Journal of Gerontology: MEDICAL SCIENCES
Cite journal as: J Gerontol A Biol Sci Med Sci. 2011 September;66A(9):994–1000
doi:10.1093/gerona/glr073

Measurements of Stepping Accuracy in a Multitarget Stepping Task as a Potential Indicator of Fall Risk in Elderly Individuals

Minoru Yamada,[1] Takahiro Higuchi,[2] Buichi Tanaka,[1] Koutatsu Nagai,[1] Kazuki Uemura,[1]
Tomoki Aoyama,[1] and Noriaki Ichihashi[1]

[1]Department of Human Health Sciences, Kyoto University Graduate School of Medicine, Japan.
[2]Department of Health Promotion Science, Graduate School of Human Health Science,
Tokyo Metropolitan University, Japan.

Address correspondence to Minoru Yamada, PT, PhD, Department of Human Health Sciences, Kyoto University Graduate School of Medicine,
53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan. Email: yamada@hs.med.kyoto-u.ac.jp

Background. Elderly individuals who are at high risk for a fall generally exhibit increased gait variability, a decline in visuomotor control of foot movement, and cognitive impairment, particularly in executive functions. A new walking test, a multitarget stepping task, was developed in the present study to identify elderly individuals with impaired stepping performance on a walkway requiring the involvement of executive functions to find a footfall target.

Methods. Thirty-one high-risk (82.7 ± 6.4 years) and 87 low-risk (80.7 ± 7.9 years) elderly individuals performed the multitarget stepping task on 2 days with a 2-week interval. For the multitarget stepping task, they walked while stepping on squares with an assigned color as a footfall target continuously along the 15 lines while avoiding other colors (distracters). Two types of failure were measured: (a) failure to step precisely on the target (stepping failure) and (b) failure to avoid distracters (avoidance failure). The two groups' performance was compared. A logistic regression analysis was also performed to determine whether the measurements were independently associated with falling.

Results. The high-risk groups showed a significantly higher rate in stepping (64.5 vs 25.3% of participants in the group) and avoidance (54.8 vs 17.2%) failure than the low-risk groups. The test–retest analyses showed good agreement for both measurements. A logistic regression analysis demonstrated that the stepping failure was independently associated with falling (odds ratio = 19.365, 95% confidence interval = 3.28–113.95; $p < .001$).

Conclusions. Measurements of stepping accuracy while performing the multitarget stepping task, particularly precise stepping failure, could contribute to identifying high-risk elderly individuals.

Key Words: Elderly—Fall—MTST.

Received June 21, 2010; Accepted March 23, 2011

Decision Editor: Luigi Ferrucci, MD, PhD

ACCIDENTAL falls among elderly individuals are frequently attributed to tripping while walking. Age-related inability to step precisely on the ground (1–7), particularly under challenging conditions (8–11), is likely to cause tripping. Although previous research on stepping behavior in elderly individuals has shown the usefulness of measuring the accuracy of stepping on a ground during gait as a clinical tool to distinguish individuals who are at high risk (HR) for a fall from those who are at low risk (LR), attempts to develop such clinical tests are limited (12). For the current study, we developed a walking test, the multitarget stepping task (MTST). During the test, two types of failure, stepping and avoidance, were measured while the participants walked along a 10-m walkway and stepped on multiple targets. Our objective was to determine whether the indices of stepping accuracy, as well as the time required for performing the task, could be used to identify elderly individuals at risk of falling.

Elderly individuals generally demonstrate increased variability of stride length (1–3). Increased variability in gait has been shown to be associated with a greater risk of falling among elderly participants (1,2). Evidence is increasing that age-related declines in visuomotor control of foot movements are likely to contribute to such stepping variability. When instructed to step precisely on a footfall target, HR elderly individuals showed less accurate and more variable foot placement than younger and LR elderly individuals while stepping on footfall targets (4). Analyses of their gaze behavior showed that the HR elderly individuals looked sooner and longer at imminent stepping targets than younger individuals. This tendency was more pronounced with increased task difficulty (5). The fact that HR elderly individuals looked at targets longer indicates that they require more time to process visual information regarding targets and/or program appropriate motor responses (4–6). Elderly individuals also exhibit impaired visuomotor control of foot movement in a feed-forward manner. When a target was invisible prior to the onset of stepping on that target, the rate of failure to step onto a footfall target was 42% in older participants but less than 10% in younger participants (6). Overall, these findings suggest that an age-related decline in visuomotor control of foot movement is likely to be one of the causes for impaired stepping performance.

Another factor relating to impaired stepping performance during gait is an age-related decline in the cognitive functions, particularly the executive functions (e.g., attention control, working memory, and problem solving) (12–19). Persad et al. (13) showed that, for elderly participants, difficulties with a complex walking task, including stepping precisely on a ground, have been linked to measures of executive function but were independent of other cognitive functions, such as memory and language.

Alexander et al. (12) developed a Walking Trail Making Test (W-TMT) in which a participant walked at a comfortable pace while stepping on multiple targets in a specific order. Participants were instructed to step on targets so that the number printed beside the stepping target would sequentially increase (W-TMT A) or to step on targets so that the number and letter beside the targets would increase in an alternating manner (ie, 1-A-2-B; W-TMT B). They demonstrated that the difference in the time taken to perform the W-TMT B (ie, cognitively high demand with respect to executive function) from the W-TMT A (ie, cognitively moderate) was extraordinarily high in older participants. With these findings, Alexander et al. concluded that elderly individuals have difficulty in performing accurate stepping movements with increased cognitive demands. A recent study by Persad et al. (14) demonstrated that the time taken to perform the W-TMT B diminished significantly in patients with deficits in executive function. This suggests that performing the W-TMT B involves executive function during gait and, therefore, should be effective to identify HR elderly individuals.

To date, attempts to develop a clinical test to measure the accuracy with which elderly individuals step on the ground have been limited. In the W-TMT, only the time taken to perform the task was measured. Given previous findings on the age-related decline in the visuomotor control of foot movement, measurement of the stepping accuracy itself could be an important contributory factor for identifying HR elderly individuals. Moreover, in the W-TMT, multiple targets and distracters were randomly placed. However, to thoroughly analyze the involvement of age-related decline in the spatiotemporal coordination between eye and foot movement into less stepping accuracy in HR elderly individuals, a more structured arrangement of the targets and distracters would be useful.

Considering these issues, we developed a new clinical test, a MTST, to measure the stepping accuracy in a simplified manner and compare the performance between HR and LR elderly individuals. In the MTST, participants walked along a 10-m walkway on which 15 lines of three colored squares were placed. They were instructed to step on an assigned square (the footfall target) continuously along the 15 lines while avoiding the other squares (distracters). As in the W-TMT (12), performing the MTST involved visual scanning of the targets while simultaneously stepping precisely on the target; participants would, thus, perform the MTST with the involvement of their executive functions. We investigated whether HR elderly individuals had significantly higher rates of stepping failure, that is, stepping on the target and avoiding the distracters, than the LR elderly. The participants also performed other standard clinical tests frequently used in clinical setting to identify elderly individuals at HR of falling, that is, a timed-up-and-go (TUG) test (20), a functional reach (FR) test (21), a one-leg standing (OLS) test (22), and a 10-m walking test (10-m walking) (23). Correlation analyses between each measurement collected from the MTST and each of the other standard clinical tests used were conducted to evaluate their associations. We further examined a logistic regression analysis to clarify which of these measurements, including the measurements taken from the MTST, were independently associated with falling.

METHODS

Participants

A total of 118 community-dwelling older individuals (mean age, 84.5 ± 6.5years) participated. The exclusion criteria ensured that none of the participants had any indications of the following symptoms: (a) serious visual impairment (cataract, glaucoma, or color blindness), (b) inability to ambulate independently (those requiring the assistance of a walker were excluded), (c) score of less than 7 on the rapid dementia screening test (24), (d) symptomatic cardiovascular disease, (e) neurological and orthopedic disorders, (f) peripheral neuropathy of the lower extremities, or (g) severe arthritis. The participants wore flat-soled footwear while participating in the present study. Written informed consent was obtained from each subject in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1975.

A participant who met the following two criteria was classified as an HR elderly individual: (a) a self-report of the occurrence of at least one fall within the past year and (b) the time required for performing a TUG test was greater than 13.5 seconds (25,26). A fall was defined as any event that led to an unplanned unexpected contact with a supporting surface during walking. Details of the protocols for the TUG test are described later. As a result, 31 HR and 87 LR elderly individuals participated (see Table 1 for participant details). We ensured that there were no significant group

Table 1. Characteristics of Both Groups of Participants

Characteristics	High-Risk Elderly Participants, $n = 31$	Low-Risk Elderly Participants, $n = 87$	p
Age	82.7 ± 6.4	80.7 ± 7.9	.214
Gender distribution (% men)	25.80	26.40	.574
Height (cm)	153.5 ± 10.9	156.8 ± 9.8	.377
Weight (kg)	55.6 ± 12.8	58.1 ± 11.1	.568
Rapid dementia screening test (s)	8.80 ± 1.37	9.21 ± 1.51	.198
Trail Making Test Part A (s)	129.3 ± 43.3	143.6 ± 46.4	.159
Visual acuity score (decimal)	0.65 ± 0.32	0.69 ± 0.33	.550
10 m walking time (s)	21.57 ± 10.65	12.77 ± 3.63	<.001
Number of 10 m walking steps	34.45 ± 13.74	23.02 ± 4.36	<.001
Timed up and go test (s)	20.15 ± 6.26	11.57 ± 3.41	<.001
Functional reach (cm)	14.51 ± 6.31	21.57 ± 7.33	<.001
One-leg standing (s)	2.67 ± 5.57	5.75 ± 7.59	.041

differences in age, gender distribution, height, weight, the score of the rapid dementia screening test, and the visual acuity score (binocular acuity scored on the basis of a Landolt C; Table 1). Furthermore, comparisons of the scores of the TMT-A test between the two groups partly showed did not show any critical group differences in their cognitive impairment (Table 1).

Data Collection and Analyses of the MTST

The MTST was performed on a black elastic mat (10 m long and 1 m wide). There were 45 pieces of a 10 × 10 cm square on the mat (see Figure 1). These squares were arranged into three rows (15 cm between each row) and 15 lines (61 cm between each line). Each square was marked with red, blue, or yellow tape. Each line had one of the three colored squares in a randomized order. One square (blue or yellow) was regarded as a footfall target, whereas the others were distracters. The color of the footfall target was counterbalanced among the participants and announced to each participant prior to initiating walking.

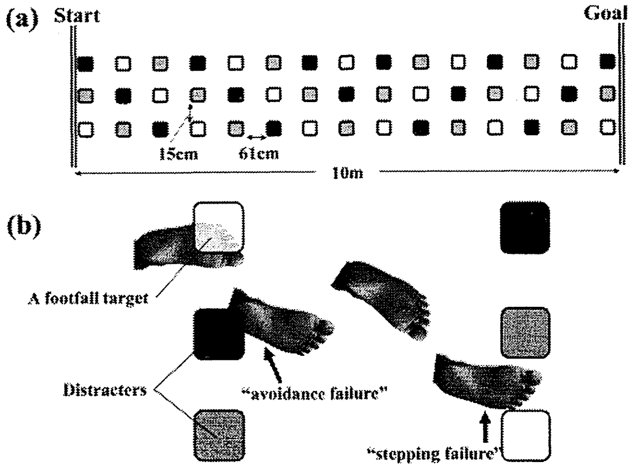

Figure 1. (a) The 10-m walkway used in the multitarget stepping task (MTST). Each square was made of red, blue, or yellow tape. (b) An example of the two types of failure measured in the MTST. A participant intends to step on footfall targets (displayed in white in this figure). The failure to step on the footfall target was regarded as the stepping error. The failure to avoid a distracter was regarded as an avoidance failure. As shown in this figure, avoidance failure was always the result of an accidental step as the participant walked from target to target, but it did not occur as a result of the wrong selection of a target out of the three squares on the line the participants intended to step on.

The participants walked on the mat at a self-selected pace while stepping on the target square placed on each line. The participants were instructed (a) to step on a footfall target with either side of the foot and any part of the sole, (b) to take as many steps as necessary while walking between the lines to comfortably walk toward the next footfall target, and (c) not to step on the distracters. At the beginning of the trial, they stood at the start position with their eyes closed to prevent them from looking at the locations of the targets beforehand. They opened their eyes as soon as they heard an experimenter's command of "Go!" and then started walking toward the first target. The participants performed one main trial. One or two (generally one) practice trials were performed before the main trial until the participants understood the task requirements and were familiar with walking on the mat. To investigate the test–retest reliability of the performance of the MTST, the participants performed the MTST twice (a single main trial each day) with a 2-week interval.

The main dependent measures were two types of failure indicating less accurate stepping performance: a stepping failure (ie, failure to step on the footfall target) and an avoidance failure (ie, failure to avoid distracters). Even a step on the edge of the target was regarded as successful; therefore, the existence of a stepping failure indicated that a participant did not seem to be able to control the placement of the foot on the target. A single experimenter observed the stepping and avoidance failures while walking next to the participant performing the MTST.

The main dependent measures were analyzed statistically from two perspectives. First, the participants who experienced each type of failure at least once were totaled for both the HR and LR groups. For each failure, the numbers, expressed as the frequency of failure occurring in the group (%), were compared statistically between the groups with a chi-square analysis. To investigate the test–retest reliability for the two types of the stepping failure, Kappa coefficients (k values) were calculated. A k value of 0.61–0.80 was regarded as good agreement (27). Second, each number of failure for each participant was statistically compared between the two groups with a *t* test.

The use of a retrospective fall risk in the present study is less compelling as a risk for falls than the use of prospective falls. To partially address this limitation, we further conducted comparisons of the numbers of each failure for each participant while performing the MTST among three groups, namely, the HR elderly participants who reported more than one fall (the HR multifallers, $n = 11$), those who reported only one fall (the HR single fallers, $n = 20$), and the LR participants ($n = 87$). We expected that the stepping accuracy would be worse for the multifallers than for the single fallers. A one-way analysis of variance was used as a statistical test.

Another dependent measure was the time taken to perform the MTST (a MTST performance time). The time (seccond) required from the verbal command for initiating walking until the participants reached the goal line was measured with a stop watch. A *t* test was performed to statistically compare the time between the groups. To investigate the test–retest reliability for the MTST performance time, the intertrial correlation coefficient = 1.1 between the two measurements with a 2-week interval was calculated.

Data Collection and Analyses of Other Clinical Tests

The other clinical tests that have been used to identify HR elderly adults in many studies (TUG, FR, OLS, and 10 m walking) were measured prior to performing the MTST on the first measurement day. The order of performing these tests was randomized. The participants performed each task for two trials. The score of each task was calculated as an average of the score obtained from the two trials. A *t*-test analysis was examined for each clinical test to statistically compare the scores between the HR and LR groups.

In the TUG, the participants were instructed to stand up from a standard chair with a seat height of 40 cm, walk a distance of 3 m at a comfortable pace, turn, walk back to the chair, and sit down. The time required from the verbal command to begin the task until completion was measured with a stopwatch. A TUG score was defined as the time in seconds for the completion in their second trials. In the FR, the participants initially stood next to a wall while raising one arm at 90° in the sagittal dimension with all fingers extended. The participants then intended to reach forward as far as possible without moving or lifting their feet from an initial upright posture. The distance (cm) between the initial and final fingertip positions of the middle finger was obtained from each of two trials. An FR score was defined as the better performance of their two trials.

In OLS, the participants stood initially with both legs in an upright posture with their eyes were open and their arms positioned to their sides. They were then instructed to stand with only their pivot foot without any assistance. The time the participant could stand on one leg was measured with a stopwatch as an OLS score (second). The participants stopped the OLS if the time exceeded 60 seconds. When a participant could not perform the OLS, his/her OLS score was 0 second. In the 10 m walking, the participants walked alone at their usual speed over a distance of 10 m. The time recorded in the two trials was averaged as the 10 m walking score. The number of steps the participants made during the 10 m walking was also averaged in two trials and used as another score of the 10 m walking.

To quantitatively describe the associations between these clinical tests and the stepping performance in the MTST, correlation analyses were conducted between each of the three measurements in the MTST (ie, the number of stepping and avoidance failures and the MTST performance time) and each of the clinical tests.

Logistic Regression Analysis

A multivariate analysis by means of logistic regression using a stepwise-forward method was performed to investigate which of these measurements (ie, the stepping and avoidance failures; MTST performance time; or scores of TUG, FR, OLS, or 10 m walking) was independently associated with falling. For the independent variables that remained in the final step of the regression model, odds ratios (ORs) with 95% confidence intervals (CIs) were presented.

RESULTS

The frequency of failure occurring in the group (%) and the ORs of the two types of failure that occurred in each group are shown in Table 2. The chi-square test indicated that the HR elderly participants showed significantly higher frequency of the stepping failure than the LR elderly participants ($p < .001$). The HR elderly participants also showed significantly higher frequency of the avoidance failure than the LR elderly participants ($p < .001$). Avoidance failure always occurred as the participants were walking from target to target but not when they intended to step on the target. The investigation of test–retest reliability indicated that the kappa coefficient was .758 for the stepping error and .688 for the avoidance error. Both coefficients showed good agreement between the first- and second-time measurements.

The average numbers of each failure occurring in each group are shown in Table 2. The HR elderly participants showed a significantly greater number of stepping and avoidance failures than the LR elderly participants. The average numbers of stepping failures occurring in the HR multifallers, the HR single fallers, and the LR participants were 0.64 ± 1.03, 2.30 ± 2.45, and 0.69 ± 1.53, respectively. The group differences were significant ($p < .01$); the HR single fallers showed significantly greater number of stepping failures than the HR multifallers and LR elderly participants. The average numbers of avoidance failures occurring in the three groups were 1.27 ± 1.73, 1.90 ± 2.55,

Table 2. Group Comparisons of the Stepping and the Avoidance Failure

	High-Risk Elderly Participants, $n = 31$	Low-Risk Elderly Participants, $n = 87$	p
Stepping failure, n (%)	20 (64.5)	22 (25.3)	<.001
Number of stepping failure, times	1.71 ± 2.19	0.69 ± 1.53	<.001
Avoidance failure, number (%)	17 (54.8)	15 (17.2)	<.001
Number of avoidance failure, times	1.68 ± 2.28	0.47 ± 1.28	<.001
Multitarget stepping task performance time (s)	31.58 ± 11.73	21.57 ± 7.64	<.001

and 0.47 ± 1.28, respectively. The significant group differences showed that the HR single fallers had a significantly greater number of stepping failures than the LR elderly participants.

The MTST performance times are also shown in Table 1. The HR elderly participants required significantly more time to perform the MTST than the LR elderly participants ($p < .05$). The investigation of test–retest reliability indicated that the correlation between the first- and second-time measurements was very high (intertrial correlation coefficient = 0.956; 95% CI = 0.92–0.95; $p < .001$).

The average results of the other clinical test are summarized in Table 1. Except for the results of the OLS ($p > .05$), all clinical tests demonstrated that the LR elderly participants had significantly better scores than the HR elderly participants. The correlation between each of the three measurements in the MTST (ie, the number of stepping and avoidance failures and the MTST performance time) and each of the clinical tests is shown in Table 3. The stepping failure was mildly correlated with the time and steps of the 10 m walking and the TUG, OLS, and FR scores, whereas the avoidance failure was mildly correlated with the steps of the 10 m walking and the TUG and OLS scores. The MTST performance time was highly correlated with each of the clinical tests.

The logistic regression analysis indicated that the precise stepping error (OR = 19.365; 95% CI = 3.28–113.95; $p < .001$) and TUG (OR = 1.911; 95% CI = 1.45–2.50; $p = .001$) were the independent variables that remained in the final step of the regression model and, therefore, were considered to be independently associated with falling. The adapted regression model was able to classify 78.0% of cases correctly ($R^2 = .395$, $p < .001$). The specificity was 80.3% and the sensitivity was 75.4%.

DISCUSSION

The aim of the present study was to investigate whether a simplified measurement of stepping accuracy while performing the MTST was able to identify HR elderly individuals. The results demonstrated that 64.5% of the HR elderly participants failed to step precisely on the target at least once. This was a surprisingly high rate of failure when considering our criteria that even a step on the edge of the target was regarded as successful. The HR elderly participants also showed a significantly higher rate of avoidance failure and a slower time for performing the MTST than the LR groups. The test–retest examination showed that these measurements were statistically reliable. Unfortunately, we failed to demonstrate an association between the number of retrospective falls and the number of stepping and avoidance failures; the HR single fallers showed significantly higher frequency of both types of failure. Furthermore, although the logistic regression analysis showed a significantly high OR for the stepping failure (19.365), the very large range of 95% CI indicated that the results need to be interpreted cautiously. Taken collectively, these findings led us to the tentative conclusion that measuring the stepping accuracy while performing the MTST, particularly the stepping error, is potentially an important factor in the identification of HR elderly individuals.

The high rate of stepping failures clearly indicated that HR elderly individuals were unable to step precisely on their intended target, which could result in tripping while walking. The high rate of the avoidance failure also showed that the HR elderly participants were unable to avoid stepping distracters. It is noteworthy that avoidance failure always occurred as a result of an accidental step in the way the participants were walking from target to target but not as a result of the wrong selection of a target from the three

Table 3. The Correlation Variables Between Each of Three Measurements in the Multitarget Stepping Task (MTST) and Each of Clinical Tests

	Number of Stepping Failure	Number of Avoidance Failure	MTST Performance Time
10 m walking time	0.24*	0.15	0.75**
Number of 10 m walking steps	0.21*	0.20*	0.70**
Timed up and go test	0.20*	0.25*	0.70**
One-leg standing	−0.14	−0.19*	−0.35**
Functional reach	−0.21	−0.15	−0.39**
Trail Making Test Part A	0.05	−0.01	0.22
Number of stepping failure		0.345**	0.23*
Number of avoidance failure	0.345**		0.12
MTST performance time	0.23*	0.12	

Note: *$p < .05$. **$p < .01$.

squares in the line that they intended to step on. Avoidance failure, therefore, resulted mainly from incorrect planning of the walking path from target to target and not from the wrong selection of a target from the three squares in a line due to age-related decline in visual acuity and/or visual search. Correlation analyses between each of the three measurements and standard clinical tests showed that the stepping and avoidance failures were correlated only mildly with several tests (Table 3). This was in contrast with the findings that the MTST performance time was highly correlated with all clinical tests. It seems that a decline in stepping accuracy results in an increased fall risk somewhat independently of the balance and gait features assessed by other standard clinical tests.

One possible explanation for the reason that measuring the stepping accuracy, particularly the stepping failure, could predict falls in spite of the multifocal etiology of falls was that these measurements could be associated directly with increased gait variability (1–3) and a decline in the visuomotor control of foot movement (4–6) in HR elderly individuals. This explanation was plausible, given that some clinical tests that have components of measuring the gait variability and visuomotor control of foot movement, such as the Dynamic Gait Index (28) or the Four Square Step Test (29), contributed to identifying HR elderly individuals.

In addition, some factors characterizing the MTST could make a significant contribution to enhance its predictive power. As in the W-TMT (12), to perform the MTST, the participants visually scanned the target while simultaneously attempting to step on it; participants would thus perform the MTST with the involvement of their executive functions. Due to an apparent decline in executive functions (12–15), HR elderly individuals would have difficulty walking in the MTST. Furthermore, the placement of multiple targets on a walkway could test the ability to step quickly in different directions. Because of the difficulty in maintaining a stabilized upright posture after stepping in different directions (29,30), especially with turning behavior (31), the HR elderly individuals may have less accurate stepping performance. To evaluate the validity of these possible explanations, future studies should investigate age-related changes in gaze behavior while performing the MTST; the frequency of turning behavior; and the functional relationship among the gaze, turning behavior, and accuracy of stepping performance.

We failed to demonstrate an association between the number of retrospective falls and the number of stepping and avoidance failures; the HR single fallers showed significantly higher frequency of both types of failure. This was in contrast to the relatively small individual differences in other standard tests (Table 1). We have no clear explanation for the reasons for such large individual differences; future studies should address this issue to reliably predict future falls on the basis of stepping and avoiding failures. Future studies should also address the possibility that the numbers of stepping and avoidance failures are associated with the circumstances under which falls occurred but not with the frequency of falls.

There are several issues that limit the conclusions to be drawn from this study. First, we measured only a single performance of the MTST from each participant; an examination of the within-participant reliability with a different walking path would be necessary in future research. Second, we did not measure participants' executive functions. Whether the difference in executive functions really underlies group differences between HR and LR elderly individuals should be a topic for future research.

In conclusion, the present findings provide general evidence that measuring the accuracy of foot placement while performing the MTST is potentially an effective clinical tool to identify HR elderly individuals. Possible explanations for the reason that measuring the stepping accuracy, especially the stepping failure, could predict falls would be (a) these measurements could be associated directly with increased gait variability and a decline in visuomotor control of foot movement in HR elderly individuals and (b) performing the MTST required the involvement of executive functions to find a footfall target. However, several findings, such as the lack of an association between the number of retrospective falls and the number of stepping and avoidance failures or the very large range in 95% CI observed in the logistic regression analysis, also suggest that the present results need to be interpreted cautiously.

REFERENCES

1. Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Arch Phys Med Rehabil.* 2001;82(8):1050–1056.
2. Verghese J, Holtzer R, Lipton RB, Wang C. Quantitative gait markers and incident fall risk in older adults. *J Gerontol A Biol Sci Med Sci.* 2009;64(8):896–901.
3. Brach JS, Perera S, Studenski S, et al. Meaningful change in measures of gait variability in older adults. *Gait Posture.* 2010;31(2): 175–179.
4. Chapman GJ, Hollands MA. Evidence for a link between changes to gaze behaviour and risk of falling in older adults during adaptive locomotion. *Gait Posture.* 2006;24(3):288–294.
5. Chapman GJ, Hollands MA. Evidence that older adult fallers prioritise the planning of future stepping actions over the accurate execution of ongoing steps during complex locomotor tasks. *Gait Posture.* 2007;26(1):59–67.
6. Chapman GJ, Hollands MA. Age-related differences in stepping performance during step cycle-related removal of vision. *Exp Brain Res.* 2006;174(4):613–621.
7. Marigold DS, Patla AE. Age-related changes in gait for multi-surface terrain. *Gait Posture.* 2008;27(4):689–696.
8. Di Fabio RP, Greany JF, Zampieri C. Saccade-stepping interactions revise the motor plan for obstacle avoidance. *J Mot Behav.* 2003;35(4): 383–397.
9. Galna B, Peters A, Murphy AT, Morris ME. Obstacle crossing deficits in older adults: a systematic review. *Gait Posture.* 2009;30(3):270–275.
10. Kelly VE, Schrager MA, Price R, Ferrucci L, Shumway-Cook A. Age-associated effects of a concurrent cognitive task on gait speed and stability during narrow-base walking. *J Gerontol A Biol Sci Med Sci.* 2008;63(12):1329–1334.
11. Menant JC, St George RJ, Fitzpatrick RC, Lord SR. Impaired depth perception and restricted pitch head movement increase obstacle

contacts when dual-tasking in older people. *J Gerontol A Biol Sci Med Sci.* 2010;65(7):751–757.

12. Alexander NB, Ashton-Miller JA, Giordani B, Guire K, Schultz AB. Age differences in timed accurate stepping with increasing cognitive and visual demand: a walking trail making test. *J Gerontol A Biol Sci Med Sci.* 2005;60(12):1558–1562.
13. Persad CC, Giordani B, Chen HC, et al. Neuropsychological predictors of complex obstacle avoidance in healthy older adults. *J Gerontol B Psychol Sci Soc Sci.* 1995;50(5):P272–P277.
14. Persad CC, Jones JL, Ashton-Miller JA, Alexander NB, Giordani B. Executive function and gait in older adults with cognitive impairment. *J Gerontol A Biol Sci Med Sci.* 2008;63(12):1350–1355.
15. Persad CC, Cook S, Giordani B. Assessing falls in the elderly: should we use simple screening tests or a comprehensive fall risk evaluation? *Eur J Phys Rehabil Med.* 2010;46(3):457–460.
16. Herman T, Mirelman A, Giladi N, Schweiger A, Hausdorff JM. Executive control deficits as a prodrome to falls in healthy older adults: a prospective study linking thinking, walking, and falling. *J Gerontol A Biol Sci Med Sci.* 2010;65(10):1086–1092.
17. van Iersel MB, Kessels RP, Bloem BR, Verbeek AL, Olde Rikkert MG. Executive functions are associated with gait and balance in community-living elderly people. *J Gerontol A Biol Sci Med Sci.* 2008; 63(12):1344–1349.
18. Hajjar I, Yang F, Sorond F, et al. A novel aging phenotype of slow gait, impaired executive function, and depressive symptoms: relationship to blood pressure and other cardiovascular risks. *J Gerontol A Biol Sci Med Sci.* 2009;64(9):994–1001.
19. Li KZ, Roudaia E, Lussier M, et al. Benefits of cognitive dual-task training on balance performance in healthy older adults. *J Gerontol A Biol Sci Med Sci.* 2010;65(12):1344–1352.
20. Podsiadlo D, Richardson S. The timed "up & go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc.* 1991;39(2): 142–148.
21. Duncan PW, Studenski S, Chandler J, Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. *J Gerontol.* 1992;47(3):M93–M98.
22. Vellas BJ, Wayne SJ, Romero L, et al. One-leg balance is an important predictor of injurious falls in older persons. *J Am Geriatr Soc.* 1997;45(6):735–738.
23. Lopopolo RB, Greco M, Sullivan D, Craik RL, Mangione KK. Effect of therapeutic exercise on gait speed in community-dwelling elderly people: a meta-analysis. *Phys Ther.* 2006;86(4):520–540.
24. Kalbe E, Calabrese P, Scgwalen S, Kessler J. The rapid dementia screening test (RDST): a new economical tool for detecting possible patients with dementia. *Dement Geriatri Cogn Disord.* 2003;16:193–199.
25. Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the timed up & go test. *Phys Ther.* 2000;80(9):896–903.
26. Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. *J Am Geriatr Soc.* 2001;49:664–672.
27. Naessens JM, O'Byrne TJ, Johnson MG, et al. Measuring hospital adverse events: assessing inter-rater reliability and trigger performance of the Global Trigger Tool. *Int J Qual Health Care.* 2010;22(4):266–274.
28. Shumway-Cook A, Woollacott M. *Motor Control: Theory and Practical Applications*; Baltimore, MD: Williams & Wilkins; 1995.
29. Dite W, Temple VA. A clinical test of stepping and change of direction to identify multiple falling older adults. *Arch Phys Med Rehabil.* 2002;83(11):1566–1571.
30. Tseng SC, Stanhope SJ, Morton SM. Impaired reactive stepping adjustments in older adults. *J Gerontol A Biol Sci Med Sci.* 2009;64(7): 807–815.
31. Taylor MJ, Dabnichki P, Strike SC. A three-dimensional biomechanical comparison between turning strategies during the stance phase of walking. *Hum Mov Sci.* 2005;24(4):558–573.

Archives of Gerontology and Geriatrics 54 (2012) e102–e108

Contents lists available at SciVerse ScienceDirect

Archives of Gerontology and Geriatrics

journal homepage: www.elsevier.com/locate/archger

Maladaptive turning and gaze behavior induces impaired stepping on multiple footfall targets during gait in older individuals who are at high risk of falling

Minoru Yamada [a,*], Takahiro Higuchi [b], Shuhei Mori [a], Kazuki Uemura [c], Koutatsu Nagai [a], Tomoki Aoyama [a], Noriaki Ichihashi [a]

[a] *Department of Human Health Sciences, Kyoto University Graduate School of Medicine, 53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan*
[b] *Department of Health Promotion Science, Graduate School of Human Health Science, Tokyo Metropolitan University, 1-1 Minami-Ohsawa, Hachioji, Tokyo 192-0397, Japan*
[c] *Department of Physical Therapy, Graduate School of Medicine, Nagoya University, 1-1-20 Daikouminami, Higashi-ku, Nagoya 461-8673, Japan*

ARTICLE INFO

Article history:
Received 18 June 2011
Received in revised form 18 August 2011
Accepted 20 August 2011
Available online 9 September 2011

Keywords:
Gaze behavior
Falls
Older
MTST

ABSTRACT

It was recently reported that the measurement of stepping accuracy while performing a new walking test, a multi-target stepping task (MTST), could contribute to identifying older individuals at high risk (HR) of falling. The present study was designed to identify factors leading HR older individuals to an impaired stepping performance in terms of frequency of maladaptive turning behavior (spin turn) and spatio-temporal patterns of fixations. Eleven HR (80.8 ± 3.6 years), 26 low-risk (LR) (77.1 ± 7.7 years) older individuals, and 20 younger individuals performed the MTST. For the MTST, stepping accuracy was measured with two types of failure (stepping target and avoiding distracters). The frequency of a spin turn (i.e., a crossover step) was compared among the groups. The location and duration of each fixation were also compared. The HR older and younger participants showed a higher rate of spin turns. Whereas the younger participants fixated approximately three steps ahead, the older participants directed their fixation closer toward the imminent footfall target, demonstrating their difficulty to use the visual information regarding the target in a feedforward manner. Such patterns of fixations were significantly associated with the frequency of stepping and avoidance failures. The higher rate of stepping and avoidance failures in the MTST were attributed to maladaptive turning behavior, which is potentially destabilizing, and the tendency to fixate on/around an imminent footfall target, which prevented older individuals from considering the locations of future footfall targets.

1. Introduction

Older individuals who are at high risk for a fall generally exhibit increased gait variability (Verghese et al., 2009; Brach et al., 2010), a decline in visuomotor control of foot movement (Chapman and Hollands, 2006a,b, 2007), and cognitive impairment, particularly in executive functions (Alexander et al., 2005; Persad et al., 2008; Herman et al., 2010). As a result, when instructed to step precisely on a footfall target on the ground, they show more impaired performance than older individuals who are at low risk for a fall (Chapman and Hollands, 2006b, 2007). Measurement of stepping accuracy during gait is therefore useful as a clinical tool to distinguish HR older individuals from LR older individuals.

Recently, we developed a new clinical test, a multi-target stepping task, to measure the stepping accuracy in a simplified manner (Yamada et al., 2011). In the MTST, participants were instructed to step on an assigned square (the footfall target) continuously along the 15 lines while avoiding the other squares (distracters). The results demonstrated that 64.5% of HR older participants failed to step precisely on the target at least once (referred to as a stepping failure). The HR older participants also showed a significantly higher rate of failure to avoid stepping on distracters (avoidance failure) than LR older participants. A logistic regression analysis showed a significantly high odds ratio for the stepping failure (19.365), although the very large range of 95% CI (3.28–113.95) indicated that the results need to be interpreted cautiously. These findings led us to the tentative conclusion that measuring the stepping accuracy while performing the MTST is potentially an important factor in the identification of HR older individuals.

Understanding factors contributing to enhance a predictive power of the MTST to identify HR older individuals is necessary for its clinical use and a development of an intervention technique to improve stepping accuracy while performing the MTST. For this purpose, the present study was designed to measure two behaviors while performing the MTST: turning and gaze behavior.

Inaccurate stepping performance may well result from maladaptive strategies for stepping in a different direction, i.e.,

---

* Corresponding author. Tel.: +81 75 751 3964; fax: +81 75 751 3909.
E-mail address: yamada@hs.med.kyoto-u.ac.jp (M. Yamada).

0167-4943/$ – see front matter © 2011 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.archger.2011.08.012

turning behavior. The placement of multiple targets in the MTST could lead participants to turn quickly in a different direction. HR older individuals generally show difficulty in maintaining a stabilized posture after stepping in a different direction (Dite and Temple, 2002; Tseng et al., 2009). Two main strategies for turning exist: step and spin turns. Whereas a step turn involves a change in the direction opposite to the stance limb, the spin turn is taking a crossover step, i.e., changing in the direction toward the same side of the stance limb. A spin turn is potentially destabilizing because, if appropriate pro-active action is not taken, the center of mass (COM) of the body will be outside of the base of support (BOS) (Moraes et al., 2004; Taylor et al., 2005). We hypothesized that impaired stepping performance while performing the MTST in HR older individuals was accompanied by more frequent spin turns.

Spin turns could occur more frequently when participants concentrated on stepping accurately on an imminent footfall target and did not consider the locations of future footfall targets. Measuring gaze behavior while performing the MTST was an effective approach to address this issue. By measuring how far ahead the fixation was located, we examined whether age-related differences existed in the visual scanning of footfall targets while performing the MTST.

The hypothesis regarding the location of fixation was that fixation in older individuals should be directed closer toward an imminent footfall target. The spatial demand of stepping in the MTST is relatively moderate, considering the criteria that even a step on the edge of the target was regarded as successful. Under such moderate conditions, younger individuals generally fixate a few steps ahead to step on multiple footfall targets (Patla and Vickers, 2003). This means that visual information regarding the location of an imminent footfall target is used in a feedforward manner, i.e., based on "stored" visuospatial information (Zettel et al., 2008), rather than in an on-line, feedback manner. In contrast, older individuals have difficulty using vision in a feedforward manner (Chapman and Hollands, 2006a). It was therefore hypothesized that fixation in older individuals should be directed closer toward an imminent footfall target.

To further understand the characteristics of gaze behavior in HR older individuals, we examined the duration of each fixation, particularly toward a target. Chapman and colleagues demonstrated that HR older individuals looked at targets longer when they walked while stepping on multiple footfall targets with relatively strict spatial demand (Chapman and Hollands, 2006b, 2007). With these findings, they proposed that they would require more time to process visual information regarding targets and/or program appropriate motor responses. We investigated whether a similar tendency would occur while they performed the MTST in spite of its moderate spatial demand.

Our primary analyses were to compare stepping performances, turning and gaze behaviors among the HR older, LR older, and the younger control groups. In addition, it was important to address which of several measurements were significantly associated with stepping avoidance failures. To do so, secondary analyses were conducted. Older participants were divided into two groups according to whether they had experienced stepping and avoidance failures (i.e., regardless of whether they were in the HR or older LR group). Each measurement regarding gaze behavior and other clinical measurements were compared statistically between the two groups. Furthermore, to determine whether the maladaptive spin turn occurred as a result of the participants' fixation being directed closer to the target, we conducted another statistical analysis in which the older participants were divided into two groups according to their experience of the spin turn. Comparisons of the gaze behavior were made between the two groups.

2. Methods

2.1. Participants

A total of 37 community-dwelling older individuals (mean age, 78.1 ± 6.8 years) participated. The exclusion criteria ensured that none of the participants had any indications of the following symptoms: (a) serious visual impairment (cataract, glaucoma, or color blindness), (b) inability to ambulate independently (those requiring the assistance of a walker were excluded), (c) score of less than 7 on the Rapid Dementia Screening Test (Kalbe et al., 2003), (d) symptomatic cardiovascular disease, (e) neurological and orthopedic disorders, (f) peripheral neuropathy of the lower extremities, or (g) severe arthritis. None of them had performed the MTST before. Twenty younger individuals (mean age, 21.1 ± 1.4 years) also took part in this experiment as control participants. Written informed consent was obtained from each subject in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1975.

Following an earlier study (Yamada et al., 2011), a participant who met the following two criteria was classified as an HR older individual: (a) a self-report of the occurrence of at least one fall within the past year and (b) a time requirement greater than 13.5 s for performing a Timed Up and Go test (TUG) (Shumway-Cook et al., 2000). A fall was defined as any event that led to an unplanned, unexpected contact with a supporting surface during walking. Our definition that the experience of falls was restricted to those during walking (i.e., falls during standing or transferring were not included) was suitable for the present study, considering that the MTST was developed to differentiate older HR individuals from LR ones in terms of stepping accuracy during walking. We ensured that none of the participants had any fall experience during standing or transferring.

As a result, 11 HR and 26 LR elderly individuals participated (see Table 1 for participant details). A one-way ANOVA conducted for each data of age, height, weight, the score of the Rapid Dementia Screening Test, and the visual acuity score (binocular acuity scored on the basis of a Landolt C) showed no significant differences between the HR and LR groups (Table 1). A Chi-square analysis conducted for the data of gender distribution also showed no significant differences between the HR and LR groups (Table 1).

2.2. Setup and protocols for data collection of the MTST

The MTST was performed on a black elastic mat (10 m long and 1 m wide). There were 45 pieces of a 10 cm × 10 cm square on the mat (see Fig. 1a). These squares were arranged into three rows (15 cm between each row) and 15 lines (61 cm between each line). Each square was marked with red, blue, or yellow tape. Each line had one of the three colored squares in a randomized order. One square (blue or yellow) was regarded as a footfall target, while the others were distracters.

Gaze behavior was measured using a head-mounted eye tracker (EMR-9, Nac Image Technologies, Japan). The eye tracker we used was a binocular corneal reflection system that measures the eye line of gaze with respect to a hat. The participant's gaze was indicated by a circle mark on a video-based image of the visual field as recorded by a scene camera mounted on the hat at a temporal resolution of 30 Hz (see Fig. 1b). Three-dimensional accelerometers (WAA-006, ATR-Promotions, Japan) were attached to each heel to measure the timing of participants' heel contact for each stepping.

The participants wore flat-soled footwear and walked on the mat at a self-selected pace while stepping on the target square placed on each line without stepping on the distracters. The participants performed two main trials. For each trial, a different color square was assigned as a footfall target. Detailed information

Table 1
Group comparisons of the characteristics of participants, MTST performance, gaze behavior, and other clinical tests.

	HR older ($n=11$)		LR older ($n=26$)		Younger ($n=20$)		ANOVA	
	Mean	SD	Mean	SD	Mean	SD	p value	
Participant details								
Age	80.8	3.6	77.1	7.7	21.1	1.4	<0.001*	b,c
Height, cm	155.1	8.8	153.8	10.2	164.4	9.7	<0.001*	b,c
Weight, kg	48.8	5.8	55.5	10.1	56.3	9.0	<0.001*	b
Gender (male = 0, female = 1), %	63.6		61.5		50.0			
Rapid Dementia Screening Test, point	8.91	1.13	9.27	1.60	12.00	0.00	<0.001*	b,c
Vision acuity score, decimal	0.75	0.39	0.77	0.30	0.73	0.33	0.885	
MTST performance								
Stepping failure (yes = 1, no = 0), %	72.7		7.6		0.0			a,b
Number of stepping failure, times	0.7	0.5	0.1	0.3	0.0	0.0	<0.001*	a,b
Avoidance failure (yes = 1, no = 0), %	100.0		15.3		0.0			a,b
Number of avoidance failure, times	3.7	2.9	0.5	1.6	0.0	0.0	<0.001*	a,b
Performance time, s	36.2	4.0	29.8	8.9	18.7	6.2	<0.001*	b,c
Stepping interval time, s	2.8	0.4	2.5	1.4	1.2	0.4	<0.001*	b,c
Spin (yes = 1, no = 0), %	63.6		15.3		50.0			a,c
Gaze toward target								
Gaze duration, s	0.85	0.38	0.78	0.63	0.62	0.24	0.402	
Gaze initiation, s (before stepping)	1.36	0.26	1.94	1.09	3.54	1.56	<0.001*	b,c
Gaze termination, s (before stepping)	0.52	0.42	1.17	0.97	2.91	1.60	<0.001*	a,b,c
Initiation/interval	0.50	0.09	0.89	0.53	2.94	1.21	<0.001*	a,b,c
Termination/interval	0.19	0.16	0.61	0.56	2.41	1.27	<0.001*	a,b,c
Other clinical tests							*t*-Test	
10 m walking time, s	16.1	2.7	11.5	3.7			0.001*	
Timed Up and Go, s	19.8	4.3	13.1	4.4			<0.001*	
One leg stand, s	1.2	1.5	9.3	12.7			0.005*	
Functional reach, cm	18.3	3.9	24.1	4.7			0.006*	
5 chair stand, s	19.7	11.2	13.3	3.5			0.020	

ANOVA: Bonferroni correction $p=0.016$ (0.05/3).
Post hoc test: $p<0.016$.
[a] Post hoc test: HR vs LR.
[b] Post hoc test: HR vs young.
[c] Post hoc test: LR vs young.

about the protocol of the MTST has been given in an earlier study (Yamada et al., 2011).

2.3. Data analyses of the MTST

All dependent measures were obtained only from the first main trial (Yamada et al., 2011). This was because, as other clinical standard tests used for identifying HR older individuals, the MTST had been developed so that participants could complete the task in a short time. The earlier study demonstrated that analyzing stepping performance in a single trial was effective to identify HR older individuals (Yamada et al., 2011). The stepping performance obtained from the second main trial was used only to calculate test–retest reliability.

The main dependent measures were two types of failure indicating less accurate stepping performance: a stepping failure

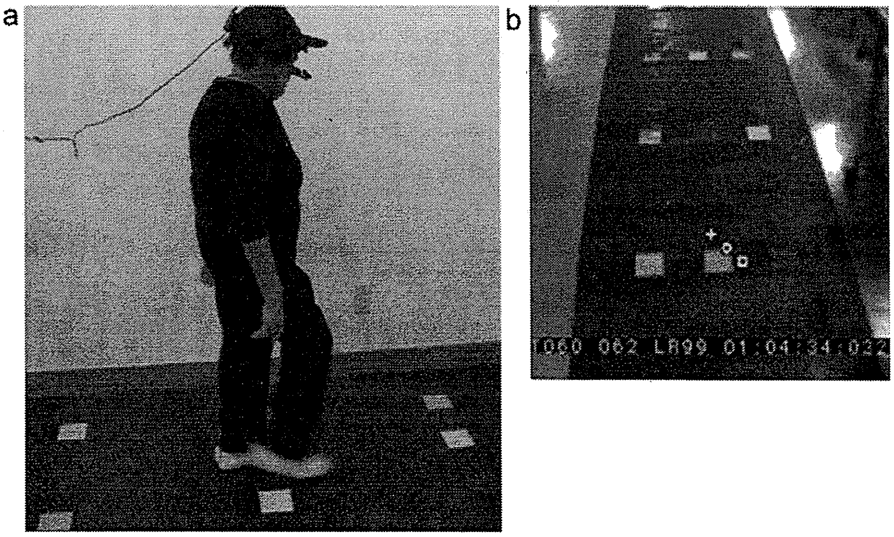

Fig. 1. (a) An older participant performing the MTST. Each square in each line was made of red, blue, or yellow tape. The participant intended to walk at a self-selected pace while stepping on a target square of an assigned color while avoiding to step on other squares. (b) A video-based image of the visual field while performing the MTST. The location of fixation, indicated by a circle mark, was calculated with the information obtained from the left (a plus mark) and right (a square mark) eyes.

(i.e., failure to step on the footfall target) and an avoidance failure (i.e., failure to avoid distracters). Even a step on the edge of the target was regarded as successful. These measures were analyzed statistically from two perspectives. First, the participants who experienced each type of failure at least once were totaled for both the HR and LR groups. For each failure, the numbers, expressed as the frequency of failure occurring in the group (%), were compared statistically among the groups with a Chi-square analysis. Secondly, the number of failures for each participant was statistically compared among the groups with a one-way analysis of variance (ANOVA). To investigate the test–retest reliability for the two types of the stepping failure, Kappa coefficients (*k*-values) between the two trials were calculated. A *k*-value of 0.61–0.80 was regarded as good agreement (Naessens et al., 2010).

The time (s) taken to perform the MTST, referred to as the MTST performance time, was measured with a stopwatch. The time of the interval between each step was also measured with the accelerometers attached to each heels. The timing of each step was defined as the time when peak acceleration occurred in the vertical direction. Each MTST performance time and stepping interval was compared statistically among the groups with a one-way ANOVA. To investigate the test–retest reliability for the MTST performance time, the inter-trial correlation coefficient (ICC 1.1) between the two trials was calculated.

Regarding the frequency of the maladaptive turning behavior (spin turn), the participants who experienced crossover steps at least once in a trial were totaled for each of the three groups. The frequencies of failure occurring in the group (%) were compared statistically among the groups with a Chi-square analysis. To investigate the test–retest reliability for the frequency of the spin turn, a *k*-value between the two trials was calculated.

Frame-by-frame video-based analyses were performed to identify where fixations were located. Stabilization of the gaze at one location for a minimum of 100 ms (three video frames) was defined as a fixation. The locations of fixations were classified into one of four categories: target, distracter, path, or other. The durations of each fixation were quantified and statistically compared among the groups using a one-way ANOVA. To statistically test the fixation patterns, each participant's average fixation time, as a percentage of total fixations, in each fixation-location was compared among the groups using a one-way ANOVA.

2.4. Data collection and analyses of gaze behavior

For the purpose of examining how far ahead the participants' fixations were located, the time to initiate (referred to as gaze initiation) and terminate (gaze termination) gazing at a given target before stepping on it was measured. The data of the gaze initiation (termination) were calculated by subtracting the time to initiate (terminate) fixation toward the imminent footfall target from the time to step on the target, which was obtained through the three-dimensional accelerometers attached to each heel. Dividing these timing data by the duration of the stepping interval (referred to as initiation/interval and termination/interval) expressed the degree to which the participants directed their fixation toward a future target. For instance, when the value of initiation/interval was 1.0 (i.e., the duration between the initiation of fixation toward a certain target and stepping on that target was equal to the duration of the stepping interval), a participant began to fixate a next footfall target just when stepping on the imminent footfall target. A value smaller than 1.0, therefore, meant that a fixation was directed toward the imminent target, whereas a value larger than 1.0 meant that a fixation was directed toward a future footfall target. A one-way ANOVA was used to compare these measurements statistically among the groups.

2.5. Data collection and analyses of other clinical tests

Other clinical tests that have been used to identify high-risk elderly adults in many studies, i.e., the TUG (Podsiadlo and Richardson, 1991), the functional reach test (FR) (Duncan et al., 1992), the one-leg standing test (OLS) (Vellas et al., 1997), the 10 m walking test (10 m walking) (Lopopolo et al., 2006), and the 5-chair stand (5CS) test (Guralnik et al., 1994), were measured prior to performing the MTST on the first measurement day. All tests except the 5CS were used in the earlier study (Yamada et al., 2011). In the 5CS, participants were asked to stand up and sit down five times as quickly as possible. A 5CS score was defined as the average of two trials regarding the time in seconds for the completion of this task. The order in which these tests were performed was randomized. The participants performed each task for two trials. A *t*-test analysis was examined for each clinical test to statistically compare the scores between the HR and LR groups.

2.6. Associations among the measurements

To quantitatively describe the associations between the stepping accuracy in the MTST and other measurements, the 37 older participants were divided into two groups according to whether they experienced both stepping and avoidance failures or not. Each of all measurements regarding gaze behavior and the clinical tests was compared statistically between the two groups with a *t*-test. To examine whether a spin turn was likely to occur when a participant's fixations were directed closer to an imminent footfall target, the participants were also divided into two groups according to whether they experienced a spin turn. Each of all measurements regarding gaze behavior was compared statistically between the two groups with a *t*-test. Furthermore, whether the experience of a spin turn was associated with the scores of the clinical tests was also analyzed. A comparison with a *t*-test was performed between the two groups.

2.7. Adjustment of a significance level for multiple statistical comparisons

In the present study, three different analyses were undertaken with the same data set (i.e., a comparison among the HR, LR older and young groups, and two two-group comparisons for testing associations among the measurements). To avoid a risk of committing a Type 1 error, the alpha-level was adjusted for multiple comparisons using the Bonferroni correction (Feise, 2002). In particular, the alpha-level of 0.05 was corrected to reflect five different comparisons, resulting in an adjusted alpha of 0.016 (0.05/3).

3. Results

3.1. MTST performance, gaze behavior, and clinical tests (Table 1 and Fig. 2)

The HR older participants experienced significantly higher frequency of both stepping and avoidance failures than the LR older and younger participants. The average number of each failure occurring in each group was greater for the HR older participants than for the LR older and younger participants. Both the MTST performance time and the stepping interval were significantly shorter for the younger participants than the HR and LR older participants. The HR older and younger participants experienced significantly higher frequency of the spin turns than the LR participants. The investigation of the test–retest reliability indicated that the *k*-value was 0.724 for the stepping failure, 0.746 for the avoidance failure, and 0.877 for the spin turn. The

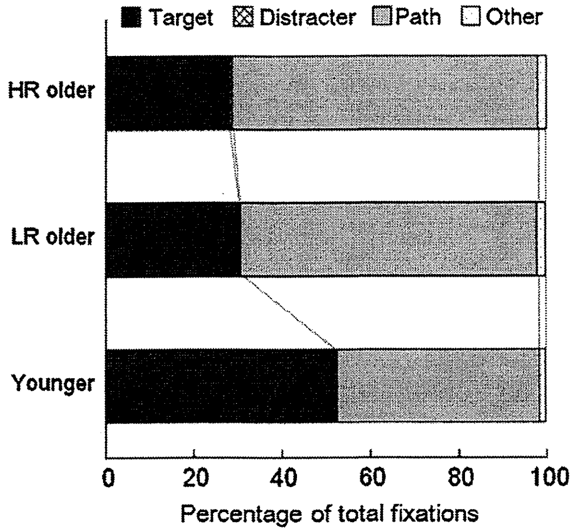

Fig. 2. Frequency of fixation directed toward each location in each group. The location-category of the distracter is not included because none of the participants fixated toward the distracters.

correlation between the first- and second-time measurements of the MTST performance time was very high (ICC = 0.969 (95%CI: 0.954–0.979)).

The group differences in the gaze duration were not statistically significant. The timing of gaze initiation was significantly earlier for the younger participants than the HR and LR older participants. The difference in this measurement was not significant between the HR and LR participants. The differences in the gaze termination, initiation/interval, and termination/interval were all significant for each pair in the three groups. The average percentages of total fixation durations (Fig. 2) showed that the fixation was directed toward the target more frequently for the younger participants than for the HR and LR older participants ($p < 0.016$). Participants rarely directed their fixation toward the distracters (0.4, 0.2, and 0% for the HR, LR, and younger groups, respectively). The younger participants directed their fixation toward the path less frequently than the HR and LR participants ($p < 0.016$).

Comparison of the performances in other clinical tests between the HR and LR participants showed that the HR older participants showed a significantly lower score than the LR older participants in all clinical tests except the 5CS.

3.2. Associations among the measurements (Tables 2 and 3)

Eight older participants experienced both stepping and avoidance failures (other two participants experienced only stepping failures, whereas seven experienced only avoidance failures). Regarding the association of stepping accuracy with gaze behavior and clinical tests (Table 2), the participants who experienced both failures initiated and terminated fixation toward an imminent target significantly later than those who did not. The mean values of initiation/interval and termination/interval were significantly greater for the participants who experienced both types of failures than for those who did not. The participants who experienced both failures showed significantly lower scores for the TUG, OLS, and FR than the participants who did not. No significant differences in all measurements on gaze behavior and on the clinical tests were identified between the participants who experienced a spin turn and those who did not (Table 3).

4. Discussion

The purpose of the present study was to examine whether maladaptive turning and gaze behavior existed while HR older individuals were performing the MTST. Before discussing this issue it is important to address that the present findings successfully replicated earlier ones (Yamada et al., 2011) regarding the fact that the HR older participants showed less stepping accuracy in the MTST. The HR older participants showed a significantly higher rate of stepping and avoidance failures than the LR older and younger participants. It is noteworthy that avoidance failure always occurred as a result of an accidental step in the way the participants were walking from target to target but not as a result of the wrong selection of a target from the three squares in the line that they intended to step on. Avoidance failure, therefore, resulted mainly from incorrect planning of the walking path from target to target and not from the wrong selection of a target from the three squares in a line due to impaired contrast sensitivity. The test–retest examination showed that these measurements were statistically reliable. These findings supported the conclusion of the earlier study (Yamada et al., 2011) that measuring the stepping accuracy while performing the MTST is potentially an important factor in the identification of HR older individuals.

Analysis of the frequency of the spin turn supported the hypothesis that impaired stepping performance in HR older individuals was accompanied with more frequent spin turns. Seven out of 11 HR older participants (63.6%) made a spin turn at least once to change their walking direction. In contrast, many of the LR older participants (22 out of 26 participants) did not select a

Table 2
Associations of the experience of stepping and avoidance failures with gaze behavior and clinical tests.

	Failure				p value	E/S
	Yes (n = 8)		No (n = 29)			
	Mean	SD	Mean	SD		
Gaze toward target						
Gaze duration, s	0.87	0.40	0.78	0.61	0.61	0.24
Gaze initiation, s (before stepping)	1.28	0.26	1.97	1.06	0.01*	2.63
Gaze termination, s (before stepping)	0.41	0.35	1.13	0.93	0.00*	2.05
Initiation/interval	0.50	0.11	0.85	0.51	0.00*	3.10
Termination/interval	0.17	0.17	0.57	0.54	0.00*	2.36
Other clinical tests						
10 m walking time, s	14.92	1.77	12.23	4.23	0.02	1.52
Timed Up and Go, s	17.67	1.75	14.41	5.75	0.01*	1.86
One leg stand, s	0.76	1.18	9.06	12.52	0.00*	7.05
Functional reach, cm	19.67	1.37	23.52	5.42	0.00*	2.82
5 chair stand, s	17.25	10.10	14.17	5.41	0.30	0.30

Bonferroni correction $p = 0.016$ (0.05/3).

Table 3
Associations of the experience of spin turns with gaze behavior and clinical tests.

	Spin turn				p value	E/S
	Yes ($n=11$)		No ($n=26$)			
	Mean	SD	Mean	SD		
Gaze toward target						
Gaze duration, s	0.80	0.36	0.79	0.64	0.959	0.020
Gaze initiation, s (before stepping)	1.49	0.47	1.89	1.09	0.127	0.850
Gaze termination, s (before stepping)	0.69	0.68	1.10	0.95	0.152	0.600
Initiation/interval	0.65	0.34	0.83	0.52	0.242	0.510
Termination/interval	0.34	0.39	0.55	0.55	0.201	0.530
Other clinical tests						
10 m walking time, s	12.6	3.3	12.8	4.4	0.917	0.040
Timed Up and Go, s	15.3	3.9	15.0	5.9	0.860	0.080
One leg stand, s	4.1	5.8	9.1	13.5	0.161	0.860
Functional reach, cm	21.3	2.9	23.5	5.9	0.193	0.750
5 chair stand, s	15.5	8.2	14.4	5.7	0.701	0.140

Bonferroni correction $p=0.016$ (0.05/3).

spin turn. This suggests that the LR older individuals successfully avoided the risk of destabilization while performing the MTST. The existence of such a clear difference in turning strategy between the HR and LR older participants is likely to contribute to enhancing the predictive power of the MTST to identify HR older individuals.

Interestingly, the younger participants also showed a higher rate of spin turns. A similar finding was reported in a previous study (Moraes et al., 2004), which demonstrated that their young participants preferred stepping medially (i.e., making a spin turn) rather than stepping laterally (i.e., making a step turn) to avoid a planar obstacle. The authors argued that modification of foot placement in response to an obstacle involves minimum displacement of the foot from its normal landing spot; stepping medially could be more suitable to satisfy this goal than stepping laterally. According to these previous findings, the younger participants in the present study may have not hesitated to select a spin turn because they had the ability to take pro-active action to bias the location of COM to ensure that it did not fall outside the BOS.

Analysis of gaze behavior supported another hypothesis that fixation in older individuals should be directed closer toward the imminent footfall target. The measurements of the initiation/interval and termination/interval revealed that the HR and LR older participants directed their gaze toward the imminent footfall target. Such a tendency was significantly higher for the HR older participants than the LR older ones. In contrast, the younger participants directed their gaze toward approximately 3 targets ahead. These findings clearly supported previous findings that, whereas younger individuals use visual information regarding the location of an imminent footfall target in a feedforward manner, older individuals appear to use it in an online, feedback manner (Patla and Vickers, 2003; Chapman and Hollands, 2006a).

Analyses of the association of stepping accuracy with gaze behavior demonstrated that the observed fixation patterns in the HR older participants were related to the stepping and avoidance failures (Table 2). The participants who experienced both the stepping and avoidance failures initiated and terminated fixation toward an imminent target significantly later than those who did not. From these findings, we suggest that one of the reasons for the higher rate of stepping and avoidance failures in the HR older individuals could be attributed to their tendency to fixate on/around the imminent footfall target, which prevented them from considering the locations of future footfall targets.

The HR older participants showed a higher rate of failure of stepping on the footfall targets in spite of the fact that they concentrated on fixation toward the imminent footfall target. The measurements of gaze termination showed that, on average, the HR older participants terminated fixation on the imminent footfall target approximately 0.5 s before stepping on that target. This indicated that they did not fixate on the imminent footfall target until they stepped on it; that is, the imminent footfall target was captured through peripheral vision or out of sight. The present findings suggest that the observed spatiotemporal patterns of fixation toward the imminent footfall target in the HR older participants may not have led to accurate foot control for stepping on a footfall target. Similarly, the average percentages of total fixation durations (Fig. 2) demonstrated that the participants rarely fixated toward the distracters (only 0.4% of total fixation times for the HR older, 0.2% for the LR older, and 0% for the younger participants). This suggests that the information regarding the locations of the distracters was obtained through peripheral vision (Patla and Vickers, 1997; Zietz and Hollands, 2009; Miyasike-daSilva et al., 2011). The failure to avoid the distractors may have resulted from their impaired ability to control their foot placement based on peripheral vision (Di Fabio et al., 2005).

The duration of fixation was not significantly different among the groups. This was inconsistent with previous findings demonstrating that HR individuals looked at footfall targets longer (Chapman and Hollands, 2006b, 2007). The contradictory findings between the previous and present studies may have been attributed to the difference in the spatial demand for stepping between these studies. In other words, a longer target fixation of the target would have been necessary when the spatial demand for stepping on the target was relatively strict, as in previous studies. Alternatively, given that the fixation was directed toward the path more frequently for the HR and LR older participants (Fig. 2), fixation on the place of each step, rather than on the target alone, may have been necessary while the HR older participants were performing the MTST. As a result, they may not have directed their fixation toward the target for a particularly longer time.

Theoretically, a spin turn could occur more frequently as fixation was located closer toward the imminent footfall target and, as a result, the locations of future footfall targets were not considered. However, we failed to demonstrate a significant association between the frequency of the spin turn and the pattern of fixations (Table 3). In fact, the experience of a spin turn was not significantly associated with any measurements about gaze behavior and other clinical tests. The precise mechanism for causing maladaptive turning behavior remains unclear. A future study should address this issue.

Analyses of the association of stepping accuracy with other clinical measurements demonstrated that the participants who experienced both stepping and avoidance failures showed lower scores for the TUG, OLS, and FR (Table 2). This was generally consistent with the findings in our earlier study (Yamada et al., 2011), which demonstrated that the number of avoidance failures showed mild negative correlation with the performance of the TUG and OLS. These findings suggest that impaired stepping performance in the MTST was likely to be associated with the impairment of general balance abilities, lower extremity function, and mobility.

In conclusion, the present study demonstrated impaired stepping performance of the HR older individuals in the MTST was accompanied with their maladaptive turning and gaze behavior. One of the most important findings was that the HR older individuals fixated closer toward the imminent footfall target. This suggests that they have difficulty in using visual information regarding the location of an imminent footfall target in a feedforward manner. Such a pattern of fixations would prevent them from considering the locations of future footfall targets and, therefore, can cause a maladaptive strategy to step in a different direction. In fact, the stepping performance in HR older individuals was accompanied with more frequent spin turns. Due to the lack of a significant association of the spin turn with the patterns of fixations, future studies should identify a precise mechanism for selecting the maladaptive turning behavior.

Funding

None.

Conflict of interest statement

None.

References

Alexander, N.B., Ashton-Miller, J.A., Giordani, B., Guire, K., Schultz, A.B., 2005. Age differences in timed accurate stepping with increasing cognitive and visual demand: a walking trail making test. J. Gerontol. A: Biol. Sci. Med. Sci. 60, 1558–1562.

Brach, J.S., Perera, S., Studenski, S., Katz, M., Hall, C., Verghese, J., 2010. Meaningful change in measures of gait variability in older adults. Gait Posture 31, 175–179.

Chapman, G.J., Hollands, M.A., 2006a. Age-related differences in stepping performance during step cycle-related removal of vision. Exp. Brain Res. 174, 613–621.

Chapman, G.J., Hollands, M.A., 2006b. Evidence for a link between changes to gaze behaviour and risk of falling in older adults during adaptive locomotion. Gait Posture 24, 288–294.

Chapman, G.J., Hollands, M.A., 2007. Evidence that older adult fallers prioritise the planning of future stepping actions over the accurate execution of ongoing steps during complex locomotor tasks. Gait Posture 26, 59–67.

Di Fabio, R.P., Zampieri, C., Henke, J., Olson, K., Rickheim, D., Russell, M., 2005. Influence of elderly executive cognitive function on attention in the lower visual field during step initiation. Gerontology 51, 94–107.

Dite, W., Temple, V.A., 2002. A clinical test of stepping and change of direction to identify multiple falling older adults. Arch. Phys. Med. Rehabil. 83, 1566–1571.

Duncan, P.W., Studenski, S., Chandler, J., Prescott, B., 1992. Functional reach: predictive validity in a sample of elderly male veterans. J. Gerontol. 47, M93–M98.

Feise, R.J., 2002. Do multiple outcome measures require *p*-value adjustment? BMC Med. Res. Methodol. 2, 1–4.

Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G., Scherr, P.A., Wallace, R.B., 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J. Gerontol. 49, M85–M94.

Herman, T., Mirelman, A., Giladi, N., Schweiger, A., Hausdorff, J.M., 2010. Executive control deficits as a prodrome to falls in healthy older adults: a prospective study linking thinking, walking, and falling. J. Gerontol. A: Biol. Sci. Med. Sci. 65, 1086–1092.

Kalbe, E., Calabrese, P., Scgwalen, S., Kessler, J., 2003. The Rapid Dementia Screening Test (RDST): a new economical tool for detecting possible patients with dementia. Dement. Geriatr. Cogn. Disord. 16, 193–199.

Lopopolo, R.B., Greco, M., Sullivan, D., Craik, R.L., Mangione, K.K., 2006. Effect of therapeutic exercise on gait speed in community-dwelling elderly people: a meta-analysis. Phys. Ther. 86, 520–540.

Miyasike-daSilva, V., Allard, F., McIlroy, W.E., 2011. Where do we look when we walk on stairs? Gaze behaviour on stairs, transitions, and handrails. Exp. Brain Res. 209, 73–83.

Moraes, R., Lewis, M.A., Patla, A.E., 2004. Strategies and determinants for selection of alternate foot placement during human locomotion: influence of spatial and temporal constraints. Exp. Brain Res. 159, 1–13.

Naessens, J.M., O'Byrne, T.J., Johnson, M.G., Vansuch, M.B., McGlone, C.M., Huddleston, J.M., 2010. Measuring hospital adverse events: assessing inter-rater reliability and trigger performance of the Global Trigger Tool. Int. J. Qual. Health Care 22, 266–274.

Patla, A.E., Vickers, J.N., 1997. Where and when do we look as we approach and step over an obstacle in the travel path? Neuroreport 8, 3661–3665.

Patla, A.E., Vickers, J.N., 2003. How far ahead do we look when required to step on specific locations in the travel path during locomotion? Exp. Brain Res. 148, 133–138.

Persad, C.C., Jones, J.L., Ashton-Miller, J.A., Alexander, N.B., Giordani, B., 2008. Executive function and gait in older adults with cognitive impairment. J. Gerontol. A: Biol. Sci. Med. Sci. 63, 1350–1355.

Podsiadlo, D., Richardson, S., 1991. The Timed Up & Go: a test of basic functional mobility for frail elderly persons. J. Am. Geriatr. Soc. 39, 142–148.

Shumway-Cook, A., Brauer, S., Woollacott, M., 2000. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. Phys. Ther. 80, 896–903.

Taylor, M.J., Dabnichki, P., Strike, S.C., 2005. A three-dimensional biomechanical comparison between turning strategies during the stance phase of walking. Hum. Mov. Sci. 24, 558–573.

Tseng, S.C., Stanhope, S.J., Morton, S.M., 2009. Impaired reactive stepping adjustments in older adults. J. Gerontol. A: Biol. Sci. Med. Sci. 64, 807–815.

Vellas, B.J., Wayne, S.J., Romero, L., Baumgartner, R.N., Rubenstein, L.Z., Garry, P.J., 1997. One-leg balance is an important predictor of injurious falls in older persons. J. Am. Geriatr. Soc. 45, 735–738.

Verghese, J., Holtzer, R., Lipton, R.B., Wang, C., 2009. Quantitative gait markers and incident fall risk in older adults. J. Gerontol. A: Biol. Sci. Med. Sci. 64, 896–901.

Yamada, M., Higuchi, T., Tanaka, B., Nagai, K., Uemura, K., Aoyama, T., Ichihashi, N., 2011. Measurements of stepping accuracy in a multi-target stepping task as a potential indicator of fall risk in elderly individuals. J. Gerontol. A: Biol. Sci. Med. Sci. 66, 994–1000.

Zettel, J.L., McIlroy, W.E., Maki, B.E., 2008. Gaze behavior of older adults during rapid balance-recovery reactions. J. Gerontol. A: Biol. Sci. Med. Sci. 63, 885–891.

Zietz, D., Hollands, M., 2009. Gaze behavior of young and older adults during stair walking. J. Mot. Behav. 41, 357–365.

Journal of Clinical Gerontology & Geriatrics 2 (2011) 42–46

Contents lists available at ScienceDirect

Journal of Clinical Gerontology & Geriatrics

journal homepage: www.e-jcgg.com

Original article

Differential determinants of physical daily activities in frail and nonfrail community-dwelling older adults

Minoru Yamada, RPT, PhD *, Hidenori Arai, MD, PhD, Koutatsu Nagai, RPT, Kazuki Uemura, RPT, Shuhei Mori, RPT, Tomoki Aoyama, MD, PhD

Department of Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, Japan

ARTICLE INFO

Article history:
Received 14 January 2011
Received in revised form
26 January 2011
Accepted 8 February 2011

Keywords:
Fear of falling
Frail adults
Physical function
physical activity

ABSTRACT

Background/Purpose: The purpose of this study was to determine whether or not daily activities determined by average daily steps are associated with age, gender, body mass index, fear of falling, and physical functions (locomotive function, balance function, and muscle power) in community-dwelling nonfrail and frail older adults.

Methods: This is a cross-sectional study conducted in community-dwelling older adults in Japan. Based on the Timed Up and Go (TUG) test, 629 elderly adults were divided into two groups: 515 were grouped to nonfrail elderly (TUG time less than 13.5 seconds, mean age 77.0 ± 7.2 years) and 114 to frail elderly (TUG time of 13.5 seconds or more, mean age 76.1 ± 7.5 years). Daily physical activities were determined by average daily steps measured by pedometer and four other physical function tests (10-m walk test, single-leg standing, functional reach, and five-chair stand test) were performed along with the assessment of fear of falling.

Results: Stepwise regression analysis revealed that age, gender, 10-m walk test, and single-leg standing were significant and independent determinants of the average step counts in the nonfrail elderly ($R^2 = 0.282$, $p < 0.001$), whereas fear of falling was the only significant and independent determinant of the average step counts in the frail elderly ($R^2 = 0.119$, $p < 0.001$).

Conclusion: These results indicate that differential factors may be related to daily activities depending on the level of frailty in community-dwelling older adults.

1. Introduction

Physical activities show positive associations with various components of physical functions, such as walking speed, lower-limb strength, and balance and negative associations with the incidence of coronary artery disease, obesity, osteoporosis, and other causes of morbidity and mortality in elderly.[1–4]

Higher physical activities can also improve quality of life and physical and psychological functions, facilitate independent living, and reduce the risk of dementia in older adults.[5–8] Physical Activity Guidelines for Americans concluded that, for older adults, in addition to the well-known health benefits of a physically active lifestyle, "strong evidence indicates that being physically active is associated with higher levels of functional health and a lower risk of falling."[9]

However, Yoshida et al[10] showed that the association between physical fitness and ambulatory activity is affected by the level of instrumental activity of daily life in elderly women, suggesting the effect of frailty on the association. We demonstrated that the resistance training program is effective at decreasing the fear of falling in frail elderly but not in nonfrail elderly (Yamada et al, present study), indicating the difference of the effect of physical training in elderly with different physical fitness. We hypothesized, therefore, that differential factors could affect the level of physical daily activities in the presence or absence of frailty. The purpose of this study was to determine whether or not physical activities determined by average daily steps are associated with age, gender, body mass index (BMI), fear of falling, and physical function (locomotive function, balance function, and muscle power) in community-dwelling nonfrail and frail older adults.

---

* Corresponding author. Department of Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Kawaharcho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan.

E-mail address: yamada@hs.med.kyoto-u.ac.jp (M. Yamada).

2210-8335/$ – see front matter Copyright © 2011, Asia Pacific League of Clinical Gerontology & Geriatrics. Published by Elsevier Taiwan LLC. All rights reserved.
doi:10.1016/j.jcgg.2011.02.004

2. Methods

2.1. Participants

Participants were recruited by an advertisement in a local press. We used the following criteria to screen participants in the initial interview and invited to participate in this study if he or she was aged 65 years or older , was community-dwelling, had a score of eight or more by Rapid Dementia Screening Test,[11] and was able to walk independently.

We excluded participants based on the following exclusion criteria: the presence of severe cardiac, pulmonary, or musculoskeletal disorders; comorbidities associated with an increased risk of falls (i.e., Parkinson's disease or stroke); and use of psychotropic drugs. We obtained written informed consent from each participant in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1975.

2.2. Definition of frailty

The definition of frailty is based on the results of previous study. The Timed Up and Go (TUG) is a simple test developed to screen basic mobility performance and has been shown to be significantly associated with activities of daily living function in frail older adults.[12] It has been reported that elderly with a TUG score greater than 13.5 seconds have an increased risk of falls.[13] Therefore, frailty was defined as a TUG score greater than 13.5 seconds. Based on key components of the screening examination (TUG score greater than 13.5 seconds), 114 elderly were classified as frail, whereas 515 elderly as nonfrail.

2.3. Measurement of physical activities

A valid, accurate, and reliable pedometer, Yamax PowerWalker EX-510 (Yamax Corp., Tokyo, Japan), was used to measure free-living step counts.[14] Measurement of step counts was conducted between October and November 2010. Participants were instructed to wear the pedometer in their pocket of dominant leg for 14 consecutive days except during bathing, sleeping, and performing water-based activities. This pedometer has a 30-day data storage capacity. We calculated the averages of their daily step counts for 2 weeks.

2.4. Measurement of fear of falling

We assessed fear of falling by asking a single yes or no question, "Are you afraid of falling,?" which has a high test-retest reliability.[15] The test-retest reliability using the Kappa coefficient was 0.960.

2.5. Measurement of physical function

The participants received four other physical function tests that are widely used to identify high-risk elderly: 10-m walk test, single-leg standing, functional reach, and five-chair stand. In 10-m walk test, the participants were asked to walk as fast as possible along a 10-m straight line, with a 1 m approach at both ends, making a total length of 12 m. The time required was taken as the measured value. In single-leg standing, the length of time for which participants were able to stand on one leg with their hands placed on their waist was measured. The time was measured twice for each leg and the maximum length of time was taken. Functional reach was measured using the simple clinical apparatus consisting of a leveled yardstick secured to the wall at right acromion height as previously described.[16] In five-chair stand, participants were asked to stand up and sit down five times as quickly as possible and were timed from the initial sitting position to the final standing position at the end of the fifth stand.[17] For each function test, the participants performed twice, and the average score was then calculated. All test measurements were completed before the daily step measurement.

2.6. Statistical analysis

The relationship between the average daily steps and physical function was investigated with the Pearson correlation coefficient. The t test and χ^2 test were used to compare the results of measurements between frail and nonfrail groups.

A multivariate analysis by means of multiple regression using a stepwise method was performed to investigate which of the age, gender, BMI, fear of falling, and five measures of physical function (i.e., 10-m walk test, TUG, single-leg standing, functional reach, and five-chair stand test) were independently associated with the average daily steps in each group.

Data were analyzed using the Statistical Package for Social Science (Windows version 18.0; SPSS Inc., Chicago, IL, USA).

3. Results

There were no significant differences in age (nonfrail = 77.0 ± 7.2, frail = 76.1 ± 7.5, $p = 0.241$), gender (nonfrail = 67.5%, frail = 67.5%, $p = 0.541$), height (nonfrail = 153.5 ± 7.6 cm, frail = 153.7 ± 6.1 cm, $p = 0.743$), weight (nonfrail = 53.0 ± 9.6 kg, frail = 53.6 ± 4.5 kg, $p = 0.576$), and BMI (nonfrail = 22.4 ± 3.2, frail = 22.7 ± 1.9, $p = 0.393$) between the two groups (Table 1). However, all physical function tests and average daily steps were significantly different between the two groups. More fear of falling was observed (nonfrail = 39.1%, frail = 73.6%, $p < 0.001$), longer time was required for 10-m walk test (nonfrail = 9.9 ± 2.2 seconds, frail = 17.1 ± 6.6 seconds, $p < 0.001$), single-leg standing (nonfrail = 13.3 ± 12.1 seconds, frail = 3.1 ± 6.0 seconds, $p < 0.001$), and five-chair stand (nonfrail = 8.9 ± 3.6 seconds, frail = 17.6 ± 8.5 seconds, $p < 0.001$) in frail elderly. Less functional reach (nonfrail = 25.0 ± 8.2 cm, frail = 17.9 ± 8.4 cm, $p < 0.001$), and average daily steps (nonfrail = 4414 ± 2726 steps, frail = 1585 ± 1013 steps, $p < 0.001$) were observed in frail elderly.

To determine the association of average step counts with physical functions and demography, we analyzed Pearson's correlation coefficients in frail and nonfrail elderly. Table 2 shows that average step counts in the nonfrail group were correlated with age ($r = -0.311$, $p < 0.001$), BMI ($r = 0.167$, $p < 0.001$), 10-m walk test ($r = -0.475$, $p < 0.001$), TUG ($r = -0.412$, $p < 0.001$), functional

Table 1

Comparison of demography, fear of falling, and physical function and activities between nonfrail and frail elderly

Items	Nonfrail group ($n = 515$)		Frail group ($n = 114$)		p
	Mean	SD	Mean	SD	
Age (yr)	77.0	7.2	76.1	7.5	0.241
Gender (male = 0, female = 1)	67.5		67.5		0.541[a]
Height	153.5	7.6	153.7	6.1	0.743
Weight	53.0	9.6	53.6	4.5	0.576
BMI (kg/m^2)	22.4	3.2	22.7	1.9	0.393
Fear of falling (yes = 1, no = 0)	39.1		73.6		<0.001[a]
10-m walking time (s)	9.9	2.2	17.1	6.6	<0.001
Timed up & go test (s)	8.8	2.1	20.2	6.8	<0.001
Single leg standing (s)	13.3	12.1	3.1	6.0	<0.001
Functional reach (cm)	25.0	8.2	17.9	8.4	<0.001
Five chair stand (s)	8.9	3.6	17.6	8.5	<0.001
Average daily step (step)	4414.4	2726.3	1585.0	1012.6	<0.001

BMI = body mass index; SD = standard deviation.

[a] χ^2 test.

Table 2
Pearson's correlation coefficients (r) between average daily steps and physical functions, age, and BMI

Items	Nonfrail group ($n = 515$)	Frail group ($n = 114$)	Overall ($n = 629$)
Age (yr)	−0.311**	−0.109	−0.241**
BMI (kg/m^2)	0.167**	−0.013	0.130**
10-m walking time (s)	−0.475**	−0.047	−0.448**
Timed up & go test (s)	−0.412**	−0.131	−0.450**
Functional reach (cm)	0.348**	0.175	0.406**
Five-chair stand (s)	−0.297**	−0.226*	−0.397**
Single-leg standing (s)	0.440**	0.077	0.502**

BMI = body mass index.
*$p < 0.05$; **$p < 0.01$.

reach ($r = 0.348$, $p < 0.001$), five chair stand test ($r = -0.297$, $p < 0.001$), and single-leg standing test ($r = 0.440$, $p < 0.001$). In the frail group, however, a significant association was found only with five-chair stand test ($r = -0.226$, $p < 0.001$). Figure 1 shows linear regressions between physical functions and average step counts in nonfrail and frail elderly. Average step counts had a positive association with functional reach (Fig. 1C) and negative associations with 10-m walk test (Fig. 1A) and TUG (Fig. 1B) only in nonfrail elderly. However, step counts had a negative association with five-chair stand (Fig. 1D) both in nonfrail and frail elderly.

Stepwise regression analysis revealed that age ($\beta = -0.108$, $p = 0.03$), gender ($\beta = 0.255$, $p < 0.001$), 10-m walk test ($\beta = -0.202$, $p < 0.001$) and single-leg standing ($\beta = 0.306$, $p < 0.001$) were

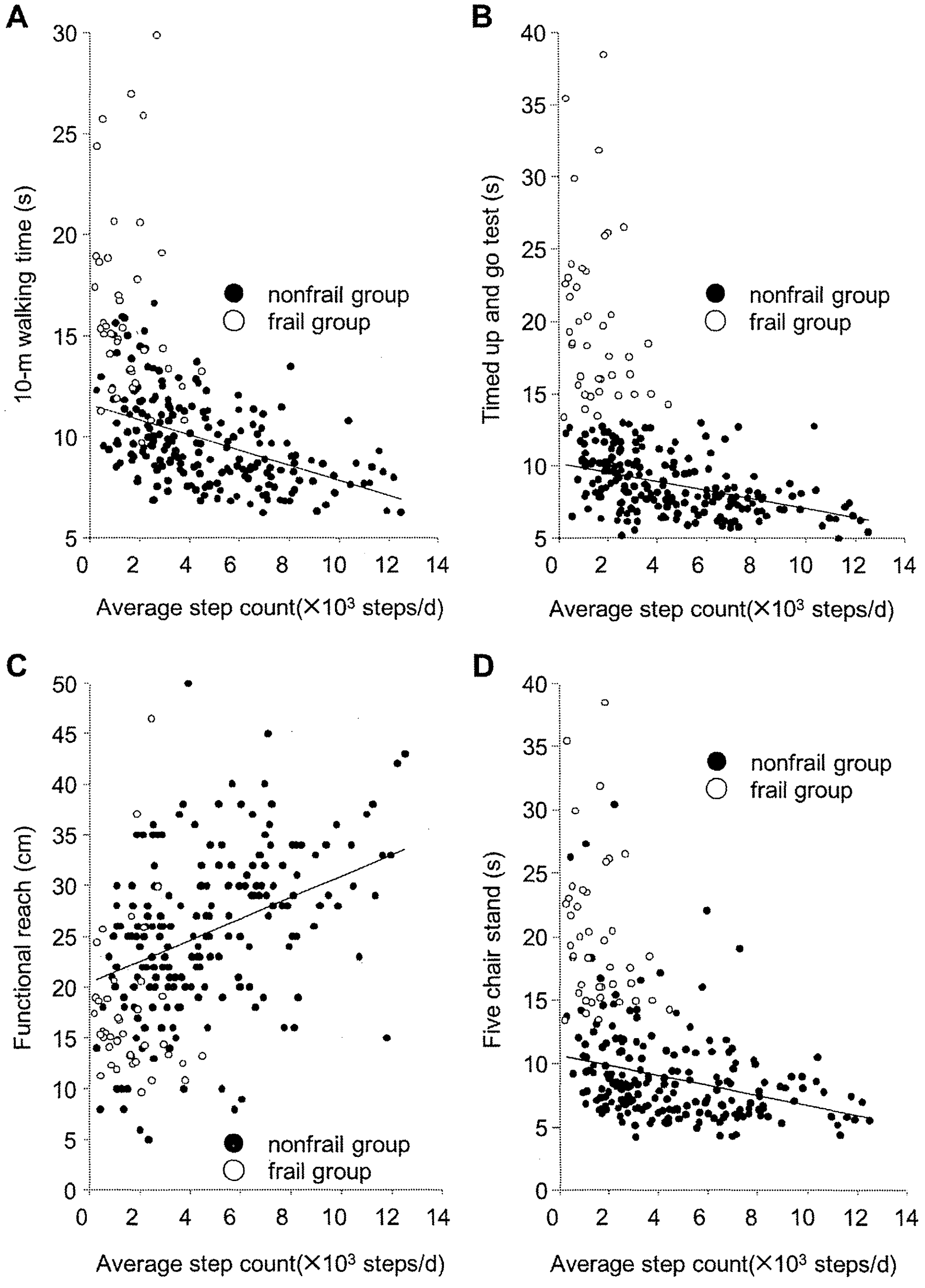

Fig. 1. Relationships between average daily steps and physical function. The physical function was associated with physical activities in nonfrail but not in frail elderly. (A) 10-m walk test; (B) Timed up and go test; (C) Functional reach; (D) Five-chair stand test.

Table 3
Multiple stepwise regression analysis

Independent variables	Nonfrail group Adjusted R^2 value = 0.282 standard regression value	Frail group Adjusted R^2 value = 0.119 standard regression value	Overall Adjusted R^2 value = 0.345 standard regression value
Age (yr)	−0.108*		−0.137**
BMI (kg/m^2)			
Gender (male = 0, female = 1)	0.255**		0.238**
Fear of falling (yes = 1, no = 0)		−0.356**	−0.089*
10-m walking time (s)	−0.202**		−0.172**
Timed up & go test (s)			
Functional reach (cm)			
Five chair stand (s)			−0.147**
Single leg standing (s)	0.306**		0.314**

*$p < 0.05$; **$p < 0.01$.

significant and independent determinants of the average step counts in nonfrail elderly ($R^2 = 0.282$, $p < 0.001$) (Table 3). Stepwise regression analysis also revealed that fear of falling ($\beta = -0.356$, $p < 0.001$) was the only significant and independent determinant of the average step counts in frail elderly ($R^2 = 0.119$, $p < 0.001$) (Table 3).

4. Discussion

In the present study, we showed that the differential factors of physical functions may relate to the daily activities in frail and nonfrail community-dwelling elderly Japanese. Our data implicate that physical daily activities can be maintained in the robust elderly with high physical function, whereas fear of falling plays a more important role for the maintenance of physical daily activities if an older adult becomes functionally impaired and frail. Previous studies also indicated that the low self-efficacy for daily activities reduces physical activity, and psychological well-being is an important predictor for staying physically active.[18,19] Thus, differential approaches should be taken to keep the daily activities depending on their physical fitness in elderly.

The physical functions, age, and gender were associated with daily activities in nonfrail elderly but not in frail elderly. Rantanen et al[20] also reported that the relationship between muscle strength and physical disability in older adults is nonlinear. Moreover, in most of previous reports, the participants were nonfrail older adults.[1–4] Therefore, it has been assumed that there is an association between daily activities and physical functions. In addition, daily activities tended to be greater in women than in men. The reason for greater daily activities in women is often ascribed to activities, such as housework and gardening.[20]

On the other hand, we demonstrated that fear of falling was associated with physical daily activities in frail elderly but not in nonfrail elderly. Fear of falling is shown to be associated with frailty.[21,22] Several studies have indicated that people who are afraid of falling appear to enter a debilitating spiral of loss of confidence, restriction of physical activities, physical frailty, lack of social participation, falls, and loss of independence.[23–28] However, Wolf et al[29] reported that increased core and lower extremity strength with exercise decreases the fear of falling. Moreover, cognitive behavioral therapy has been shown to reduce fear of falling.[30–32]

There were several limitations of this study that warrant mention. First, although we used TUG to define frailty, TUG may not be enough to define frailty. Edmonton frail scale adopts eight other domains, such as cognition, general health status, functional independence, social support, medication use, nutrition, mood, and continence other than TUG.[33] Further study is required to test the levels of these domains in this cohort. Second, participants have used pedometer measurements limited to only 2 weeks. If seasonal changes in activity pattern were taken into consideration, long-term use would be more appropriate. Third, the participant's community was not in the rural area. The present study is the result of being restricted to older adults in the urban area.

This is the first study to demonstrate that differential factors affect daily activities depending on the level of frailty. Future work should determine whether individualized intervention can effectively improve physical activity in both nonfrail and frail elderly.

Acknowledgments

We would like to thank Nippon-Shooter Co. Ltd. for their contribution to data collection and Mr Minoru Ikeda and Mr Yusuke Terasaki for their helpful advice.

References

1. Aoyagi Y, Katsuta S. Relationship between the starting age of training and physical fitness in old age. *Can J Sport Sci* 1990;**15**:65–71.
2. Aoyagi Y, Shephard RJ. Aging and muscle function. *Sports Med* 1992;**14**:376–96.
3. Aoyagi Y, Shephard RJ. Steps per day: the road to senior health? *Sports Med* 2009;**39**:423–38.
4. Nelson ME, Rejeski WJ, Blair SN, Duncan PW, Judge JO, King AC, et al. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 2007;**39**:1435–45.
5. Singh NA, Clements KM, Singh MA. The efficacy of exercise as a long-term antidepressant in elderly subjects: a randomized controlled trial. *J Gerontol A Biol Sci Med Sci* 2001;**56**:M497–504.
6. Mazzeo RS, Cavanagh P, Evans WJ, Fiatarone M, Hagberg J, McAuley E, et al. American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc* 1998;**30**:992–1008.
7. Simons LA, Simons J, McCallum J, Friedlander Y. Lifestyle factors and risk of dementia: Dubbo study of the elderly. *Med J Aust* 2006;**184**:68–70.
8. Spirduso WW, Cronin DL. Exercise dose-response effects on quality of life and independent living in older adults. *Med Sci Sports Exerc* 2001;**33**: S598–608.
9. Physical Activity Guidelines Advisory Committee. *Physical Activity Guidelines Advisory Committee Report, 2008.* Washington, D.C.: U.S. Department of Health and Human Services; 2008.
10. Yoshida D, Nakagaichi M, Saito K, Wakui S, Yoshitake Y. The relationship between physical fitness and ambulatory activity in very elderly women with normal functioning and functional limitation. *J Physiol Anthropol* 2010;**29**: 211–8.
11. Kalbe E, Calabrese P, Scgwalen S, Kessler J. The Rapid Dementia Screening Test (RDST): a new economical tool for detecting possible patients with dementia. *Dement Geriatr Cogn Disord* 2003;**16**:193–9.
12. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc* 1991;**39**:142–8.
13. Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Phys Ther* 2000;**80**:896–903.
14. Crouter SE, Schneider PL, Karabulut M, Bassett Jr DR. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Med Sci Sports Exerc* 2003;**35**:1455–60.
15. Reelick MF, van Iersel MB, Kessels RP, Rikkert MG. The influence of fear of falling on gait and balance in older people. *Age Ageing* 2009;**38**:435–40.
16. Duncan PW, Weiner DK, Chandler J, Prescott B. Functional reach: a new clinical measure of balance. *J Gerontol* 1990;**45**:M192–7.
17. Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, et al. A short physical performance battery assessing lower extremity function:

association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol* 1994;**49**:M85–94.

18. Ruuskanen JM, Ruoppila I. Physical activity and psychological well-being among people aged 65-84 years. *Age Ageing* 1995;**24**:292–6.
19. Kono A, Kai I, Sakato C, Rubenstein LZ. Frequency of going outdoors: a predictor of functional and psychosocial change among ambulatory frail elders living at home. *J Gerontol A Biol Sci Med Sci* 2004;**59**:275–80.
20. Rantanen T, Guralnik JM, Ferrucci L, Penninx BW, Leveille S, Sipila S, et al. Coimpairments as predictors of severe walking disability in older women. *J Am Geriatr Soc* 2001;**49**:21–7.
21. Cumming RG, Salkeld G, Thomas M, Szonyi G. Prospective study of the impact of fear of falling on activities of daily living, SF-36 scores, and nursing home admission. *J Gerontol A Biol Sci Med Sci* 2000;**55**:299–305.
22. Delbaere K, Crombez G, Vanderstraeten G, Willems T, Cambier D. Fear-related avoidance of activities, falls and physical frailty. A prospective community-based cohort study. *Age Ageing* 2004;**33**:368–73.
23. Friedman SM, Munoz B, West SK, Rubin GS, Fried LP. Falls and fear of falling: which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. *J Am Geriatr Soc* 2002;**50**:1329–35.
24. Lachman ME, Howland J, Tennstedt S, Jette A, Assman S, Peterson EW. Fear of falling and activity restriction: the survey of activities and fear of falling in the elderly (SAFE). *J Gerontol B Psychol Sci Soc Sci* 1998;**53**:P43–50.
25. Arfken CL, Lach HW, Birge SJ, Miller JP. The prevalence and correlates of fear of falling in elderly persons living in the community. *Am J Public Health* 1994;**84**:565–70.
26. Howland J, Peterson EW, Levin WC, Fried L, Pordon D, Bak S. Fear of falling among the community-dwelling elderly. *J Aging Health* 1993;**5**:229–43.
27. Cumming RG, Salkeld G, Thomas M, Szonyi G. Prospective study of the impact of fear of falling on activities of daily living, SF-36 scores, and nursing home admission. *J Gerontol A Biol Sci Med Sci* 2000;**55**:M299–305.
28. Delbaere K, Crombez G, Vanderstraeten G, Willems T, Cambier D. Fear-related avoidance of activities, falls and physical frailty. A prospective community-based cohort study. *Age Ageing* 2004;**33**:368–73.
29. Wolf S, Barnhart H, Kutner N, McNeely E, Coogler C, Xu T, et al. Selected as the best paper in the 1990s: reducing frailty and falls in older persons: an investigation of tai chi and computerized balance training. *J Am Geriatar Soc* 2003;**51**:1794–803.
30. Brouwer BJ, Walker C, Rydahl SJ, Culham EG. Reducing fear of falling in seniors through education and activity programs: a randomized trial. *J Am Geriatr Soc* 2003;**51**:829–34.
31. Tennstedt S, Howland J, Lachman M, Peterson E, Kasten L, Jette A. A randomized, controlled trial of a group intervention to reduce fear of falling and associated activity restriction in older adults. *J Gerontol B Psychol Sci Soc Sci* 1998;**53**:384–92.
32. Zijlstra GAR, Van Haastregt JCM, Ambergen T, Van Rossum E, Van Eijk JTM, Tennstedt SL, et al. Effects of a multicomponent cognitive behavioral group intervention on fear of falling and activity avoidance in community-dwelling older adults: results of a randomized controlled trial. *J Am Geriatr Soc* 2009;**57**:2020–8.
33. Rolfson DB, Majumdar S, Tsuyuki RT, Tahir A, Rockwood K. Validity and reliability of the Edmonton Frail Scale. *Age Ageing* 2006;**35**:526–9.

Aging Clinical and Experimental Research

SHORT COMMUNICATION

Fallers choose an early transfer gaze strategy during obstacle avoidance in dual-task condition

Minoru Yamada[1], Hidenori Tanaka[2], Shuhei Mori[1], Koutatsu Nagai[1], Kazuki Uemura[1], Buichi Tanaka[1], Tomoki Aoyama[1] and Noriaki Ichihashi[1]

[1]Human Health Sciences, Graduate School of Medicine, Kyoto University, Shogoin, Sakyo-ku, Kyoto,
[2]Department of Rehabilitation, Higashi Ikoma Hospital, Ikoma-city, Nara, Japan

ABSTRACT. ***Background and aims:*** *The aim of the present study is to compare the gaze behavior between fallers and non-fallers during obstacle avoidance in dual-task conditions.* ***Methods:*** *Nine older adults who had no experience of falling (mean age 79.9±5.4) and 9 older adults with known experience of falling (83.4±3.6) participated in the study. We examined their gaze behavior during obstacle avoidance in single-task (ST) and dual-task (DT) conditions.* ***Results:*** *In the ST condition, compared with the faller group, the non-faller group showed no significant difference in timing of gaze transfer from the obstacle (faller: gaze transfer from obstacle when 1.6±1.1 steps before; non-faller: 1.9±0.7 steps before,* p=*0.493). In the DT condition, the faller group chose a transfer of gaze strategy significantly earlier than the non-faller group (faller: 2.7±1.4 steps before; non-faller: 1.6±0.5 steps before,* p=*0.008).* ***Conclusion:*** *Our findings suggest that fallers chose an early transfer of gaze strategy when challenged with an obstacle in DT conditions.*
(Aging Clin Exp Res 2011; 23: 316-319)

INTRODUCTION

Previous studies have shown that tripping over obstacles constitutes a major category of falls in older adults (1). Since many falls occur while simultaneously walking and performing a second task such as engaging in a conversation or carrying an object (1, 2), examining the attention demands of secondary tasks on balance control in gait is a critical research area.

Previous research on dual-task (DT) conditions has mainly been limited to the study of balance control during stance and level walking; thus, the effect of performing a secondary task on stability during obstacle avoidance is poorly understood. In this regard, both Chen et al. (3) and Weerdesteyn et al. (4) have demonstrated that the obstacle avoidance success rate is worsened by the performance of a secondary task. However, the effect of obstacle avoidance on the secondary task is still unclear.

The results of recent studies suggest that there are age-related differences in coordination between eye and stepping movements. Di Fabio et al. (5) showed that age-related differences in eye movement behavior are observed in participants stepping over obstacles. These results suggest that older adults need more time to process visual information describing targets and obstacles and/or to program appropriate motor responses. However, the effect of gaze behavior during obstacle avoidance while performing a secondary task is still unclear.

The aim of the present study is to compare the gaze behavior between fallers and non-fallers during obstacle avoidance in DT conditions.

METHODS

Participants

Participants were recruited by advertisements in the local press. Nine relatively healthy older adults who had no experience of falling (mean age 79.9±5.4, range 71-86 yrs) and 9 relatively healthy older adults with experience of falling (mean age 83.4±3.6, range 75-88 yrs) participated in the study. The occurrence of falls within the past year was also measured. A fall was defined as an event that resulted in a person unintentionally coming to rest on the ground, floor, or other lower level, with or without loss of consciousness or in-

Key words: Dual tasks, faller, gaze behavior, obstacle-avoidance.

Correspondence: Minoru Yamada, Physical Therapist, PhD, Human Health Sciences, Graduate School of Medicine, Kyoto University, Shogoin, Sakyo-ku, Kyoto, Japan.
E-mail: yamada@hs.med.kyoto-u.ac.jp

Received May 24, 2010; accepted in revised form September 6, 2010.
First published ahead of print September 9, 2010 as DOI: 10.3275/7258