under the dual-task condition ($p = 0.001$, $d = 0.99$), and that there was no statistical difference between groups under the single-task condition ($p = 0.67$, $d = 0.16$). Fallers had significant increases in the APA phase under the dual-task condition compared with the single-task condition ($p < 0.001$, $d = 1.2$), while there was no statistical difference between task conditions in Non-fallers ($p = 0.093$, $d = 0.33$).

4. Discussion

To our knowledge, this is the first study to focus on APA during gait initiation among older adults with FoF. No significant differences were observed between the No-fear and Fear groups in any clinical measurements (WT, TUG, and FR) or in the reaction or APA phases under the single-task condition; however, the Fear group showed significantly longer APA phases than the No-fear group under the dual-task condition. Thus, the experience of FoF may be associated with balance control during gait initiation while dual tasking even if there are no differences in basic characteristics and physical functions among individuals.

Dual tasking requires participants to divide their attention, which may interfere with gait and balance control [24]. Prolonged APA phase among the subjects in the Fear group might have been caused by dual-task interference between motor and cognitive tasks, because FoF may reduce the amount of attention resources available for gait and balance control [10]. Reelick et al. reported that FoF does not influence the ability to attend to a secondary cognitive task during steady-state gait [11]. Gait initiation is a transition phase, which requires voluntary motor control and more attention resource, while a steady-state gait is a highly automated movement [13,25]. FoF possibly affects a specific aspect of movement, which is challenging to the motor control system (i.e. gait or step initiation) of individuals, even if their physical functions are comparable to subjects without FoF.

In this study, FoF was associated with only the APA phase during gait initiation under the dual-task condition, but there was no difference in the reaction phase between the No-fear and Fear groups. In contrast, fall experience was associated with both the reaction phase and the APA phase. The reaction phase was defined as the time required for perception of the cue and recollection of the motor plan [26], while weight transfer is executed and the actual step is initiated during the APA phase [27]. Prolonged APA phase may be partly explained by an increase in the time for weight transfer towards the stance leg [28]. The time to release co-contraction of antagonistic muscles during standing may act to delay the APA before the actual movement [29]. Okada et al. reported that individuals with FoF show greater co-contraction under perturbed conditions [30]. The present study focused on voluntary movement and suggest that FoF might affect postural synergy (i.e. weak response of the gluteus medius on the stepping side, co-contraction of antagonistic muscles), which causes non-smooth weight transfer in the Fear group. While FoF appears to be associated with prolonged APA during gait initiation under dual-task conditions, a history of falls appears to be associated with both prolonged processing time and prolonged APA.

Previous studies infer that FoF may lead to unnecessary avoidance of activities [7,8], which could be the start of a downward spiral leading to social isolation, deconditioning, increased risk of falling, and a further increase of FoF [31]. Gait initiation is frequently repeated during daily activities, and the transition phase of movement subjects individuals to accidental falls [12]. The extended APA phase, which may result from specific deficits in balance control during gait initiation while dual tasking (i.e. non-smooth weight transfer), may contribute to a high risk of falling among older adults with FoF. In contrast, the extended APA phase is also interpreted as an attempt at stabilisation in order to reduce the risk of falling in older adults with FoF. As with other cross-sectional studies, the design of the current study limits the interpretation of the results with regard to causality between FoF and prolonged APA during gait initiation. A longitudinal study may be useful in examining the causal relationship between FoF, gait initiation parameters and prospective falls in older adults.

In conclusion, we demonstrated that subjects with FoF have a significantly longer APA phase during gait initiation under the dual-task condition than those without FoF. The present study is the first to evaluate the association between this psychological factor and the balance control ability during gait initiation in daily activities. The major implication of our findings is that specific deficits in balance control, which prolongs the APA phase, occur in subjects with FoF during gait initiation while dual tasking, even if their physical functions are comparable to subjects without FoF. Further research is needed to clarify the causal relationship between FoF, gait initiation parameters and prospective falls in older adults.

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Conflicts of interest statement

None of the authors have any conflicts of interest associated with this study. We have no financial affiliations and/or involvement with any commercial organization.

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Older Adults At High Risk of Falling Need More Time for Anticipatory Postural Adjustment in the Precrossing Phase of Obstacle Negotiation

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Background. Obstacles are a common cause of falls among older adults. Anticipatory motor planning for obstacle negotiation must be completed during the precrossing phase in order to step over the obstacle safely. This cognitive load may affect anticipatory postural adjustments (APAs) in older adults at high risk of falling. This study explored the effect of obstacle negotiation on APA during gait initiation in older adults at high risk of falling.

Methods. Seventy-six elderly volunteers (mean age: 80.5 [7.6 years]) from the community participated in this study. Participants performed gait initiation tasks from a starting position on a force platform under the following two conditions: (1) unobstructed (smooth walkway) and (2) obstructed (walkway with an obstacle placed at 1 m from the initial position). The reaction and APA phases were measured from the data of center of pressure. Each participant was categorized as a high-risk or a low-risk individual according to the presence or absence of a fall experience within the past year.

Results. High-risk participants had significantly longer APA phases than low-risk participants under the obstructed condition even though there was no significant difference between groups under the unobstructed condition. Reaction phase was not significantly different between groups in either the unobstructed or the obstructed condition.

Conclusion. Motor performance deterioration occurred in high-risk participants in the beginning of the precrossing phase of obstacle negotiation. A slow and inefficient APA at the precrossing phase of obstacle negotiation might be one of the causes of accidental falls.

Key Words: Accidental fall—Rehabilitation—Postural control.

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IN the elderly population, trip is a common cause of falls and contributes to approximately 35%–53% of all falls (1–3); a large number of falls are reportedly caused by stepping on or tripping over obstacles (4,5). Trip-related falls are specifically responsible for 12%–22% of hip fractures suffered by older adults. There is, therefore, a need for effective interventions to reduce the incidence of trip-related falls in older adults.

Obstacle negotiation appears to stress the availability of cognitive resources, particularly among older adults. This finding is based on previous work demonstrating that successful obstacle crossing was compromised when participants were required to concurrently perform a cognitively demanding task (4,5). Obstacle negotiation, from the precrossing phase, is attentionally demanding due to the need for motor planning and visually dependent gait regulation (6,7). From these reports, the possibility of motor performance deterioration may precede the obstacle crossing event. However, other reports on obstacle negotiation examined only the crossing phase (ie, obstacle clearance, foot placement) (8–10), and no reports have focused on anticipatory postural adjustment (APA) during the precrossing phase of obstacle negotiation. In addition, few studies have examined the pattern of postural activity during obstacle negotiation in the older adults who are at a high risk of falling.

Many older adults fall while walking only short distances (11), suggesting that they have difficulty in balance control during the transition phase, including gait initiation and termination, which are frequently repeated during daily activities. It is considered that gait initiation requires more attentional resources than does steady-state walking (12,13). It is therefore necessary to clarify the postural control strategies employed by older adults at a high risk of falling in order to examine the gait initiation task. Gait initiation with motor planning for obstacle negotiation may demand high levels of attention and cause dual-task interference for older adults with attention allocation deficits.

Anticipatory motor planning for obstacle negotiation (eg, change of foot placement and obstacle clearance) may be the key component of successful obstacle crossing. The goal of this study was to clarify motor performance deterioration specific to the older adults at a high risk of falling during obstacle negotiation, particularly in the precrossing phase. The present study compared APA during gait initiation under unobstructed and obstructed (with an obstacle placed anteriorly) conditions in older adults who were or were not at high risk of falling. We hypothesized that APA will be affected by motor planning for obstacle negotiation in older adults with a high risk of falling.

Methods

Participants

Seventy-six older adults (mean age [*SD*], 80.4 [7.0 years]; height, 155.1 [9.9 cm]; weight, 54.7 [10.9 kg]) participated in this study. Volunteer participants were recruited from the community through advertisements in various local papers. Because approximately one third of people more than 65 years of age in the community experience a fall each year (14), we selected this convenient sample for investigation. Inclusion criteria consisted of age ≥65 years, minimal hearing and visual impairments, and the ability to ambulate at least 10 m without the assistance of another person (cane permitted but not a walker).

Exclusion criteria were as follows: inability to see an obstacle or visual cue used during the experiment due to a visual impairment not correctable with glasses; severe cardiac, pulmonary, or musculoskeletal disorders; pathologies associated with an increased risk of falling (ie, Parkinson's disease); use of psychotropic drugs; and the inability to follow multiple commands given by a physical therapist (eg, inability to perceive light-emitting diode [LED] illumination as a cue). Written informed consent was obtained from all 76 older adults included in the trial in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine (approval number: E-809) and the Declaration of Human Rights, Helsinki, 1975.

Our sample size estimation was based on work by Melzer and colleagues (15) who showed that step execution (foot contact times) during the execution of a cognitive task was 1,414 ± 417 ms for elderly fallers. In their study, the foot contact time of all 11 elderly fallers was 1,050 ms or higher. Using the earlier values for a two-sided estimate at a significance level of 0.05 and 80% power, at least 22 participants are required to detect a significant change in foot contact from 1,414 to 1,050 ms.

Falls were assessed using the item "Have you fallen in the last year?" with two response categories (yes/no) (3). Each participant was categorized as being a high-risk (HR) or a low-risk (LR) elderly individual according to the presence or absence of a fall experience within the past year. (16). A fall was defined as an event that results in a person unintentionally coming to rest on the ground or any other lower level with or without injury or loss of consciousness (17). We specifically explained the definition of "fall" to the participants so that they could report falls correctly. If they were unclear as to whether they had experienced a fall, we consulted their families to verify the occurrence of a fall. The number, characteristics, and consequences of falls were recorded using a standardized questionnaire. Falls resulting from extraordinary environmental factors (eg, traffic accidents and falls while riding a bicycle) were excluded.

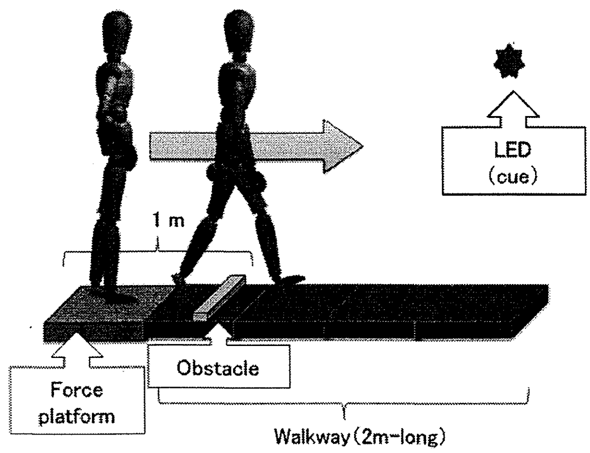

Figure 1. Schematic representation of the gait initiation test under the obstructed condition. Each participant initially stood upright on a force platform. Participants were instructed to execute the first step as quickly as possible after a visual cue. The obstacle was placed at 1 m from the initial position.

We recorded the following demographic and medical variables: the number of drugs used, mental status (Rapid Dementia Screening Test (18)), and fear of falling (a modified Fall Efficacy Scale [FES] (19)). The total score for the modified FES can range from 10 to 40, with low scores indicating greater confidence.

Experimental Protocol

Participants initially stood upright on a force platform and loaded their weight evenly on both legs with their feet abducted 10° and their heels separated mediolaterally by 6 cm. In the gait initiation task (Figure 1), participants were instructed to execute a first step using the self-selected leg as quickly as possible after a visual cue of LED illumination and to continue walking for several steps on the 2-m walkway. An LED was set 2.5 m in front of the participants at eye level. The test was performed under two different conditions: (1) unobstructed (normal gait initiation on the smooth walkway) and (2) obstructed (gait initiation on walkway with an obstacle placed 1 m from the initial position). Under both conditions, participants were made to gaze at the LED in the initial position and were allowed to see the floor and an obstacle after the visual cue of the LED. The obstacle was wooden and white (91.0 cm wide × 2.4 cm high × 1.0 cm deep). The walkway floor was dark brown. The obstacle location in the present study was defined as being 1 m from the initial position because it is a length the older adults could not step over in the first step and would instead initiate anticipatory motor planning, which demands attention during gait initiation on the force platform. It is reported that the average first-step length during gait initiation is 52.5 cm in healthy older adults (mean age: 73 years) (16). If an obstacle were placed directly ahead, anticipatory motor planning during gait initiation would demand little attention because participants would know that they could cross the obstacle by the first step. Researchers made the participants check the location of the obstacle before the trial and instructed them to step over the obstacle. The number of steps to the obstacle crossing was arbitrarily prescribed. The obstacle would tip with a small external force, so it was expected that the risk of accidental falling by tripping was minimal. The order of the tasks was randomized. Before the experimental data were collected, the participants performed at least three trials to familiarize themselves with equipment, gait initiation task (except for the obstacle), and conditions.

All participants underwent three clinical measurements—a 10-m walking test (WT) (20), a timed up and go test (TUG) (21), and a functional reach (FR) test (22)—in the presence of an experienced physiotherapist.

In the WT, steady-state walking time (seconds) at a self-selected pace on a 10 m–long straight walkway was measured. Walking time was calculated using a stopwatch to measure the time taken to cover the central 10 m of the walkway (2 m at the start and finish were used for acceleration and deceleration). A WT score was calculated as the average time in seconds for completion of two trials.

In the TUG test, 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 was stopped when the participant's back touched the chair backrest. The data of the second TUG trial were used for analyses.

In the FR test, each participant was positioned next to a wall with one arm raised at 90° and 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. In this trial, participants used both arms. An FR score was calculated as the average distance (centimeters) between the initial and final fingertip positions of the middle finger obtained from each of two trials.

Data Collection and Analysis

Center of pressure (COP) data during gait initiation tests were collected with a portable Kister 9286 Force Platform (Kistler Instrument Corp., Winterthur, Switzerland). The

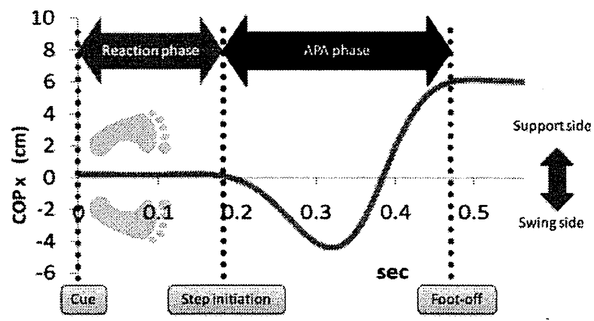

Figure 2. An example of gait initiation data. The following events are marked: onset of the visual cue (cue), the first mediolateral deviation of the center of pressure (COP) toward the swing leg (step initiation), and the end of the mediolateral shift of the COP toward the stance leg (foot-off). See text for further details.

force platform data were sampled at a frequency of 1 kHz and low-pass filtered at 6 Hz. The analysis of gait initiation data extracted specific temporal events using a program written in MATLAB (MathWorks, Inc., Cambridge, MA). The following events were extracted from the COP data: (i) Step initiation was defined as the first mediolateral deviation of the COP toward the swing leg (COP excursion >3 *SD* away from the initial COP position defined as the mean amplitude in the 1,500-ms period prior to the onset of the visual cue) (23) and (ii) foot-off was defined as the end of the mediolateral shift of the COP toward the stance leg (absolute COP slope <100 mm/s, two samples in a row) (15). The reaction phase was calculated as the time from cue to step initiation. The APA phase was calculated as the time from step initiation to foot-off (Figure 2). The means and standard deviations were determined using data from three trials.

Statistical Analysis

For each parameter, the mean dependent variables were calculated by SPSS II (SPSS, Inc., Chicago, IL) using a two-way analysis of variance that included groups (HR and LR) as the between-subjects factor with repeated measures on the within-subjects factors of tasks (unobstructed and obstructed). A probability of $p < .05$ was considered statistically significant. When interaction effects were detected, Bonferroni post hoc comparisons were performed to assess group and task differences. The significance level of the multiple comparisons was adjusted by the Bonferroni correction ($p < .0125$). Student's t test for independent measures was used to evaluate the differences between fallers and nonfallers in the WT, TUG, and FR tests. Partial η^2 and Cohen's d values were calculated as measures of effect size.

To assess the predictive abilities of the gait initiation measures and whether the relationship between these measures and fall risk persisted in multivariate analyses after adjusting for confounding effects, logistic regression analysis, performed as an enter analysis, was carried out. In this analysis, HR and LR were used as the dependent variables,

Table 1. Participant Characteristics

	HR (n = 26)	LR (n = 50)	p Value
Age (y)	81.6 [7.3] (65–95 y)	79.7 [6.9] (65–93 y)	.32
Height (cm)	156.7 [11.0]	155.6 [9.0]	.41
Weight (kg)	57.9 [11.8]	54.2 [10.3]	.29
Gender (% males)	34.6%	34%	.96[a]
No. of medications	7.0 [4.7]	4.7 [4.7]	.09
RDST	5.3 [3.2]	5.4 [3.1]	.95
FES	17.7 [6.0]	13.9 [5.8]	.01
WT (s)	13.8 [5.9]	11.9 [4.7]	.14
TUG (s)	15.2 [6.3]	11.2 [4.6]	.013
FR (cm)	18.1 [10.4]	21.1 [5.7]	.13

Notes: FES = Fall Efficacy Scale; FR = functional reach test; HR = high-risk elderly individual; LR = low-risk elderly individual; RDST = Rapid Dementia Screening Test; TUG = timed up and go test; WT = walking test. Values are shown as mean [*SD*].

*p values are based on t test or chi-square.

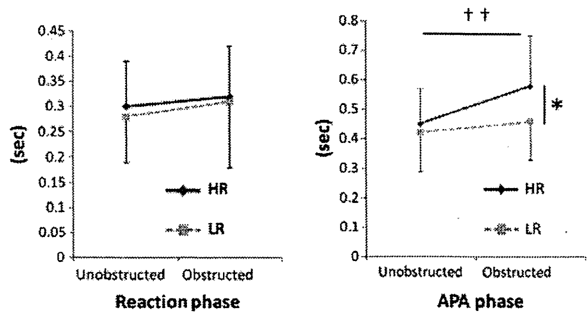

Figure 3. Average measurement parameters for both groups of participants in unobstructed and obstructed conditions. *Significant difference between high-risk (HR) and low-risk (LR) participants in the individual task condition (Bonferroni, $p < .0125$). ††Significant difference between unobstructed and obstructed conditions in individual groups (Bonferroni, $p < .0025$).

and gait initiation measures (the reaction and APA phase, under the obstructed and unobstructed conditions), WT, TUG, FR, FES, and the number of drugs used were employed as independent variables.

Results

Participant Characteristics

Of the 76 participants aged 65–96 years who participated in the study, 26 (34%) were classified as HR (one or more falls) and 50 (66%) were classified as LR in terms of events over the past year. Table 1 shows the demographic and medical variables and performance characteristics of the 76 participants and the differences in performance test scores between HR and LR. There were no significant differences in age, height, weight, gender, number of medications, or Rapid Dementia Screening Test score between the groups. HR, however, showed a higher score in the FES than LR (p = .01). In clinical measurements, no significant differences were detected in the WT (p = .14, d = .37) or FR (p = .13, d = 0.40) tests. In the TUG test, HR participants had significantly slower times than LR participants (p = .013, d = 0.67).

Performance of Gait Initiation Test

There were no unsuccessful crossings or obstacle contacts recorded in this study. Table 2 depicts all variables for HR and LR participants in the individual task condition.

No interaction effects between group and task conditions were detected in the reaction phase; p = .65, $F(1,74) = 0.21$, $\eta^2 = 0.003$; Figure 3. There was a significant main effect of the task condition; p = .031, $F(1,74) = 4.82$, $\eta^2 = 0.061$; whereas there was no significant group effect; p = .51, $F(1,74) = 1.95$, $\eta^2 = 0.027$.

Interaction effects between group and task condition were detected in the APA phase; p = .025, $F(1,74) = 5.25$, $\eta^2 = 0.066$; Figure 3. There were significant main effects of task condition; $p < .001$, $F(1,74) = 24.7$, $\eta^2 = 0.25$; and group; p = .04, $F(1,74) = 4.35$, $\eta^2 = 0.056$. The main effect was qualified by the interaction. Post hoc comparison showed that the APA phases of the HR participants were significantly longer than those of the LR participants under the obstructed condition (HR: 0.58 [0.17] seconds; LR: 0.46 [0.13] seconds; p = .008, d = 0.84) and that there was no statistical difference between groups under the unobstructed condition (HR: 0.45 [0.12] seconds, LR: 0.42 [0.13] seconds; p = .36, d = 0.25). HR participants had significant delays in the APA phase under the obstructed condition compared with the unobstructed condition ($p < .0025$, d = 0.88), whereas there was no statistical difference between task conditions in LR participants (p = .025, d = 0.31).

The data of the gait initiation measures (the reaction and APA phase, under the obstructed and unobstructed conditions), WT, TUG, FR, FES, and the number of drugs used were entered in the logistic regression models by using enter analysis. The APA phase under the obstructed condition was the only independent variable that persisted in the final

Table 2. Two-Way Repeated Measures Analysis of Variance Findings on Measurement Parameters

	Unobstructed		Obstructed		Interaction		
	HR	LR	HR	LR	F Value	p Value	η^2
Reaction phase, s	0.30 (0.09)	0.28 (0.09)	0.32 (0.10)	0.31 (0.13)	0.21	.65	0.003
APA phase, s	0.45 (0.12)	0.42 (0.13)	0.58 (0.17)*	0.46 (0.13)†	5.25	.025	0.066

Notes: Values are shown as mean (*SD*). HR = high risk; LR = low risk.

* Significant difference between unobstructed and obstructed condition in individual groups (Bonferroni, $p < .0025$).

† Significant difference between HR and LR participants in individual task condition (Bonferroni, $p < .0125$).

step of the regression model after adjusting for confounding effects ($p = .036$, odds ratio = 1453.1). The model was well calibrated between deciles of observed and expected risk (Hosmer–Lemeshow $\chi^2 = 6.4$, $p = .60$).

Discussion

No significant differences were observed between HR and LR participants in the reaction or APA phases under the unobstructed condition. This indicates that HR and LR individuals use the same motor program in normal gait initiation on the smooth walkway. In the present study, even HR participants might have sufficient ability to perform a gait initiation task on a smooth walkway as successfully as LR participants because it requires little anticipatory motor planning.

On the other hand, HR participants had significantly longer APA phases than LR participants under the obstructed condition. During the precrossing phase, specific deterioration of motor performance in HR participants arose from the anteriorly placed obstacle. The precrossing phase of obstacle negotiation is a visually guided process (24), and it is thought that visually dependent regulation of gait incurs an additional attention cost (6,7). Greanyand colleagues (25) reported that elderly community dwellers at high risk of falling demonstrate longer saccade-footlift latency during the crossing phase than those at low risk of falling and that the delay may be attributed to the greater central nervous system processing time necessary to plan precise foot placement. It is also likely that delayed central cognitive processing can cause an increase in preparation (ie, APA) phase duration for which older adults may need more time to plan an anticipatory control strategy (26,27). We focused on the beginning of the precrossing phase and suggest that prolonged APA phases (ie, weight transfer to the stance limb for safe stepping) under the obstructed condition in HR participants may be associated with the delay in central processing time for developing a motor plan from visual anchors in the working memory.

In the reaction phase, no interaction effects between group and task conditions were detected. The reaction phase was defined as the time required for perception of the cue and recollection of the motor plan (28). Secondary cognitive tasks prolong the reaction phase of step initiation, particularly in HR individuals (15). In the present study, even HR participants could focus all their attention on a visual cue because participants were not instructed to perform a secondary task while awaiting a cue.

Logistic regression analysis revealed that the prolonged APA phase observed under the obstructed condition was associated with a fall risk after adjusting for confounding effects. In addition, effect size (Cohen's d) for the difference in the duration of the APA phase under the obstructed condition between HR and LR was the largest among the variables measured in the present study. Therefore, the prolonged APA phase observed under the obstructed condition in HR participants may be one of the reasons why some older adults fall or trip more frequently than others when walking in situations in which precise foot placement is required, such as obstacle negotiation. The movement of the stepping leg during gait initiation is preceded by APA serving to shift the center of mass toward the supporting side so that the leg can be raised (23). Cognitive load, such as motor planning for obstacle negotiation, might cause the affected postural synergy (ie, weak response of the gluteus medius on the stepping side, cocontraction of antagonistic muscles) that makes center of mass movement nonsmooth in HR participants.

Obstacle negotiation necessitates modifications to the gait pattern that occur at least two steps prior to stepping over (29). Impairment of motor planning and gait regulation for obstacle negotiation may be one of the causes for trips or falls. Rehabilitation strategies that correct not only the obstacle crossing but also the cognitive process and the APA phase during the precrossing phase would be potentially beneficial for fall prevention in older adults.

The major limitation of this study is that prolonged APA during the precrossing phase could not be used to predict falling in older adults. This is because the study was based on fall experiences within the past year. It is therefore necessary to examine the validity of the predictions by investigating the occurrence of falls prospectively. Second, the reason why the time for APA increased in HR remains unclear. In order to clarify this, we need to investigate the association between prolonged APA and various cognitive functions (eg, working memory and planning). Third, we did not report data on obstacle clearance and foot placement during obstacle crossing. However, by focusing on the APA phase of the precrossing phase, we revealed specific deterioration of motor performance in older adults who are at high risk of falling during obstacle negotiation.

In conclusion, we demonstrated a significantly longer APA phase in HR participants during gait initiation under the obstructed condition. The present study is the first to investigate postural activity during the precrossing phase of obstacle negotiation. The major implication of our findings is that specific deterioration of motor performance occurs in HR individuals in the beginning of the precrossing phase of obstacle negotiation. Insufficient central processing capacity for motor planning and gait regulation may be one of the causes of trip-related falls in older adults.

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ORIGINAL ARTICLE

Complex obstacle negotiation exercise can prevent falls in community-dwelling elderly Japanese aged 75 years and older

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Objectives: The aim of the present study was to evaluate whether a complex course obstacle negotiation exercise (CC), a 24-week exercise program, can reduce falls and fractures in older adults, as compared with a simple course obstacle negotiation exercise (SC).

Methods: This trial was carried out on older adults, aged 75 years and above in Japan. In total, 157 participants were randomized into the CC group ($n = 78$) and the SC group ($n = 79$). Participants were enrolled in the exercise class using the CC program or the SC program for 24 weeks. The outcome measure was the number of falls and fracture rates in CC and SC groups for 12 months after the completion of the 24-week exercise class.

Results: Two participants (2.8%) in the CC group and 19 (26.0%) in the SC group experienced falls during 12 months. During the 12-month follow-up period after the intervention, the incidence rate ratio (IRR) of falls in the SC group against the CC group was 9.37 (95% CI = 2.26–38.77). One participant (1.4%) in the CC group and eight (10.9%) in the SC group had experienced fractures during 12 months after the exercise class. The IRR of fractures in the SC group compared with the CC group was 7.89 (95% CI = 1.01–61.49).

Conclusions: The results of the present trial show that the participants who received individualized obstacle avoidance training under complex tasks combined with a traditional intervention had a lower incidence rate of falls and fractures during the 12 months after the intervention. **Geriatr Gerontol Int 2011; ••: ••–••.**

Keywords: fall prevention, obstacle negotiation exercise, older adults, randomized controlled trial.

Introduction

Falls are relatively common events in older people. One-third of community-dwelling people, aged 65 years and older, and up to 50% of those aged 80 years and older experience a fall each year.[1,2] A previous study also reported that in community-dwelling elderly individuals, over 50% of the falls are a result of trips and slips that usually occur during walking.[3] In many of these cases, there is an external factor, such as an obstacle, that provokes and contributes to the fall.[4] In addition, the incidence of osteoporotic fractures is reported to increase with age,[5] and more than 50% of all fragility fractures in the community arise in women aged 75 years and older.[6] A recent systematic review of fall prevention programs has convincingly shown that exercise interventions are effective for reducing the risk of

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falls and fall injuries.[7,8] However, the kind of exercise intervention most effective for fall prevention is not fully addressed.

Concurrent cognitive or motor tasks, such as talking or carrying objects, are crucial for mobility in daily life. Because of the increasingly recognized role of cognition in postural control and gait, many researchers have used complex task paradigms incorporating a concurrent cognitive task to improve their studies investigating fall risk.[9] Changes in performance during multitasking are significantly associated with an increased risk for falls in older adults.[9] The ability to modulate attention might also play an important role in the acquisition of complex task coordination skills. Therefore, we developed a trail walking exercise (TWE), in which a person walks from numbered flags in either an ascending or descending order, to evaluate cognitive and motor function simultaneously.[10] Our previous randomized controlled trial (RCT) showed that TWE has the benefit of decreasing the incidence of falls in community-dwelling elderly adults.

In everyday life, when walking in a challenging and distracting environment, older people might have to avoid ground level obstacles when their attention is divided. In this instance, obstacle-avoidance performance is likely to be further impaired, as shown by most multitask research among older adults.[11–13] In addition, Jasmine *et al.* reported that when their attention is divided, older people negotiate obstacles more slowly and contact more obstacles.[14] Therefore, in the present study, we added obstacles to the area of TWE (complex course obstacle negotiation) to mimic a "real world" walking environment with a high fall risk.

The present RCT examined the effect of fall and fall-related fracture prevention programs on attention demands of obstacles during walking under complex task conditions in community-dwelling elderly Japanese adults aged 75 years and older. The aim of the present study was to evaluate whether the complex course obstacle negotiation exercise (CC), a new 24-week exercise program, would be effective in reducing falls and fall-related fractures in community-dwelling older adults. We hypothesized that complex task walking is improved to a greater extent with the CC program than with the simple course obstacle negotiation exercise (SC). From these results, we can assume that the CC program is more effective in preventing falls and fall-related fractures than is the SC program.

Methods

Participants

Participants were recruited using an advertisement in the local press. The following criteria were used to screen participants in an initial interview: age 75 years and older, community-dwelling, had visited a primary care physician within the past 3 years, had no severe cognitive impairment (Rapid Dementia Screening Test [RDST] score of 4 or less),[15] can walk independently (or with a cane), willingness to participate in group exercise classes for at least 6 months, has access to transportation, has no significant hearing and vision impairments, and had no regular exercise in the past 12 months.

The interview was also used to exclude participants based on the following exclusion criteria: severe cardiac, pulmonary or musculoskeletal disorders; comorbidities associated with greater risk of falls, such as Parkinson disease and stroke; and use of psychotropic drugs. Written informed consent was obtained from each participant for the trial in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1975.

Study design and randomization

Participants were randomized into two groups. Opaque envelopes bearing group names were numbered and the 157 participants were then randomly assigned to either the CC ($n = 78$) or SC ($n = 79$) group.

Intervention

All participants received 45 min of group training sessions once a week for 24 weeks. Participants were randomly assigned to one of the two training groups: standardized training with CC and standardized training with SC.

The exercise class was individualized for each group and supervised by a physiotherapist. Each exercise class used a standardized format that included 10 min of moderate-intensity aerobic exercise, 15 min of progressive strength training, 10 min of flexibility and balance exercises, and 10 min of cool-down activities. The aerobic exercise consisted of movement of the legs, trunk and arms to involve all joints and major muscle groups in activities, such as dancing. Strength training consisted of progressive resistive exercises using an elastic band. A sequence of progressively more difficult exercises was also carried out to improve static and dynamic balance. Although exercises could be carried out in a sitting position, the importance of carrying the exercises out in a standing position to improve balance was stressed. Physiotherapists evaluated the participants twice during the study period to ensure adherence with exercise protocols during classes.

Complex course with obstacle negotiation exercise

In the CC training field, the flags and obstacles were positioned as shown in Figure 1.[10] Flags were randomly

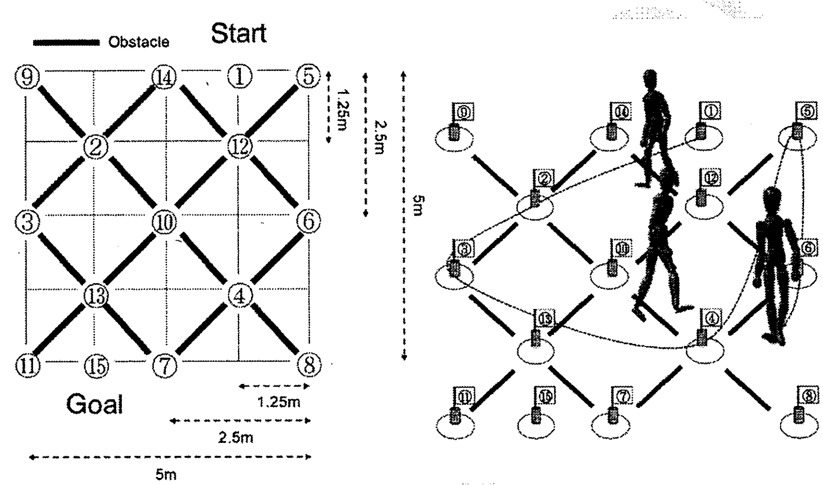

Figure 1 Schematic representation of the complex course obstacle negotiation exercise. Participants were asked to pass sequentially from numbers 1 to 15 as quickly and as correctly as possible during obstacle avoidance.

moved for each trial. Participants in the CC group were asked to sequentially pass from number 1 to 15 while avoiding the obstacles (Fig. 1). A 30-cm diameter circle was drawn on the ground around each flag, and the participants were required to step in the circle to pass the flag. The height of the flag was 30 cm. The tester gave the following instructions to participants, "Please move to flag number 15 as quickly and correctly as possible while avoiding obstacles". Throughout the weeks, the obstacles were made increasingly more difficult for participants to notice. The obstacles consisted of 16 wooden white (contrasting the floor colour) blocks (3, 100 and 1 cm in height, length and width, respectively) in weeks 1–6, wooden black blocks (2, 100 and 1 cm in height, width and depth, respectively) in weeks 7–12, wooden dark brown blocks (1, 100 and 1 cm in height, length and width, respectively) in weeks 13–18 and wooden brown (matching the floor colour) blocks (0.5, 100 and 1 cm in height, length and width, respectively) in weeks 19–24. Flag and obstacle positions were changed on each day of training. Participants carried out two sets of the CC program per training session.

Simple course with obstacle negotiation exercise

Participants were asked to walk along a walkway at a self-selected speed and to avoid contact with the obstacles. These sessions were designed as controls for the additional physical activity in the CC session. Participants walked along a level walkway, 15 m in length. The obstacles used in the simple course were as follows: six wooden white (contrasting the floor colour) blocks (3, 100 and 1 cm in height, length and width, respectively) in weeks 1–6, wooden black blocks (2, 100 and 1 cm in height, length and width, respectively) in weeks 7–12, wooden dark brown blocks (1, 100 and 1 cm in height, width and depth, respectively) in weeks 13–18, wooden brown (matching the floor colour) blocks (0.5, 100 and 1 cm in height, length and width, respectively) in weeks 19–24. These obstacles were placed across the walkway at intervals randomly ranging from 30 to 150 cm for each day of training. Each participant carried out six walking trials.

Falls and fall-related fractures

The primary outcome of this trial was the occurrence of falls and fall-related fractures during the follow-up period of 12 months after the intervention was completed. Falls were defined as all situations in which a participant suddenly and involuntarily came to rest on the ground or at a surface lower than their original station.[16] Falls resulting from extraordinary environmental factors (e.g. traffic accidents or falls while riding a bicycle) were excluded. The participants were asked to record any falls in fall diaries mailed every month by research assistants. If participants failed to send the fall diaries, research assistants collected data on falls over the telephone. All participants who had fallen were interviewed during these calls using a structured questionnaire about a fall event and its consequences. The diagnosis of fractures was based on radiological evidence of fracture.

Secondary outcome measures

For all participants, the following six measurements were obtained: 10-m walking time,[17] the timed up and go (TUG) test,[18] the functional reach (FR) test,[19] the one-leg stand (OLS) test,[20] the SC test, and the CC test. A physiotherapist blinded to group allocation administered these measures at baseline, on completion of the 24-week intervention. All baseline measures were completed before randomization. Before the study started, all staff members received training on correct protocols for administering all assessment measures included in the study from one of the authors (MY). If a walking aid was normally used at home, this aid was used during the TUG test, 10-m walking, SC test and CC test.

In the 10-m walking, participants walked 15 m at a speed at which they felt comfortable. A stopwatch was used to record the time required to reach the 10 m point that was marked in the middle of this walk. The time recorded in two trials was averaged as the walking score.

In the TUG test, 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 maximum pace, turn, walk back to the chair, and sit down. The time recorded from two trials was averaged to obtain the TUG score.

In the FR test, each participant was positioned next to a wall with one arm raised at 90° and fingers extended. A meter stick 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 centimetres according to the position of the tip of the third finger against the mounted meter stick. The distances measured in two trials were averaged to obtain the FR score.

In the OLS test, participants were instructed to start from a standing position with a comfortable base as support with eyes open and arms at their sides. They were then instructed to stand unassisted on either leg. OLS was measured in seconds from the time one foot was lifted from the floor to when it touched the ground or the standing leg.

In the SC test, participants were asked to walk along the walkway at a self-selected speed and to avoid contact with the obstacles. Participants walked along a level walkway, 10 m in length. The simple course consisted of six wooden white (contrasting the floor colour) blocks (3, 100 and 1 cm in height, length and width, respectively). These obstacles were placed across the walkway at intervals of 2 m. Time to complete each walking trial was recorded using a stopwatch. The number of obstacles contacted was recorded. The SC test was carried out only once for each participant at each time-point.

In the CC test, the field test was the same as that used for the CC exercise (Fig. 1). The complex course consisted of 16 wooden white (contrasting the floor colour) blocks (3, 100 and 1 cm in height, length and width, respectively). The test–retest reliability using the intraclass correlation coefficient was 0.935. The positions in which the flags and obstacles were placed are shown in Figure 1. The tester gave the following instruction to the participants: "Please move to number 15 as quickly and as correctly as possible while avoiding obstacles". Time to complete each walking trial was recorded using a stopwatch. The number of obstacles contacted was recorded. The CC test was carried out only once for each participant at each time-point.

Required sample size

A previous study showed that approximately 30% of the Japanese community-dwelling adults, 65 years of age or older, fall at least once a year. This result was consistent with a previous report.[2] We designed the current study to detect a 30% difference in fall rate between the groups (CC group = 10% and SC group = 30%), for which a sample size of 72 per group ($\alpha = 0.05$ and power = 80%) was necessary. With an estimated dropout rate of 5%, a final sample size of 76 per group was required.

Statistical analysis

Baseline characteristics of CC and SC groups were compared to examine the comparability of the two groups. Differences in the physical function variables between the two groups were analyzed using the Student's t-test or χ^2-test.

The number of falls and fall-related fractures was calculated from the beginning of the study to the participant's death, withdrawal from the trial or the end of the 12-month follow-up period. Confidence intervals (CI) for the falls and fall-related fracture rates were calculated assuming that the number of falls and fall-related fractures followed a negative binomial distribution. Incidences of falls and fall-related fractures with 95% CI were calculated for participants in the CC and SC groups, and compared using negative binomial regression analysis. Results were presented using incident rate ratios (IRR) with their 95% CI. The effect of exercise on outcome measurements was analyzed using a mixed 2 × 2 (group [CC and SC groups] × time [pre-training, post-training]) analysis of variance. Post-hoc Tukey tests were used to assess which group or time periods showed significant differences.

Data were entered and analyzed using the SPSS (Windows version 18.0, SPSS, Chicago, IL, USA). A P-value of <0.05 was considered statistically significant for all analyses.

Results

Overall, 207 people were screened, and 157 (75.8%) who met the inclusion criteria for the trial and agreed to participate were enrolled (Fig. 2). Of the individuals not meeting the inclusion criteria ($n = 50$), most were excluded because they had exercised regularly in the 6 months before screening. Seven people who were eligible for the study withdrew their participation after a

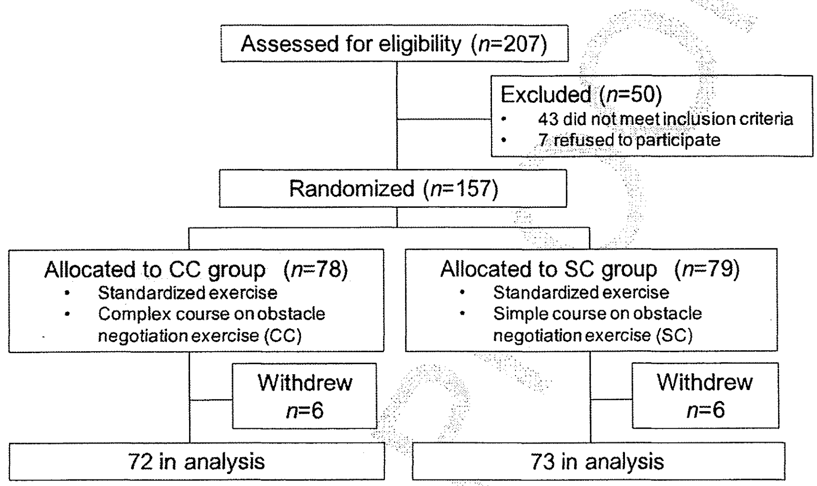

Figure 2 A flow chart showing the distribution of participants throughout the trial.

Table 1 Baseline characteristics of the study participants in complex course obstacle negotiation exercise and simple course obstacle negotiation exercise groups

Characteristic	CC group $n = 72$	SC group $n = 73$	*P*
Age (years)	85.8 ± 5.9	85.3 ± 5.7	0.71
Bodyweight, (kg)	44.9 ± 9.8	47.8 ± 9.4	0.36
Height (cm)	145.1 ± 9.0	147.8 ± 9.2	0.22
Female, *n* (%)	63 (88.7%)	64 (86.5%)	0.59
RDST (points)	7.5 ± 2.2	7.6 ± 2.5	0.80
Medication (*n*)	3.7 ± 2.9	3.8 ± 3.3	0.89
Walking aids, *n* (%)	34 (47.2%)	30 (41.1%)	0.28
Falls in the last year, *n* (%)	28 (38.9%)	29 (39.7%)	0.59

CC, complex course obstacle negotiation exercise; **RDST**, Rapid Dementia Screening Test; **SC,** simple course obstacle negotiation exercise.

telephone screening. Of the 157 individuals selected for the study, 145 (92.3%) completed the 12-month follow up: 72 in the CC group (92.3%) and 73 in the SC group (92.4%).

All 24 scheduled intervention sessions were completed. The median relative adherence was 96% (25^{th} to 75th percentile, 88–100%) in the CC group and 96% (88–100%) in the SC group. No fall incidents occurred during training sessions or testing. No health problems, including cardiovascular or musculoskeletal complications, occurred during training sessions or testing. Minor problems observed in both groups were muscle ache after the first training sessions and fatigue. All problems were managed easily using adjustment of the intervention, and they improved during the intervention. Participants in the CC and SC groups were comparable and well matched with regard to their baseline characteristics (Table 1).

Two participants (2.8%) in the CC group and 19 (26.0%) in the SC group had experienced falls during the 12 months after the exercise program. During the 12-month follow-up period, the IRR of falls in the SC group against the CC group was 9.37 (95% CI 2.26–38.77). One participant (1.4%, distal radius $n = 1$) in the CC group and 8 (10.9%, distal radius $n = 2$; proximal humerus $n = 3$; hip $n = 3$) in the SC group experienced fall-related fractures during the 12-month follow-up period. The IRR of fall-related fractures in the SC group against the CC group was 7.89 (95% CI 1.01–61.49).

Participants in the CC group had significantly greater improvements in secondary outcome measures including the performance time and the number of obstacles contacted under the CC condition ($P < 0.05$) (Table 2). However, other secondary outcome measures were not significantly different between the two groups ($P > 0.05$).

Table 2 Functional fitness items in each group at pre- and postintervention

Item	Pre-intervention	Postintervention	Group × Time Interaction	
			F-value	*P*-value
10-m walking time (s)				
CC group	16.2 ± 7.4	14.1 ± 4.4	0.01	0.91
SC group	18.6 ± 10.0	15.1 ± 6.2		
10-m walking step (*n*)				
CC group	27.5 ± 8.1	26.6 ± 7.2	1.08	0.30
SC group	31.6 ± 14.3	27.3 ± 9.9		
TUG (s)				
CC group	13.6 ± 5.2	13.7 ± 5.3	0.18	0.67
SC group	18.3 ± 9.4	14.8 ± 7.1		
Functional reach (cm)				
CC group	15.9 ± 9.3	16.1 ± 8.2	3.21	0.08
SC group	13.8 ± 7.5	14.0 ± 6.8		
One leg standing (s)				
CC group	6.0 ± 7.4	5.1 ± 5.7	2.56	0.12
SC group	3.2 ± 3.6	4.9 ± 6.1		
Performing time under simple course (s)				
CC group	15.9 ± 8.8	14.5 ± 4.0	0.28	0.60
SC group	17.2 ± 7.9	15.5 ± 5.9		
Performance time under complex course (s)				
CC group	132.6 ± 36.9	105.7 ± 18.7	5.63	0.02
SC group	152.0 ± 54.1	140.9 ± 53.8		
No. obstacles contacted under simple course (times)				
CC group	1.0 ± 1.1	0.3 ± 1.1†	0.60	0.44
SC group	1.2 ± 1.4	0.2 ± 0.6†		
No. obstacles contacted under complex course (times)				
CC group	1.9 ± 2.1	0.1 ± 0.4†	5.62	0.02
SC group	1.7 ± 2.0	1.8 ± 2.8†		

†As calculated by group comparison $P < 0.05$. Columns indicating pre- and postintervention values are expressed as mean (SD). CC, complex course obstacle negotiation exercise; SC, simple course obstacle negotiation exercise; TUG, timed up and go test.

Discussion

The SC exercise is an obstacle-avoidance program under simple task conditions. The CC exercise is an obstacle-avoidance program under complex task conditions, and is designed to address multiple domains, such as attention, short-term memory and balance, which when impaired have been shown to increase fall risk.[21] The present results show that the CC program can improve the performance time of the CC test. This result is consistent with our previous study.[10]

In the CC program, the obstacles were organized to gradually increase the level of difficulty. Therefore, it is possible that the CC program improves the participants' performance by decreasing the number of obstacles contacted under the CC conditions. This result suggested that the obstacle-avoidance program, which increases attention demands for obstacles during walking under complex task conditions, is useful for the improvement of obstacle-avoidance capability. Previous studies have shown that the obstacle-avoidance success rate was decreased by the presence of a secondary task.[22,23] Furthermore, elderly individuals with a high risk for falls chose an early transfer of gaze strategy when challenged with an obstacle under dual-task conditions.[13] The present study showed that our CC program could improve divided attention under complex task conditions.

The differences in fall and fall-related fracture rates between CC and SC groups were significant during the 12 months after the intervention. The improvement in the number of obstacles contacted and the performance time of the CC test became apparent in increased capacity in a real-life environment.

There were several limitations of the present study that warrant mention. First, the participants were probably more motivated and showed greater interest in health and fall risk than the general population of older adults. Second, the information about the medications for osteoporosis was not included in the analysis. It is possible that such medications have an effect on the fracture incidence.

The results of this RCT suggest that the CC program is more effective in improving the number of obstacles contacted and the performance time of the CC test than the SC program. In addition, participants who received individualized obstacle-avoidance training under complex tasks combined with a traditional intervention showed a lower incidence rate of falls and fall-related fractures during the 12-month follow-up period. These results implicated the importance of population-based prevention programs to reduce falls and fall-related fractures in older adults (75 years and older). This is the first study to show that the obstacle-avoidance program, focusing on attention demands of obstacles during walking under complex task conditions, is useful in preventing falls and fall-related fractures in older adults. A larger study is needed to confirm the present results and to evaluate the most effective exercises for the prevention of falls and fall-related fractures.

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Disclosure statement

The authors declare no conflict of interest.

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