES, Giladi N. Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. *Exp Brain Res*. 2005; 164:541–8.10.1007/s00221-005-2280-3 [PubMed: 15864565]
6. Holtzer R, Friedman R, Lipton RB, Katz M, Xue X, Verghese J. The relationship between specific cognitive functions and falls in aging. *Neuropsychology*. 2007; 21:540–8.10.1037/0894-4105.21.5.540 [PubMed: 17784802]
7. Cheng KC, McKay SM, King EC, Maki BE. Does aging impair the capacity to use stored visuospatial information or online visual control to guide reach-to-grasp reactions evoked by unpredictable balance perturbation? *J Gerontol A Biol Sci Med Sci*. 2012; 67:1238–45.10.1093/gerona/gls116 [PubMed: 22511290]
8. King E, McKay S, Lee T, Scovil C, Peters A, Maki B. Gaze behaviour of older adults in responding to unexpected loss of balance while walking in an unfamiliar environment: A pilot study. *J Optom*. 2009; 2:119–26.10.3921/joptom.2009.119
9. Maki BE, McIlroy WE. Control of rapid limb movements for balance recovery: Age-related changes and implications for fall prevention. *Age Ageing*. 2006; 35:12–8.10.1093/ageing/af1078
10. Cona G, Bisiacchi PS, Amodio P, Schiff S. Age-related decline in attentional shifting: Evidence from ERPs. *Neurosci Lett*. 2013; 556:129–34.10.1016/j.neulet.2013.10.008 [PubMed: 24128879]
11. Hogan MJ, Kelly CaM, Craik FIM. The effects of attention switching on encoding and retrieval of words in younger and older adults. *Exp Aging Res*. 2007; 32:153–83.10.1080/03610730600553935 [PubMed: 16531359]
12. MJS; Andres, RO.; Kennedy, TE.; Coppard, LCG. Kellogg International Work Group on the Prevention of Falls by the Elderly. The prevention of falls in later life: a report of the Kellogg International Work Group on the Prevention of Falls by the Elderly. Med Fac Univ Copenhagen Aarhus, Danish Natl Board Heal; 1987.
13. Folstein MF, Folstein SE, McHugh PR. “Mini-mental state”. A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res*. 1975; 12:189–98. [PubMed: 1202204]
14. Carlsen AN, Chua R, Inglis JT, Sanderson DJ, Franks IM. Startle response is dishabituated during a reaction time task. *Exp Brain Res*. 2003; 152:510–8.10.1007/s00221-003-1575-5 [PubMed: 12904937]
15. Nonnekes J, Carpenter MG, Inglis JT, Duysens J, Weerdesteyn V. What startles tell us about control of posture and gait. *Neurosci Biobehav Rev*. 2015; 53:131–8.10.1016/j.neubiorev.2015.04.002 [PubMed: 25882206]
16. Heuninckx S, Wenderoth N, Swinnen SP. Systems neuroplasticity in the aging brain: recruiting additional neural resources for successful motor performance in elderly persons. *J Neurosci*. 2008; 28:91–9.10.1523/JNEUROSCI.3300-07.2008 [PubMed: 18171926]
17. Maki BE, Zecevic A, Bateni H, Kirshenbaum N, McIlroy WE. Cognitive demands of executing postural reactions: does aging impede attention switching? *Neuroreport*. 2001; 12:3583–7. [PubMed: 11733716]
18. Hyman R. Stimulus information as a determinant of reaction time. *J Exp Psychol*. 1953; 45:188–96. [PubMed: 13052851]
19. Rogers MW, Hedman LD, Johnson ME, Martinez KM, Mille ML. Triggering of protective stepping for the control of human balance: age and contextual dependence. *Brain Res Cogn Brain Res*. 2003; 16:192–8. [PubMed: 12668227]
20. Close JC, Hooper R, Glucksman E, Jackson SH, Swift CG. Predictors of falls in a high risk population: results from the prevention of falls in the elderly trial (PROFET). *Emerg Med J*. 2003; 20:421–5. [PubMed: 12954679]

Research Highlights

- Reach to grasp balance responses were studied under non-spatial working memory loads.
- Fallers demonstrated slowed movement time and decreased grasp accuracy.
- Older adults resorted to non-specific reach direction compared to younger adults.
- Attention shifting should be explored as a balance rehabilitation strategy

Figure 1. Example EMG trace depicting reaction and movement time

Reaction time (RT) was defined as the time from the onset of platform movement to EMG onset of grasping arm (anterior or middle deltoid). Movement time (MT) was defined as the time from EMG onset to handrail contact. Platform displacement is depicted along the bottom trace.

Figure 2. Group differences in reaction and movement time ($\pm$ SE) in response to platform perturbations (all conditions)

(a) Reaction times of fastest recorded muscle each trial (anterior deltoid or middle deltoid) revealed no significant differences across or within groups. (b) Between-groups differences in movement time were found between older fallers and young adults for the two working memory conditions (i.e. Verb Generation and 1-Back).

Figure 3. Group differences in percentage of trials with grasp errors
Older fallers demonstrated increased frequency of grasping errors (collision, overshoot, undershoot) compared to older non-fallers and younger adults.

Figure 4. Group differences in reach to grasp direction with respect to the direction of platform displacement

Younger adults demonstrated a greater percentage of trials in which the handrail opposite to the direction of the platform perturbation was grasped. In contrast, a general aging effect was observed in both older groups, who demonstrated a tendency to grasp the rail on the same side as the platform perturbation direction in almost half of all predictable trials. This strategy shifted towards a tendency to always grab the same rail in almost half of all 1-back working memory trials, regardless of the perturbation direction.

Table 1Demographic Data for all groups^b

	Young adults (n=10)	Non-fallers (n=11)	Fallers (n=12)
Age, years	24.5±2.12	68.5±4.08	69.83±4.73
Weight, kg	73.5±10.9	80.64±14.19	81.83±18.74
Height, cm	172.2±11.12	168.36±11.59	166.33±5.99
Body mass index (kg/m ²)	24.59±4.22	28.49±4.64	29.57±6.64
Handedness (R:L)	9:1	7:4	12:0
Education level (years)	17	14	16
Mini-mental Scale (/30)	n/a	30	29
Number of falls (1:2:multiple)	n/a	n/a	5:3:4
Perturbation threshold (m/s ² ,m)	13.5, 0.06	9.5, 0.06	13.5, 0.06

^b Data are reported as mean±SD unless otherwise noted.