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The Reliability and Preliminary Validity of Game-Based Fall Risk Assessment in Community-Dwelling Older Adults

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The purpose of this study was to examine whether the Nintendo Wii Fit program could be used for fall risk assessment in healthy, community-dwelling older adults. Forty-five community-dwelling older women participated in this study. The "Basic Step" and "Ski Slalom" modules were selected from the Wii Fit game program. The following 5 physical performance tests were performed: the 10-m walk test under single- and dual-task conditions, the Timed Up and Go test under single- and dual-task conditions, and the Functional Reach test. Compared with the faller group, the nonfaller group showed a significant difference in the Basic Step ($P < .001$) and a nonsignificant difference in the Ski Slalom ($P = .453$). The discriminating criterion between the 2 groups was a score of 111 points on the Basic Step ($P < .001$). The Basic Step showed statistically significant, moderate correlations between the dual-task lag of walking ($r = -.547$) and the dual-task lag of the Timed Up and Go test ($r = -.688$). These results suggest that game-based fall risk assessment using the Basic Step has a high generality and is useful in community-dwelling older adults. (*Geriatr Nurs* 2011;32:188-194)

Falls are a major health problem among the elderly. Approximately 30% of 65-year-old community-dwelling older adults fall at least once a year, and 6% of these falls result in fractures.[1,2] Most falls occur during locomotion, and thus previous studies focused on identifying age-related differences in locomotor performance.[3,4] Several performance balance measures, such as the Timed Up and Go (TUG),[5] one-leg stand,[6] Functional Reach[7] (FR), and Tinetti Balance[8] tests are available for risk assessment in community-dwelling older people.

Dual tasking (DT), or engaging in 2 activities at the same time, is common in daily living. From a widely accepted view, the degree of DT interference is a measure of the attentional requirements of component tasks.[9] Although neural mechanisms that underlie age-related cognitive decline remain equivocal, age-related reduction in brain volume[10] and cortical thickness[11] are the most pronounced in the prefrontal cortex. Executive processes supported by the prefrontal cortex, including attention, inhibition, and working memory, are highly susceptible to age-related brain degeneration.[12-14]

With advancing age, the addition of walking to activities of daily living can create difficulties that lead to complex multitask situations, thus increasing the risk of falling.[15] Thus, it is believed that some falls occur because of an inability to recover from a near fall during an additional attention-demanding task when performing the activities of daily living. DT-related gait changes result from interference caused by competition between the attention demands of gait and walking-associated attention-demanding tasks.[16] Therefore, DT interference suggests a limitation of attentional resources.[17] Exploring DT-related gait changes is of particular interest for clinicians because a strong relationship has been found to exist between DT-related gait changes and the risk of falling in older adults.[18-20] Thus, it is believed that some falls occur because of an inability to recover from a fall during an additional attention-demanding task when performing the activities of daily living.

Professionals from various fields are increasingly exploring the use of the Nintendo Wii Fit program as a next-generation game machine. In addition to the mouse, the Nintendo Wii Fit Balance Board has a sensor like many other commercial game products. A peripheral Wii Balance Board is available with the Nintendo Wii video game console. It has a shape similar to that of a body scale and a flat rectangular design. It is a wireless device that can be powered for up to 60 hours with 4 AA batteries and communicates via Bluetooth with the Wii console. For persons with disabilities, the Wii Balance Board can be used as a high-performance, standing-posture detector. It has 4 pressure sensors situated at each corner from which enough information is available to obtain calibrated readings. The sensors show different pressure values when a user's standing posture changes, and these changes in posture can be calculated by analyzing the changes in the pressure values of the 4 sensors.

The Wii Fit program requires the distribution of attention to the motor task and the monitor (cognitive task). Thus, it is assumed that the Wii Fit program includes a constituent of DT. There are few reports about game-based trials, but there are no reports about game-based assessment. Hence, the purpose of this study is to examine whether the Wii Fit program can be used for fall risk assessment in healthy, community-dwelling older adults.

Methods

Participants

The participants were recruited by advertisements in the local press. An initial interview was conducted, and the participants were screened on the basis of the following criteria: age 65 years or older, community-dwelling, had visited a primary care physician in the last 3 years, had received a sum score of 5 or more on the Rapid Dementia Screening Test (RDST) (dementia may be assumed if the RDST score is less than 5 points),[21] were independently ambulatory with or without a cane (those individuals requiring the assistance of a walker were excluded), and had minimal hearing and vision impairment.

Fifty-three subjects volunteered to participate in this study. Of these, 8 participants did not meet the inclusion criteria. The exclusion criteria, as noted in the interview, were severe cardiac, pulmonary, or musculoskeletal disorders; pathologies associated with increased risk of falls (i.e., Parkinson's disease or stroke); and the use of psychotropic drugs. Written informed consent was obtained from the remaining 45 older women who were included in the trial in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine and Declaration of Human Rights, Helsinki, 1975.

Game-Based Performance Measures

Participants learned to swing their bodies using the Wii Fit Balance Board (Nintendo Wii; Nintendo, Minami-ku, Kyoto, Japan) with the guidance of a research assistant. As mentioned earlier, the target response was due to a change in the participants' foot position (or change in sitting posture). In this study, a Wii Fit Balance Board, which was placed under the participants' feet (or buttocks) to detect a target response, was used to transmit target response signals to a control system. Changes in foot position (or sitting posture) signals (including a change in the pressure of the 4 sensors) were transmitted via Bluetooth to the control system. This was connected to a 40-inch monitor with cables.

The "Basic Step" and "Ski Slalom" measures were selected from the Wii Fit game program. The games were modified so that they could be played in a sitting position on a standard dining room chair with a seat height of 40 cm (Figure 1). For safety and generality, modification of the position was required. Only the Basic Step and Ski Slalom could be performed in a modified seated position in the pilot experiment. The distance between the chair and monitor was 2 m. The monitor was located on a TV board that was 40 cm high. The Basic Step involves stepping on and off the Wii Fit Balance Board in time to a specified rhythm. The Ski

Slalom involves skiing down the mountain slope and trying to navigate through the flags by controlling the body (shifting weight to the right, left, or forward) on the Wii Fit Balance Board. Test—retest reliability was assessed by repeating the Wii Fit game program within 1 hour of the first trial.

Physical Performance Measures

All participants underwent 5 measurements—the 10-m walk test under single-task (ST) and DT conditions, the TUG test under ST and DT conditions, and the FR test—in the presence of a physiotherapist. Before starting the study, all staff members received training from the authors (MY and BT) concerning the correct protocols for administering all assessment measures included in the study. The locomotive functions were assessed by the 10-m walk test under ST conditions (ST walking),[22] 10-m walk test under DT conditions (DT walking),[23] TUG test under ST conditions,[5] TUG test under DT conditions,[24] DT lag of walking and TUG,[25] and FR test.[26]

In ST walking, the participants walked 15 m at a comfortable speed, and the time taken to complete the 10-m mark was recorded using a stopwatch. The time recorded in the 2 trials was averaged as the ST walking score. The parameters recorded were the time and number of steps.

In DT walking, the participants walked 15 m at a comfortable speed while counting numbers loudly, starting from 50, in reverse order. The importance of walking and counting at the same time was emphasized to all of the participants, who were asked to walk and count to the best of their capacity without prioritizing either task. Possible counting mistakes were not corrected.[23] The parameters recorded were the time and number of steps.

TUG is one of the most frequently used tests for balance and gait and is often used to assess the risk of falls in older adults. In TUG, the participants were asked to stand up from a standard chair with a seat height of 40 cm, walk a distance of 3 m at a normal pace, turn, walk back to the chair, and sit down. Time measured in seconds was counted from the moment the word "go" was said and stopped when the participant's back touched the chair backrest. Lesser time taken to accomplish this task indicated better balancing ability. The time recorded in the 2 trials was averaged to obtain the TUG score.

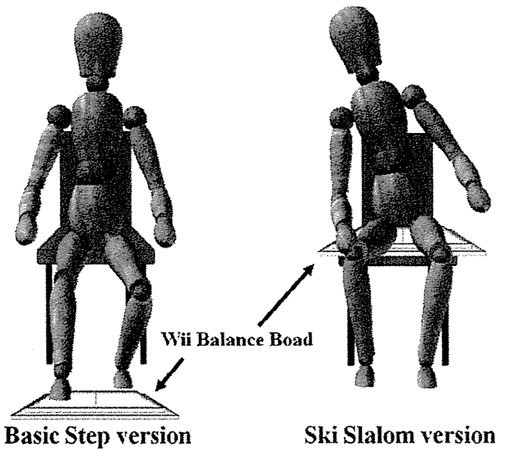

Figure 1. Schematic diagram of the game in a sitting position. The configuration of this study included a Wii Fit Balance Board, which was placed under the participants' feet (Basic Step) or buttocks (Ski Slalom). It was connected with cables to a TV for broadcasting the participants' videos.

Relative DT lag of walking and TUG were calculated using the ST performance as the comparison condition. The DT lag was then calculated as follows:[14]

$$DT\ lag\ (\%) = 100^{*}(DT\ condition - ST\ condition)/ST\ condition.$$

In FR, each participant was positioned next to a wall with 1 arm raised to a 90° level and the fingers extended. A yardstick was mounted on the wall at shoulder height. The distance that a participant could reach while extending forward from an initial upright posture to the maximal anterior leaning posture without moving or lifting the feet was visually measured in centimeters as the position of the third fingertip against the mounted yardstick. Distances measured in the 2 trials were averaged to obtain the FR score, with greater distances indicating better balancing ability. In this trial, the participants used both arms for FR.

Fall Experience

The occurrence of falls within the previous year was also measured. A fall was defined as "an event that results in a person coming to rest inadvertently on the ground or other lower level regardless of whether an injury was sustained, and not as a result of a major intrinsic event or overwhelming hazard."[27] The date, number, characteristics (e.g., while rising from a lying or sitting position, while turning in the opposite direction, while tripping over an obstacle), and consequences (e.g., bruise, fracture) of the falls were recorded using a standardized questionnaire.

Statistical Analysis

Differences in physical function variables between the groups were assessed by Student's *t* test. The Kolmogorov–Smirnov test and Mann–Whitney *U* test were used to evaluate the normality of distributions and differences in physical function variables between the groups. Test–retest reliability was examined with intraclass correlation coefficients [$ICC_{(1,1)}$] for the scores of the Basic Step and Ski Slalom, using analysis of variance. Differences in the data on physical performance variables between faller and nonfaller groups were analyzed by Student's *t* test. The utility of the Basic Step and Ski Slalom for distinguishing fall and nonfall was tested using discriminant analysis for a cutoff point on the index. Criterion-related validity was determined by evaluating the correlation between the game-based scores and physical performance using Spearman's correlation coefficient. Data were registered and analyzed using the Statistical Package for Social Science (Windows version 11.0). A *P* value < .05 was considered statistically significant for the analyses.

Results

Within the previous year, 16 older adults (35.5%) had experienced falls. The Kolmogorov–Smirnov test showed that the RDST was not normally distributed. There were no significant differences between groups for age (faller = 84.8 ± 10.1, nonfaller = 80.2 ± 6.4, *P* = .549), height (faller = 154.5 ± 6.4 cm, nonfaller = 148.2 ± 9.2 cm, *P* = .327), weight (faller = 47.5 ± 4.8 kg, nonfaller = 47.3 ± 9.6 kg, *P* = .327), body mass index (faller = 19.6 ± 3.3, nonfaller = 23.4 ± 4.8, *P* = .098), and RDST (faller = 7.2 ± 2.6, nonfaller = 7.3 ± 2.3, *P* = .934; Table 1). Individuals in the faller group had significantly higher mean values in ST (*P* = .023, effect size = 1.36) and DT number of steps (*P* = .008, effect size = 1.48) and lower mean values in the Basic Step score (*P* < .001, effect size = 1.65) compared with those in the nonfaller group. Compared with the faller group, the nonfaller group showed no significant difference in the Ski Slalom (*P* = .453, effect size = .30).

Test–Retest Reliability

Considerable consistency was observed in the test–retest reliability of the Basic Step ($ICC_{1,1}$ = 0.785; 95% confidence interval [CI], 0.35–0.93; *P* = .035) and Ski Slalom ($ICC_{1,1}$ = 0.611; 95% CI, −0.08 to 0.86; *P* = .004).

Discriminant Validity

Discriminant analysis was performed using the Basic Step scores that showed a significant difference between the 2 groups (Table 1). The discriminating criterion between the 2 groups was a score of 111 points on the Basic Step, by which 88.6% of the cases were correctly classified (*P* < .001; Figure 2).

Criterion-Related Validity

The Basic Step showed statistically significant moderate correlations with DT lag of walking (r = −.547, *P* = .023) and DT lag of TUG (r = −.688, *P* = .003). The relationship between the Basic Step and physical function was not significant (*P* > .05). The Ski Slalom showed no significant association with physical performance (*P* > .05), nor were there any significant associations between the Basic Step and Ski Slalom. See Table 2.

Discussion

The results of this study indicate that as the ICCs of both the Basic Step and Ski Slalom were substantial, and they appear to be reliable measurements. The results of the Basic Step were moderately correlated with those of DT lag of walking and DT lag of TUG. Moreover, the Basic Step showed discriminant validity in both the faller and nonfaller groups. There were no significant differences in any of the participants' characteristics between the 2 groups. Therefore, the Basic Step may be considered a measurement that is related to walking ability under DT conditions. These results suggest that the Basic Step shows high generality in the risk assessment of falls.

In real-life situations, the requirement to step commonly occurs under more complicated circumstances, with cognitive attention focused

Table 1. Subject Characteristics and Physical Performances of Faller and Nonfaller Groups

Characteristic	All (*n* = 45)	Faller (*n* = 16)	Nonfaller (*n* = 28)	*P*	Effect Size
Age, years	81.3 ± 7.4	84.8 ± 10.1	80.2 ± 6.4	.549	0.61
Body Weight, kg	47.3 ± 8.6	47.5 ± 4.8	47.3 ± 9.6	.956	0.03
Height, cm	149.3 ± 8.8	154.5 ± 6.4	148.2 ± 9.1	.327	0.72
Body Mass Index	22.2 ± 4.7	19.6 ± 3.3	23.4 ± 4.8	.098	0.25
RDST, points	7.2 ± 2.3	7.2 ± 2.6	7.3 ± 2.3	.934	0.03
Wii Score					
Basic Step, points	123.0 ± 39.9	81.1 ± 19.7	147.0 ± 26.2	<.001	1.65
Ski Slalom, seconds	106.3 ± 22.2	110.7 ± 37.3	104.1 ± 8.9	.453	0.30
Walking Ability					
ST Walking Time, points	16.5 ± 7.3	22.4 ± 6.1	14.7 ± 6.9	.079	1.05
ST No. of Steps	29.2 ± 9.7	39.3 ± 10.5	26.1 ± 7.3	.023	1.36
DT Walking Time, seconds	21.7 ± 11.1	30.0 ± 5.3	19.1 ± 11.3	.079	0.97
DT No. of Steps	31.6 ± 10.7	43.5 ± 9.0	27.7 ± 8.1	.008	1.48
DT Lag, Walking Time, seconds	31.2 ± 28.9	46.8 ± 35.7	26.4 ± 26.2	.269	0.70
DT Lag, No. of Steps	6.9 ± 6.6	12.3 ± 7.6	5.1 ± 5.5	.103	1.09
Balance Ability					
ST TUG, seconds	16.4 ± 8.4	23.2 ± 8.4	14.9 ± 7.9	.111	1.00
DT TUG, seconds	22.1 ± 14.7	33.0 ± 10.9	19.6 ± 14.6	.082	0.92
DT Lag, TUG, seconds	28.2 ± 28.4	45.9 ± 26.7	24.1 ± 28.1	.111	0.77
Functional Reach, cm	20.3 ± 7.3	14.8 ± 4.0	22.0 ± 7.3	.079	1.00

DT = dual task; RDST = Rapid Dementia Screening Test; ST = single task; TUG = Timed Up and Go test. Columns indicating fallers' and nonfallers' values are expressed as mean ± SD.

on such things as watching traffic or reading street signs or advertisements rather than performing a specific motor task.[4] With advancing age, the addition of walking to the activities of daily living can create difficulties that lead to complex multitask situations, thus increasing the risk of falling.[15] Exploring DT-related gait changes is of particular interest for clinicians because a strong relationship exists between DT-related gait changes and the risk of falling in older adults.[19] Thus, it is believed that some falls occur because of an inability to recover from a fall during an additional attention-demanding task during the activities of daily living. The Basic Step score was correlated with ability during an attention-demanding task. Thus, the Basic Step may include the constituent of a real-life situation.

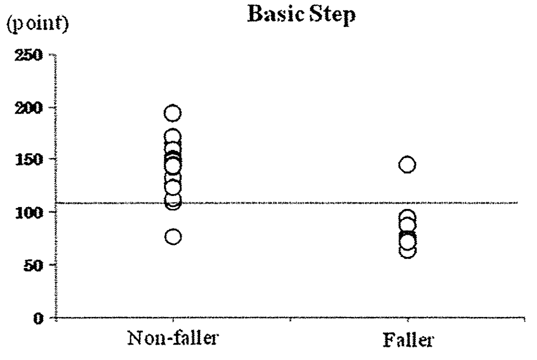

Figure 2. Scatter chart of Basic Step. A score of 111 points on the Basic Step was used to classify correctly 88.6% of the cases ($P < .001$). The borderline demonstrates the cutoff point.

DT performance is sensitive to cognitive changes associated with aging. One theory as to why DT lag increases with aging relates to the slowed perceptual speed[28] and increased complexity of the DT situation, which then requires more processing.[29] Others theorize that the reduced capacity of the working memory, attention, or perceptual-motor ability leads to greater difficulty for older adults in performing 2 tasks simultaneously.[30] Yet another theory of age-related decline in DT performance suggests

Table 2.
Correlation between Basic Step, Ski Slalom, and the Other Measures

	Basic Step	Ski Slalom
Basic Step		−0.491
Ski Slalom	−0.251	
ST Walking Time	−0.311	0.100
ST No. of Steps	−0.311	0.164
DT Walking Time	−0.429	0.147
DT No. of Steps	−0.334	0.102
DT Lag, Walking Time	−0.547*	0.138
DT Lag, No. of Steps	−0.204	0.025
ST TUG	−0.221	0.159
DT TUG	−0.372	0.187
DT Lag, TUG	−0.688*	0.262
Functional Reach	0.085	−0.100

DT = dual task; ST = single task; TUG = Timed Up and Go test.
$^*P < .05$.

that there is difficulty in the coordination and allocation of attention to multiple tasks by older adults. Kramer et al.[31] reported that there are several mechanisms responsible for the DT lag observed with aging. The Basic Step scores were moderately correlated with those of DT lag of walking and TUG. Thus, the Basic Step score might include the constituent of DT lag.

The Basic Step score showed discriminant validity in both the faller and nonfaller groups. Some researchers reported that many tests were useful for measurements related to judging the risk of fall.[5,22-26] However, there was nothing that placed the home-based fall risk assessment within professional bounds. Physical performance under DT conditions is particularly difficult. This study suggests that the Basic Step shows high generality in risk assessment for home-based falls. The home of each participant was equipped with a television set in the living room so that only the purchase of Wii would be required to continue with the activities. Game-based fall risk assessment using the Basic Step has a high generality and is useful in community-dwelling older adults. A score of 111 points on the Basic Step was considered the fall-related cutoff point. In addition, the Basic Step had the largest effect size in all of the physical performance tests. This result suggests that the Basic Step is a reliable indicator for fall risk in older adults.

There are several limitations in this study. First, the Basic Step could not predict falling in older adults because this study was based on fall experiences within the previous year. It is possible that the fall experience report may have been incorrect, because the participants were required to accurately remember their fall experiences. Second, the test−retest reliability of the Ski Slalom is not highly reliable. Third, the experimental setup involved the negotiation of the "learning curve" of using the Wii Fit program. Thus, it remains unclear how long older adults practiced before being able to complete the demanded task. Fourth, the participants were probably more motivated and showed greater interest in health issues and risk of falls than the general elderly population.

Our recent studies have shown that specific exercises are effective at improving ambulatory function under DT conditions.[32,33] Future research should focus on the specific exercises that are effective at improving this function using the Basic Step. This is the first study to examine game-based fall risk assessment in older adults. The results suggest that game-based fall risk assessment using the Basic Step has a high generality and is useful in community-dwelling older adults. A score of 111 points on the Basic Step was considered the fall-related cutoff point. The simplicity and generality of the Basic Step permits the self-administration of fall risk assessment by nurses in nonclinical settings (e.g., while visiting homes).

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DUAL-TASK WALK IS A RELIABLE PREDICTOR OF FALLS IN ROBUST ELDERLY ADULTS

To the Editor: Falls are relatively common in elderly people, with approximately 30% of individuals aged 65 and older falling at least once a year and approximately half experiencing repeated falls.[1] In daily-life situations, locomotion occurs under complicated circumstances with cognitive attention focused on a particular task, such as watching traffic or reading street signs, rather than performing the specific motor task of walking. A seminal study demonstrating that the characteristic "stops walking when talking" could serve as a predictor of falls introduced a novel method for fall prediction based on dual-task (DT) performance.[2] Recently, a number of studies have evaluated DT walking in elderly people, but one found that reliable conclusions based on DT results for fall prediction cannot be made because of the lack of standardization in DT paradigms.[3] The aim of the current study was therefore to examine prospectively whether two kinds of DT walking (cognitive task (CT) and manual task (MT)) could predict the risk of falls in a community-dwelling elderly population according to physical function.

The study population consisted of 1,038 community-dwelling elderly Japanese people aged 65 and older (401 men, 637 women, mean age 77 ± 8) in 2009. Six items of physical function were assessed: single-task (ST) 10-m walking time, DT (CT and MT) 10-m walking time, Timed Up and Go (TUG) Test,[4] functional reach, and five-chair stand test (Table 1). In CT walking, participants walked 15 m at the most comfortable speed while counting numbers aloud in reverse order starting at 100. In MT walking, participants walked 15 m at the most comfortable speed while carrying a ball (7 cm in diameter, 150 g in weight) on a tray (17 cm in diameter, 50 g in weight). The DT cost (CT and MT) was then calculated as follows:

$$\text{DT cost}[\%] = 100 \times (\text{DT walking time} - \text{ST walking time}) / ((\text{ST walking time} + \text{DT walking time})/2)$$

Information on the incidence of falls during the following year was collected from participants in a monthly

Table 1. Characteristics of 1,038 Individuals Aged 65 to 97 According to Quartiles of Timed Up and Go Test Results (Seconds)

	Mean ± Standard Deviation							
	Fastest (≤ 8.3) (n = 230)		Faster (8.4–11.0) (n = 258)		Slower (11.1–14.9) (n = 264)		Slowest (≥ 15) (n = 286)	
Characteristic	Faller, 46 (20.0%)	Nonfaller,	Faller, 47 (18.2%)	Nonfaller	Faller, 90 (34.1%)	Nonfaller	Faller, 126 (44.1%)	Nonfaller
Age	77.9 ± 7.9	78.4 ± 6.6	77.4 ± 7.3	78.2 ± 8.0	77.5 ± 8.1	78.2 ± 8.8	77.6 ± 9.3	77.3 ± 8.3
Height, cm	154.4 ± 8.4	153.3 ± 6.8	156.5 ± 9.5	154.7 ± 9.4	157.6 ± 8.3	156.3 ± 11.1	153.6 ± 10.2	154.2 ± 9.6
Body, kg	55.6 ± 11.0	53.6 ± 8.3	50.1 ± 22.9	48.9 ± 16.8	51.7 ± 14.7	53.3 ± 9.3	50.4 ± 17.1	49.7 ± 26.1
Locomotive function, seconds*	9.6 ± 2.0	9.2 ± 2.0	10.5 ± 1.9	10.5 ± 2.5	11.4 ± 2.7	11.2 ± 3.6	17.5 ± 7.1	16.8 ± 7.3
Balance function, cm†	27.1 ± 5.5	25.0 ± 5.4	24.3 ± 7.2	22.6 ± 6.4	21.4 ± 7.9	21.6 ± 7.6	16.6 ± 7.0	18.6 ± 7.0
Muscle power, seconds‡	7.7 ± 1.7	7.5 ± 1.9	9.7 ± 2.8	9.9 ± 2.4	12.8 ± 4.7	11.4 ± 3.5§	17.4 ± 9.8	14.9 ± 5.9§
Cognitive task costs, %	18.7 ± 29.7	16.4 ± 25.5	21.8 ± 23.6	10.6 ± 19.1§	20.2 ± 17.2	20.1 ± 22.2	20.8 ± 20.9	23.1 ± 23.6
Manual task costs, %	8.5 ± 15.8	0.2 ± 11.0§	2.2 ± 14.0	5.8 ± 14.7	12.8 ± 14.0	14.5 ± 16.5	14.5 ± 19.7	16.3 ± 20.7

*Time to complete single-task 10-m walk.
†Distance of functional reach.
‡Time to complete five-chair stand.
§Independent variable that remained in the final step of the regression model.

telephone interview. A fall was defined as any event that led to unplanned, unexpected contact with a supporting surface during walking.

For analysis, the TUG test results were divided into quartiles (fastest, faster, slower, and slowest). A multivariate analysis using logistic regression with a stepwise-forward method was performed to investigate which of the five measures of physical function (ST walking time, CT cost, MT cost, functional reach, and five-chair stand test) was independently associated with falls.

In the fastest group (n = 230), the regression analysis indicated that the MT cost (odds ratio (OR) = 1.068, 95% confidence interval (CI) = 1.04–1.10, $P<.001$) was an independent predictor of falling that remained in the final step of the regression model. In the faster group (n = 258), the regression analysis indicated that the CT cost (OR = 1.03, 95% CI = 1.01–1.04, $P<.001$) was an independent predictor of falling. In the slower (n = 264) and slowest groups (n = 286), the five-chair stand test (slower group OR = 1.11, 95% CI = 1.03–1.19, $P<.001$; slowest group OR = 1.05, CI = 1.01–1.09, $P=.045$) was found to be an independent predictor of falling.

In conclusion, this study demonstrated that DT cost is an independent and prospective predictor of falls in elderly adults with higher functional capacity (faster and fastest groups), although DT cost did not predict falls in elderly adults with lower functional capacity (slower and slowest groups). Thus, the finding that DT walking is a reliable predictor of falls is limited to the robust elderly population.

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TAURINE DIURETIC AND RENAL-REVITALIZING EFFECTS IN NONAGENARIANS

To the Editor: Congestive heart failure (CHF) is the most ominous cause of edema in older adults living in extended-care nursing homes. Despite no obvious CHF, edema resistant even to diuretic doses that cause hypotension, especially in fragile nonagenarians, often develops, and an alternative was sought.

Long-term oral taurine (OT 3 g/d) ameliorates CHF,[1] so it was desired to determine whether OT (1.0 g three times per day) relieves edema without causing hypotension in nonagenarians. Forty-nine residents of an extended-care nursing home (20 taking antihypertensive therapy) who developed edema (score ≥ 2, Appendix A) despite hospital-prescribed diuretics or excessive hypotension precluding effective diuretic usage were enrolled from March 1, 2007, to March 31, 2010.

The remarkable effects of OT on edema were apparent within the first month of treatment (Figure 1A); decreases in body weight occurred with some delay. Required doses of diuretics decreased after institution of OT in the majority of residents. Serum albumin levels increased in 32 hypoalbuminemic residents (Figure 1B).

Significant increases were observed in estimated glomerular filtration rate (eGFR) expressed as a percentage of baseline values from 6 months to 2.25 years of treatment in residents with chronic kidney disease (CKD) Stage 3 or greater (Figure 1C, lower panel); the effects of OT were distinctly greater in residents with CKD Stage 3 or greater than in those with CKD Stage 2 or less (two-way analysis of variance $P<.001$), with differences reaching significance in the third year (Figure 1C upper panel; Bonferroni***). The hyperuricemia (≥ 8.6 mg/dL) observed in eight residents became normal in 6 to 9 months (Figure 1D).

Factors other than CHF play a significant pathogenic role in edema in older extended-care nursing home residents

Figure 1. (A) Effects of taurine are strongest on edema, significantly decreasing body weight. (B) Taurine increases albumin levels in patients with <3.8 g/dL at baseline. (C) Effects of taurine on renal function: Lower panel: taurine significantly increases estimated glomerular filtration rate (eGFR) in patients with chronic kidney disease (CKD) Stage 3 or greater when normalized to baseline values by the sixth month of treatment, and continues to improve significantly for up to 2.25 years. Upper panel: greater improvement of eGFR in residents with CKD Stage 3 or greater compared that in those with CKD Stage 2 of less (two-way analysis of variance $P<.001$) reaches significance after 3 years of treatment (Bonferroni***). (D) Taurine decreases hyperuricemia greater than 8.6 mg/dL to normal levels in 3 to 6 months. ANOVA = analysis of variance; SEM = standard error of the mean.

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Original article

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

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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.

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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 (β = −0.108, $p = 0.03$), gender (β = 0.255, $p < 0.001$), 10-m walk test (β = −0.202, $p < 0.001$) and single-leg standing (β = 0.306, $p < 0.001$) were

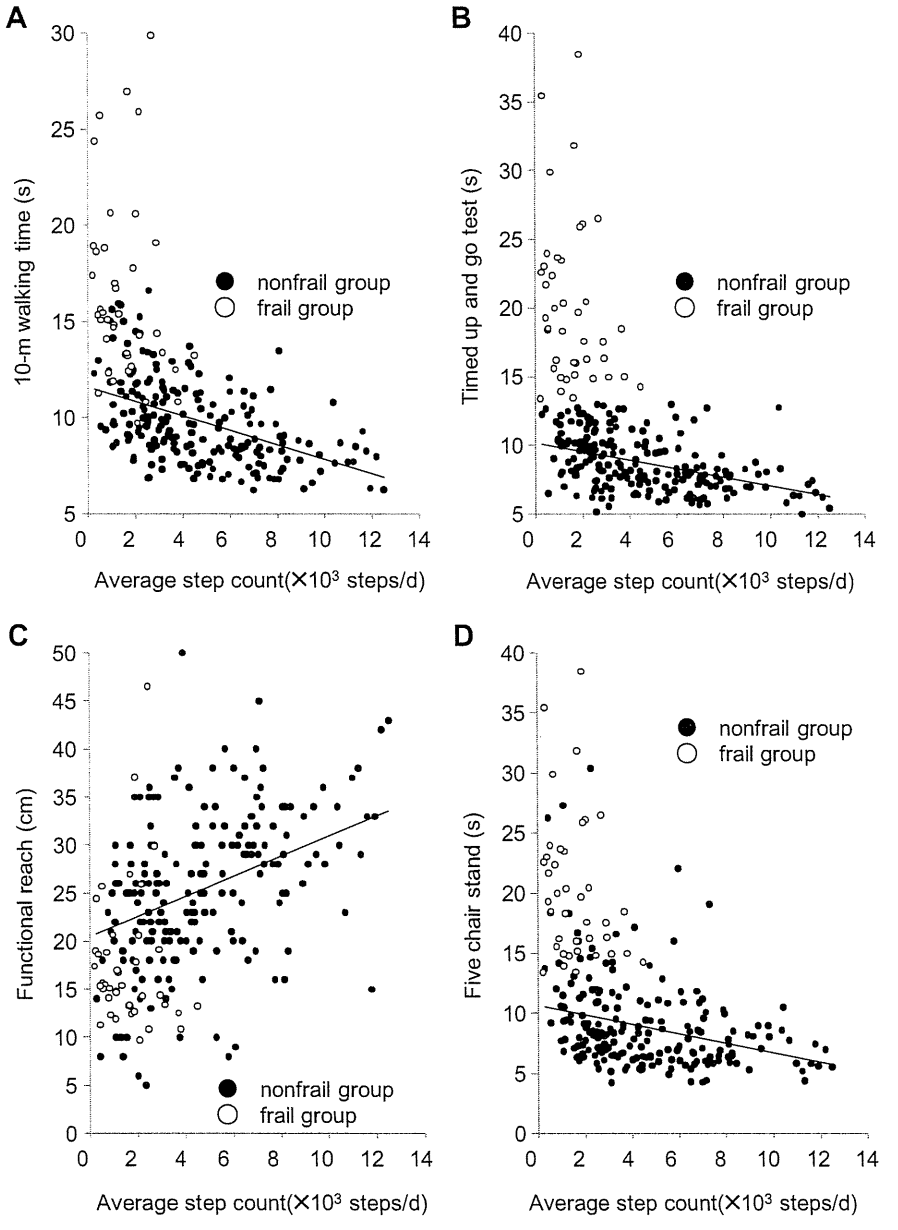

Fig. 1. Relationships between average daily steps and physical function. The physical function was associated with physical activities in nonfrail but not in frail elderly. (A) 10-m walk test; (B) Timed up and go test; (C) Functional reach; (D) Five-chair stand test.

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/m²)			
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.

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

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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.

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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.

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

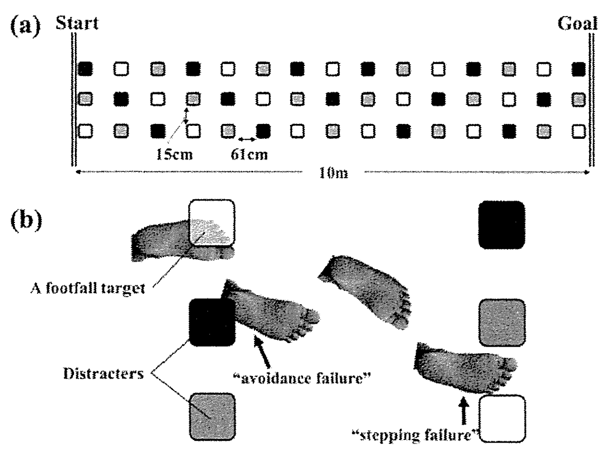

Figure 1. (a) The 10-m walkway used in the multitarget stepping task (MTST). Each square was made of red, blue, or yellow tape. (b) An example of the two types of failure measured in the MTST. A participant intends to step on footfall targets (displayed in white in this figure). The failure to step on 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.

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