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Effect of resistance training on physical performance and fear of falling in elderly with different levels of physical well-being

SIR—Several factors are involved in the maintenance of activities of daily living (ADL) in older adults. Skeletal muscle mass and strength are important factors for maintaining independence and quality of life in elderly. Several recent cross-sectional studies have shown the associations of muscle strength with physical fitness and disability [1, 2]. Loss of muscle mass (sarcopenia) is prevalent in older adults [3] and represents an impaired state of health with mobility disorders, increased risk of falls and fractures, impaired ability to perform ADL, disabilities and loss of independence [4–6].

Fear of falling is common in older adults. The prevalence varies from 21 to 85%, is higher in women than in men, and increases with age [7]. The risk factors of fear of falling are shown to be physical frailty [8], perception of poor health [9], obesity, cognitive impairment, depression, poor balance [10] and history of at least one fall [7].

Resistance training is an effective intervention to improve the physical function in older adults by increasing strength and physical performance [11]. However, it is still controversial whether resistance training is effective for all levels of elderly people. For example, we reported that decreased muscle power is a reliable predictor of falls only in frail elderly [12].

We hypothesised, therefore, that there is a differential effect of resistance training on physical performance according to the level of physical well-being. The aim of this study was to compare the effects of resistance training on skeletal muscle mass, physical performance and fear of falling in robust and frail elderly.

Methods

Participants

Participants were recruited by an advertisement in a local press. We used the following criteria to screen participants in an initial interview: aged ≥65 years, community dwelling, has visited a primary care physician within the previous 3 years, score of ≥8 by Rapid Dementia Screening Test [13], able to walk independently, willing to participate in group exercise classes for at least 6 months, access to transportation and no regular exercise in the previous 12 months.

We also used the interview to exclude participants based on the following exclusion criteria: severe cardiac, pulmonary, or musculoskeletal disorders, pathologies 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.

Frailty definition

The frailty classification was based on a composite of previous work. 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 ADL in frail older adults [14]. It has been reported that elderly with a TUG score greater than 13.5 s can have an increased risk of falling [15]. Frailty was defined as a TUG score >13.5 s. Based on key components of the screening examination (TUG score greater than 13.5 s), 159 elderly adults were classified as the frail group, whereas 178 elderly adults were classified as the robust group because they had a TUG score of ≤13.5 s.

Resistance training

All participants underwent resistance training sessions twice a week for 50 weeks. All participants performed the seated row, leg press, leg curl and leg extension exercises on resistance-training machines. Training loads were chosen using the 10-repetition maximum (10-RM, the maximal weight that can be lifted 10 times). Participants used the 10-RM for 3 sets of 10 repetitions for each machine exercise. Participants were required to adjust the training weight to ensure failure at the 10-RM. It took approximately 1 h to finish all sessions, with 15-min warm-up at the beginning and 10-min cool-down stretch at the end.

Bioelectrical impedance analysis measurement

A bioelectrical impedance data acquisition system (Physion MD; Physion Co. Ltd, Kyoto, Japan) was used to determine the bioelectrical impedance of the right upper and lower limbs [16]. This system applies a constant current of 800 mA at 50 kHz through the body. Participants lay supine with their arms and legs extended and relaxed during bioelectrical impedance measurement. Leg lean mass (LLM) per whole-body weight was used for the analysis.

Measurement of physical performance

All participants underwent five measurements upon entry into the study (pre-test), which included 10-m walk test, TUG test, single leg standing (SLS), functional reach (FR) and 5-chair stand. The order of performing these tests was random. For each performance task, the participants performed two trials, and an average score was calculated from these two trials. All baseline and pre-test measurements were completed prior to randomisation.

Measurement of fear of falling

Falls Efficacy Scale (FES) [17] is the most frequently used surrogate measure for fear of falling in older adults. The reliability and validity of FES have been previously reported [17]. FES was measured at baseline and at 12 months. FES is based on the operational definition of fear as 'low perceived self-confidence at avoiding falls during essential, relatively nonhazardous activities'. Briefly, participants were asked how concerned they were about the possibility of falling while performing 10 different activities on a 4-category scale from 1 (not at all concerned) to 4 (very concerned). If participants indicated that they did not perform or were unable to perform the activity, they were encouraged to respond hypothetically. FES emphasises mainly indoor, home-based activities.

Required sample size

We designed the effect size of the current study to be 0.4. With a significance level of 0.05, a power of 80%, and a moderate effect size (0.4), a minimum of 100 participants were needed in both the intervention and control groups. Accounting for a potential 20% attrition rate, a total of 240 participants were recruited for this study, which was deemed large enough to detect statistically significant differences.

Statistical analysis

We analysed the effects of resistance training on all outcome measures using a mixed 2 (group: robust and frail groups) × 2 (time: pre-intervention, post-intervention) ANOVA. A 0.05 type 1 error rate was chosen *a priori* to indicate statistical significance. A *post hoc* paired *t*-test for within-group comparisons was performed to compare each dependent variable. The Bonferroni procedure was used to adjust the type 1 error rate of each analysis to 0.025 (0.05/2) as an indication of statistical significance to guarantee an overall type 1 error rate of 0.05. Data were entered and analysed using the Statistical Package for Social Science (Windows version 18.0).

Results

We screened 412 elderly and enrolled 337 (81.8%) who met the inclusion criteria for the trial and agreed to participate (Figure 1A). Most of the elderly who did not meet the inclusion criteria ($n = 66$) were excluded because they had exercised regularly for 6 months prior to the screening. Nine people who might have been eligible for the study declined after telephone screening. Of the 337 individuals who were enrolled in this study, 307 (91.1%) completed the 12-month

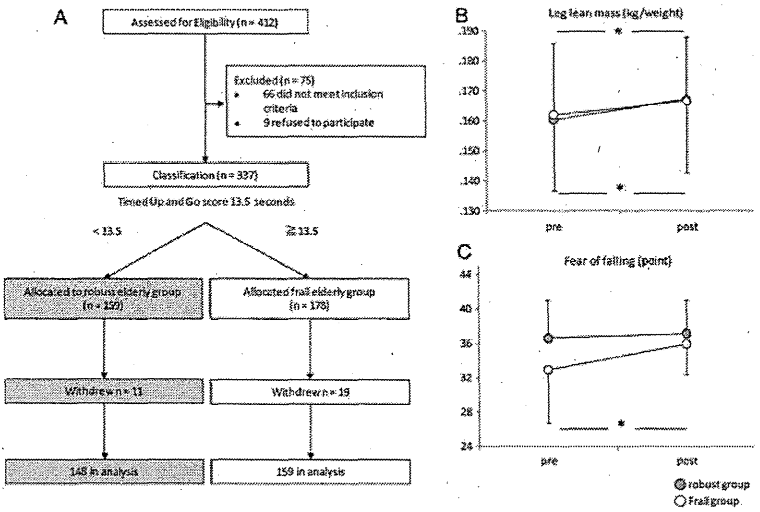

Figure 1. (A) Flow chart showing the disposition of participants throughout the trial. (B) LLM after resistance training in the robust and frail groups was significantly increased from baseline ($P < 0.05$). (C) The frail group had significantly greater improvements in fear of falling ($P < 0.025$).

intervention along with the second interview and the tests at the end of the study. Among them 148 in the robust group (93%) and 159 in the frail group (89%) completed the study.

All 100 scheduled intervention sessions were completed. The median relative adherence was 92% (25–75th percentile, 85–95%) for the robust group and 92% (85–95%) for the frail group. No health problems, such as cardiovascular and musculoskeletal complications, occurred during the training sessions or testing. Minor problems were observed in both groups such as aching muscles after the first training session and fatigue. All the problems were managed easily by adjustment of the intervention and were improved during subsequent interventions.

Effect of the resistance training on outcome measures

LLM after resistance training in the robust and frail groups was significantly increased from the baseline ($P < 0.05$) (Table 1, Figure 1B). Pre- and post-intervention group statistics and group × time interactions are summarised in Table 1. A statistically significant group × time interaction was observed for TUG, FR and fear of falling ($P < 0.05$) (Figure 1C). Bonferroni-corrected paired-sample t-tests demonstrated a significant effect of the resistance training on TUG, FR and fear of falling in the frail group ($P < 0.025$).

Discussion

In this study, we showed that LLM was improved by the resistance training programme in both groups. However, the effect on physical function was limited to frail elderly defined by TUG. The role of muscle strength on physical function is supported by numerous cross-sectional studies that have shown a strong association between low muscle strength and decreased mobility in elderly [18]. On the

Table 1. Functional fitness items by group at pre- and post-intervention

	Robust group ($n = 148$)		E/S	P-value[a]	Frail group ($n = 159$)		E/S	P-value[a]	P-value[b]	F-value 1. Time effect 2. Group × Time
	Mean	SD			mean	SD				
Age, years	75.4	7.7			76.1	8.3			0.440	
Height, cm	157.7	10.1			156.7	9.1			0.266	
Weight, kg	58.2	11.1			56.8	10.9			0.280	
Gender, female n (%)	74 (50.0%)				82 (51.5%)				0.436	
Fall incidence, n (%)	48 (32.4%)				77 (48.4%)				0.003	
Leg lean mass, kg/weight										
Pre	0.160	0.024	0.39	<0.001	0.162	0.024	0.27	0.002	0.448	32.1**
Post	0.167	0.024			0.167	0.021				1.1
Percent change, %	0.05	0.09			0.04	0.11				
Walking time, s										
Pre	10.0	1.9	0.11	0.294	16.1	3.8	0.16	0.130	0.017	1.1
Post	10.2	2.1			15.5	4.1				3.6
Percent change, %	0.3	15.5			−7.7	27.5				
Timed up and go test, sec										
Pre	9.9	1.8	0.09	0.374	17.4	3.0	0.32	0.004	0.002	6.1*
Post	10.1	2.5			16.1	3.9				10.5**
Percent change, %	0.9	18.1			−14.5	37.6				
One leg standing, s										
Pre	9.8	11.8	0.06	0.567	1.7	1.9	0.16	0.160	0.987	0.1
post	9.2	13.9			2.6	5.4				1.4
Percent change, %	−47.3	173.4			46.8	248.3				
Functional reach, cm										
Pre	23.5	5.9	0.01	0.948	18.0	5.6	0.46	<0.001	0.029	7.5**
Post	23.4	5.9			20.9	6.8				8.0**
Percent change, %	−7.2	46.4			23.6	48.1				
Five chair stand, s										
Pre	11.2	3.2	0.07	0.498	16.8	5.2	0.17	0.144	0.004	1.6
Post	11.5	4.7			15.1	8.6				3.1
Percent change, %	5.0	31.3			−29.9	72.8				
Fear of falling, points										
Pre	36.6	4.4	0.18	0.081	32.9	6.2	0.51	<0.001	<0.001	26.2**
Post	37.1	3.9			35.9	3.5				15.4**
Percent change, %	1.5	7.3			12.9	23.3				

E/S, effect size.

[a] As calculated by comparing pre- and post-intervention.

[b] As calculated by group comparison.

*$P < 0.05$.

**$P < 0.01$.

other hand, muscle strength does not depend solely on muscle mass, and the relationship between strength and mass is not linear [19]. Rantanen *et al.* reported that the relationship between muscle strength and physical disability in older adults is non-linear [20]. The discrepancy between these results may stem from the heterogeneity of subjects. In this study, we stratified subjects into robust and fail elderly groups. In frail elderly, the 50-week resistance training programme was effective for the improvement of LLM and physical performance. In contrast, there was no correlation between the change in LLM and physical performance in robust elderly undergoing the resistance training programme. These results suggested that our resistance training programme is not effective for the improvement of physical performance in robust elderly. Furthermore, resistance training improved muscle strength, but did not improve physical performance in the relatively healthy elderly [21]. On the other hand, in frail elderly, improvements in leg power, independent of strength, appear to make an important contribution to clinically meaningful improvements in physical performance [22].

Resistance training improved balance function, such as FR in frail elderly. Improved balance function with resistance training is hypothesised to occur by reduced motor-unit discharge variability [23]. However, SLS was not improved. These results suggested that balance improvement after power training may be explained, in part, by adaptations in force control. However, resistance training *per se* is not effective for balance function. For the improvement of balance function, it is useful to add not only the resistance training but also balance training, such as Tai Chi Chuan [24].

In addition to improving physical performance, the resistance training programme was effective for decreasing fear of falling, but only in the frail group. It is considered important to reduce fear of falling by targeting downstream factors such as physical functioning [25] or predictors of those factors [26]. Thus, our study has an important implication for the reduction in fear of falling in frail elderly.

There are several limitations to this study that warrant mention. First, although we used only TUG to define frailty, TUG may not be enough to define frailty. For example, the short physical performance battery evaluates balance, gait, strength and endurance by examining an individual's ability [27]. It has been recently recommended by an international working group to use a functional outcome measure in clinical trials in frail older adults [28]. Second, we did not measure muscle force. The relationship between LLM and muscle strength is still unclear and needs to be addressed in future studies. Third, no follow-up was conducted. Evidence regarding the long-term effect of exercise on fall prevention is limited, and, therefore, this issue also needs to be addressed. Finally, a control group was lacking. The participants in both groups may have had higher motivation and interest in health issues than the general elderly population.

This is the first study to demonstrate that the effects of a resistance training programme on physical performance differed according to the level of physical well-being. Future work should determine whether tailor-made interventions can effectively improve physical function in both robust and frail elderly.

Key points

- The current trial compared the effects of resistance training between robust and frail elderly on skeletal muscle mass, physical performance and fear of falling.
- Skeletal muscle mass after resistance training was significantly increased from the baseline in both groups.
- The resistance training programme was more effective for the improvement of physical performance and fear of falling in frail elderly than in robust elderly.

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Conflicts of interest

None declared.

MINORU YAMADA*, HIDENORI ARAI, KAZUKI UEMURA, SHUHEI MORI,
KOUTATSU NAGAI, BUICHI TANAKA, YUSUKE TERASAKI,
MAMORU IGUCHI, TOMOKI AOYAMA
Department of Human Health Sciences, Graduate School of Medicine, Kyoto University, 53, Kawaharcho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan
Tel: (+81) 75 751 3909; Fax: (+81) 75 751 3964.
Email: yamada@hs.med.kyoto-u.ac.jp
**To whom correspondence should be addressed*

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Transient ischaemic attack, vascular risk factors and cognitive impairment: a case–controlled study

SIR—Cognitive impairment, especially difficulties with temporal orientation and verbal recall, is associated with the increasing number and severity of vascular risk factors (VRFs) such as hypertension and diabetes [1–3] which can result in an associated impairment of the cerebral microcirculation causing white matter volume changes linked to large artery stiffness [4, 5]. These cognitive deficits can be detected by using simple standard screening tools [6] such as the Mini Mental State Examination [7], Montreal Cognitive Assessment (MoCA) [8] and the DemTec [9], and have been shown to be related to the development of both subclinical (mild) or established vascular disorders [7–12].

However, our understanding of the relation between transient ischaemic attacks (TIAs) and cognitive status is incomplete. We hypothesised that subjects with newly diagnosed TIA would have evidence of an associated mild cognitive impairment; this being a manifestation of the same pathological process underlying the pathogenesis of the vascular event being initiated and accelerated by VRFs. The aims of the current study were, therefore, (i) to examine whether patients with first ever TIA and no history of stroke have evidence of cognitive impairment and, if so, whether the extent of the impairment was greater than expected compared with an age-, sex-matched control populations without VRFs and (ii) to determine which VRFs are associated with cognitive impairment.

Methodology

We conducted a case–controlled study between August and November 2008 in a University Hospital in UK (catchment population 750,000). Cases were defined as those patients with first ever TIA aged ≥45 years, assessed in a

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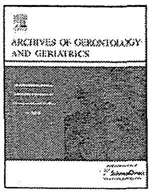

Differences in muscle coactivation during postural control between healthy older and young adults

Koutatsu Nagai [a,*], Minoru Yamada [a], Kazuki Uemura [a], Yosuke Yamada [b], Noriaki Ichihashi [a], Tadao Tsuboyama [a]

[a] *Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan*
[b] *The Fukuoka University Institute for Physical Activity, 1-19-8 Nanakuma, Jyonanku, Fukuoka 814-0180, Japan*

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ABSTRACT

The purpose of this study was to clarify the difference in muscle coactivation during postural control between older and young adults and to identify the characteristics of postural control strategies in older adults by investigating the relationship between muscle coactivation and postural control ability. Forty-six healthy older adults (82.0 ± 7.5 years) and 34 healthy young adults (22.1 ± 2.3 years) participated. The postural tasks selected consisted of static standing, functional reach, functional stability boundary and gait. Coactivation of the ankle joint was recorded during each task via electromyography (EMG). The older adults showed significantly higher coactivation than the young adults during the tasks of standing, functional reach, functional stability boundary (forward), and gait ($p < 0.01$). Postural sway area ($\rho = 0.42$, $p < 0.05$) and functional reach distance ($\rho = -0.52$, $p < 0.05$) significantly correlated with coactivation during the corresponding task in older adults, i.e., muscle coactivation was significantly higher in the elderly with low postural control ability than in the elderly with high balance ability. Increased muscle coactivation could be a necessary change to compensate for a deterioration in postural control accompanying healthy aging. Further research is needed to clarify in greater detail positive and negative effects of muscle coactivation on postural control.

1. Introduction

Appropriate temporal separation between agonist and antagonist activation of muscles has been observed for well-controlled voluntary movements (Fujii et al., 2009). In clinical situations, however, this separation is attenuated, muscle coactivation is increased, and motor control becomes poor (Dierick et al., 2002). Even with normal aging, greater coactivation is induced during single-joint movements (Klein et al., 2001; Macaluso et al., 2002) and gait (Mian et al., 2006; Hortobagyi et al., 2009) in the elderly. Greater muscle coactivation, in turn, increases the metabolic cost of gait (Mian et al., 2006), which can cause fatigue and shorten activity duration.

Although several studies have reported age-associated increases in muscle coactivation during dynamic movements (Schmitz et al., 2008; Hortobagyi et al., 2009), limited information is available regarding muscle coactivation under static postural control (Melzer et al., 2001). Increased muscle coactivation in older subjects is most commonly described as a compensatory mechanism to increase joint stiffness that thereby enhances stability (Baratta et al., 1988; Solomonow et al., 1988; Hortobagyi and DeVita, 2000). Older adults may walk with high muscle coactivation as a balance-maintaining strategy in response to perturbations during dynamic movement (Manchester et al., 1989). If the high muscle coactivation is induced in order to maintain postural balance, this elevation should be observed even in static postural control and should be associated with the level of postural control ability.

Both static and dynamic postural controls are necessary during activities of daily living. Aging has been associated with deterioration in postural control, which manifests itself by an increase in postural sway (Era and Heikkinen, 1985), a decrease in reach distance (Duncan et al., 1992), and a decrease in capacity for locomotion (Oberg et al., 1993). Deterioration in these functions leads to a higher risk of falling, which may increase the number of bedridden persons (Lord et al., 1991; Duncan et al., 1992). However, the relationship between muscle coactivation and balance ability has not been clarified. Clarification of this relationship would be helpful to developing optimal rehabilitation strategies for older people.

The purpose of this study was to clarify the differences in muscle coactivation during postural control between older and

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* Corresponding author. Tel.: +81 75 751 3935; fax: +81 75 751 3948.
E-mail address: k.nagai@ky2.ecs.kyoto-u.ac.jp (K. Nagai).

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young adults and to identify the characteristics of postural control strategies in older adults by investigating the relationship between muscle coactivation and postural control ability. We hypothesized that muscle coactivation during postural control in older adults is higher than that in young adults. We also hypothesized that muscle coactivation relates to postural control ability in young and older adults.

2. Subjects and methods

2.1. Participants

Forty-six healthy older adults (10 males, 36 females; age, 82.0 ± 7.5 years) and 34 healthy young adults (14 males, 20 females; age: 22.1 ± 2.3 years) participated in this study (Table 1). Oral and written explanations of the study were offered to participants. Subjects were excluded if they had acute neurological impairment (stroke, Parkinson's disease, paresis of the lower limbs), severe cardiovascular disease, severe cognitive impairment: rapid dementia screening test score is of four points or less (Kalbe et al., 2003), persistent joint pain, or musculoskeletal impairment. Each subject gave informed consent indicating their agreement with the study protocol. This research was approved by the Ethical Review Board of Kyoto University Graduate School of Medicine, Kyoto, Japan.

2.2. Testing procedures and protocol

The postural tasks selected for testing consisted of static standing, functional reach, functional stability boundary (forward and backward), and gait because similar movements are performed frequently during activities of daily living.

2.2.1. Postural sway

Postural sway during static standing was measured with a force plate (Kistler 9286 force platform, Kistler Instruments Inc., Amherst, NY). Signals were sampled at 20 Hz and processed by a low-pass filter (6 Hz cut off frequency). The participants were required to stand on a force plate with their feet together and then asked to gaze at a mark at eye level. Subjects were instructed to stand still as symmetrically as possible. Static standing balance was registered for a period of 10 s, from which the root mean square (RMS) area was calculated. EMG was measured for 3 s starting at the beginning of static standing.

2.2.2. Functional stability boundary

Functional stability boundary tasks were performed on the force plate (Slobounov et al., 1998). The subjects were instructed to stand with their heels positioned on a line 10 cm anterior to the posterior edge of the plate. The subjects were instructed to stand still for 5 s and then to shift their body weight first toward their toes and then toward their heels over the largest possible amplitude. They were further instructed to maintain full contact between their feet and the plate (avoiding toes off or heels off). For each direction (forward and backward), the subject maintained their posture for 3 s for EMG measurements, from which the averaged peak center of pressure (COP) displacement from the initial position was calculated. The COP displacement for each subject was normalized individually to the length of that subject's foot.

Table 1
Physical characteristics of the subjects, n, mean ± S.D., or %.

Parameters	Elderly	Young
Number	46	34
Age (years)	82.0 ± 7.5	22.1 ± 2.3
Female (%)	58.8	78.3
Height (cm)	151.3 ± 6.8	164.6 ± 7.9
Weight (kg)	51.9 ± 6.6	56.7 ± 8.0

2.2.3. Functional reach

The functional reach test (Duncan et al., 1990, 1992) measures the distance that subjects are able to reach forward while maintaining a fixed base. The position of the fingertip is determined with the shoulder of the subject flexed at 90° along a wall. The subjects then were instructed to reach as far forward as possible without moving their feet, thus moving the center of gravity forward over a fixed base. Additionally, the subjects were instructed to keep their position for 3 s for EMG measurements. Functional reach was defined as the difference between arm's length and maximal forward reach.

2.2.4. Gait

Subjects were asked to perform walking trials at their preferred speed over a 12-m walkway. The examiner measured the time and the number of steps for the middle 10-m. A single trial was conducted following instruction. Walking speed (m/s) and step cadence (steps/min) were calculated as variables. EMG was analyzed for three gait cycles as determined from signals from the foot switch sensors (Noraxon USA Inc., Scottsdale, AZ) during the one gait trial.

2.2.5. Additional physical function characteristics

The timed up and go test (TUG) (Shumway-Cook et al., 2000) and the timed one-leg standing test for the dominant leg with eyes open were performed without EMG monitoring. The maximum duration of the one-leg standing test was set at 30 s.

2.3. EMG recording

EMG data were collected with the Telemyo 2400 (Noraxon USA Inc., Scottsdale, AZ). The skin of the dominant leg was shaved over the fibula head, tibialis anterior (TA), and soleus (SOL) (Melzer et al., 2001) and then washed with alcohol. Bipolar surface electrodes (Ambu, Blue sensor M, Denmark) with a 2.0 cm inter-electrode distance were placed on the skin around the probable motor point of the muscles (Hermens, 2011). The ground electrode was affixed to the skin over the fibula head of the dominant leg. The EMG data were sampled at 1500 Hz.

EMG activity was recorded from the SOL and TA while the subjects were performing maximal voluntary contractions (MVCs). The MVC of the SOL was obtained during maximal isometric plantar flexion, and maximal TA activation was recorded during maximal isometric dorsiflexion of the ankle at 90° (anatomically neutral position). Strong verbal encouragement was given during every contraction to promote maximal effort. The EMG data from the MVCs were used to normalize the EMG amplitude (%MVC) during the postural tasks.

2.4. Muscle coactivation analysis

The original raw EMG signal was band-pass filtered at 20–500 Hz. We computed the root mean-square amplitude of the signal using a 50-ms window. The EMG of each muscle was then expressed as a percentage of the EMG value during the MVC.

To evaluate the relative level of co-contraction of the TA and SOL muscles, the co-contraction index (CI) was calculated using the method of Falconer and Winter (Falconer and Winter, 1985). Specifically, the following equation was used:

Table 2
Postural control ability of subjects, n, mean ± S.D.

Physical function	Elderly	Young	95% CI	p
Number	46	34		
Postural sway area (cm^2)	1.7 ± 1.0	0.9 ± 0.4	0.48–1.19	<0.001*
Functional reach (cm)	20.9 ± 7.9	37.0 ± 5.4	−19.1 to −12.9	<0.001*
Functional stability boundary (forward) (%)	25.5 ± 9.7	36.9 ± 5.5		<0.001†
Functional stability boundary (backward) (%)	18.4 ± 4.6	23.9 ± 5.4		<0.001†
Gait speed (m/s)	0.9 ± 0.4	1.2 ± 0.2	−0.47 to −0.12	<0.001*
TUG test (s)	11.4 ± 6.4	6.0 ± 0.7	3.16 to 7.60	<0.001*
One-leg standing (s)	9.3 ± 11.2	30 ± 0.0		<0.001†

* Student's *t*-test.
† Mann–Whitney *U*-test.

$$\mathrm{CI} = \frac{2I_{\mathrm{ant}}}{I_{\mathrm{total}}} \times 100\%$$

where I_{ant} is the area of the total antagonistic activity, calculated in accord with the following equation:

$$I_{\mathrm{ant}} = \int_{t_1}^{t_2} \mathrm{EMG}_{\mathrm{TA}}(t)\mathrm{d}t + \int_{t_2}^{t_3} \mathrm{EMG}_{\mathrm{SOL}}(t)\mathrm{d}t$$

where t_1 to t_2 denotes the period during which the TA EMG is less than the SOL EMG and t_2 to t_3 donates the period during which the SOL EMG is less than the TA EMG, I_{total} is the integral of the sum of TA and SOL EMG during performance of the task, calculated in accord with the following equation:

$$I_{\mathrm{total}} = \int_{t_1}^{t_3} [\mathrm{EMG}_{\mathrm{agon}} + \mathrm{EMG}_{\mathrm{ant}}](t)\mathrm{d}t$$

2.5. Statistics

SPSS (SPSS Inc., Tokyo, Japan) software was used for the data analysis. The test–retest intraday reliability of each EMG measurements without relocating the electrode was estimated by calculating intraclass correlation coefficients ($\mathrm{ICC}_{1,1}$). Differences in physical function between young and older adults were tested using the Student's *t*-test for continuous variables and the Mann–Whitney U test for non-normally distributed variables. Comparisons of the normalized EMG activity and CI between young and older adults were performed using the Mann–Whitney *U* test. The effect of gender differences in CI was examined with a 2 × 2 (gender × generation group) analysis of variance (ANOVA). The relationship between coactivation and physical function for each trial was analyzed by Spearman rank correlation. Statistical significance was set at $p < 0.05$.

Table 3
Mean normalized EMG activity (%MVC) during measured tasks, *n*, mean ± S.D.

Tasks	Muscle	Elderly	Young	p
Standing (%)	TA	19.4 ± 19.3	2.1 ± 2.6	<0.01
	SOL	28.6 ± 20.4	12.5 ± 8.2	0.01
Functional reach (%)	TA	18.6 ± 19.7	4.8 ± 4.2	<0.01
	SOL	45.3 ± 23.3	43.1 ± 26.7	0.36
Functional stability boundary (forward) (%)	TA	19.4 ± 17.0	6.0 ± 8.0	0.01
	SOL	52.0 ± 22.9	37.6 ± 21.5	0.01
Functional stability boundary (backward) (%)	TA	49.6 ± 22.1	28.1 ± 12.2	0.01
	SOL	37.8 ± 17.8	17.6 ± 11.5	0.01
Gait (%)	TA	35.4 ± 19.0	12.4 ± 4.6	<0.01
	SOL	48.1 ± 22.1	28.8 ± 14.0	0.01

Notes: Mann–Whitney *U*-test was used for comparison of the %MVC.

3. Results

The $\mathrm{ICCs}_{1,1}$ for CI without relocating the electrode were as follows: 0.87 (95% CI: 0.67–0.96) for static standing, 0.95 (95% CI: 0.84–0.97) for functional reach, 0.71 (95% CI: 0.22–0.91) for functional stability boundary (forward), 0.97 (95% CI: 0.92–0.99) for functional stability boundary (backward), and 0.86 (95% CI: 0.57–0.96) for gait. These ICC values indicated 'good' to 'excellent' reliability for all measurements of CI (Shrout and Fleiss, 1979).

The young adults had significantly better physical function than the older adults for all variables measured ($p < 0.01$) (Table 2). The elderly had significantly greater %MVC values in ankle muscles than the young adults for all measured tasks except for the SOL during functional reach ($p < 0.01$, Table 3).

The older adults had significantly higher CI values than the young adults for standing, functional reach, functional stability boundary (forward), and gait ($p < 0.01$, Fig. 1). The CI for functional stability boundary (backward) tended to be higher in the older adults than in the young adults but the difference did not reach statistical significance ($p = 0.072$). Two-way ANOVA identified no significant gender/generation interactions with respect to CI for all tasks ($p \geq 0.05$). Gender alone had no significant effect on CI except for functional stability boundary (backward) ($p < 0.05$).

In the older adults, Spearman rank correlation revealed a significant correlation between postural sway area and CI during static standing ($\rho = 0.42$, $p < 0.05$). Functional reach distance significantly correlated with CI ($\rho = -0.52$, $p < 0.05$) (Fig. 2). The functional stability boundary (forward) tended to correlate with CI but did not reach statistical significance ($\rho = -0.33$, $p = 0.06$). In the young adults, no correlation between physical function and CI was found.

4. Discussion

Although previous studies have reported higher muscle coactivation during MVC, gait, and static standing in older adults compared with young adults (Klein et al., 2001; Melzer et al., 2001; Macaluso et al., 2002; Mian et al., 2006; Hortobagyi et al., 2009), no studies have quantified muscle coactivation during static and dynamic postural tasks in the elderly. The present study focused on quantifying muscle coactivation at the ankle joint under postural control and yielded two major findings: (1) muscle coactivation at the ankle joint during postural control was higher in the elderly than in the young adults, and (2) the elderly who had less physical function during postural control tasks showed higher muscle coactivation at the ankle joints. These results, in turn, raise two alternative possibilities: either (1) older adults with deterioration in their postural control utilize muscle coactivation as a strategy to maintain their balance, or (2) high muscle coactivation in older adults leads to poor postural control.

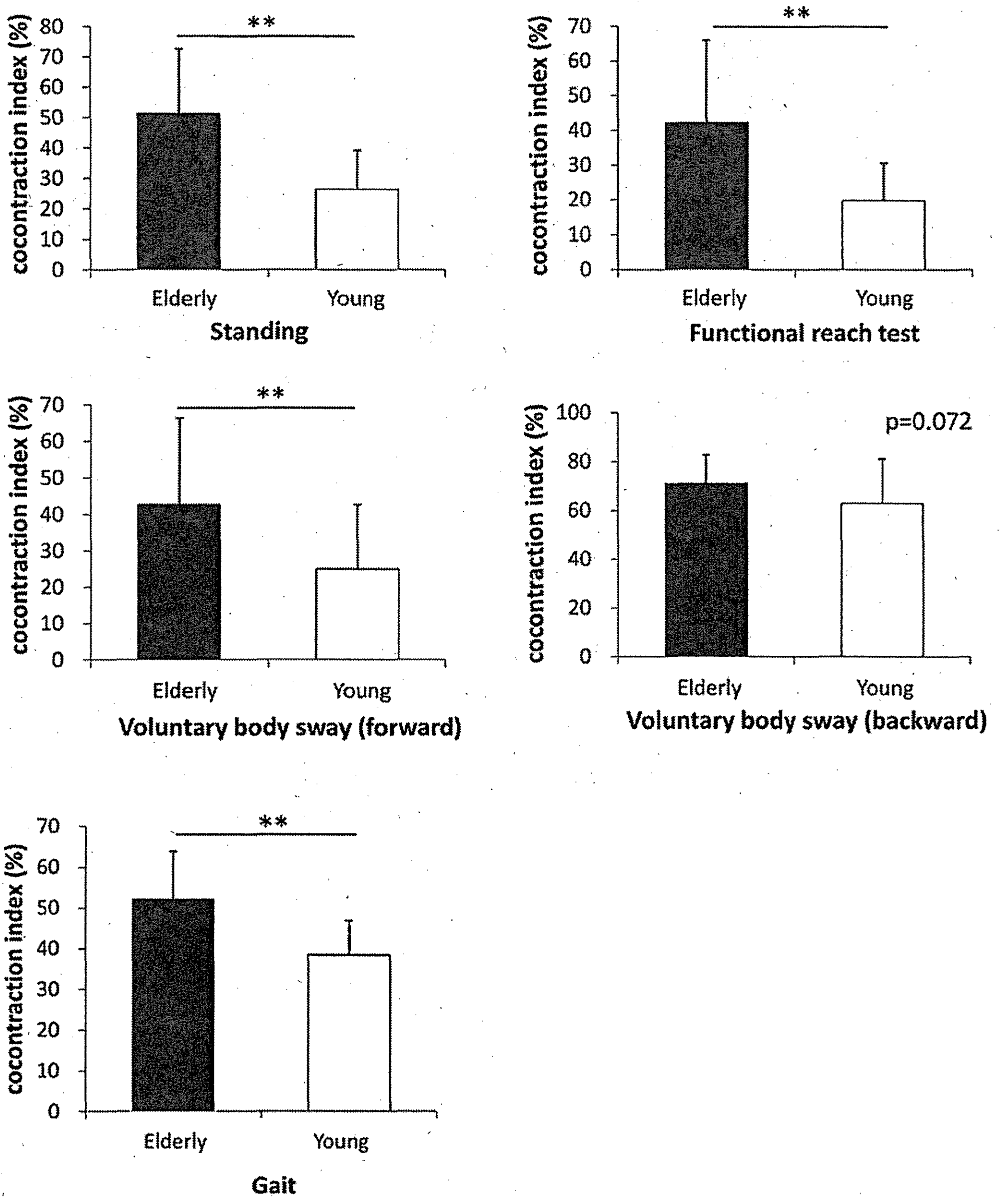

Fig. 1. Comparisons of the CI between older (filled bars) and young adults (open bars) during the measured tasks. The Mann–Whitney *U* test was used for the CI comparisons ($^*p < 0.05$, $^{**}p < 0.01$).

Regarding static postural control, the data in the study by Melzer et al. (2001) suggested higher coactivation in older adults than in young adults during static standing. Additionally, Manchester et al. (1989) have demonstrated greater amounts of co-contraction of antagonists in older adults under perturbed conditions. These researchers described the greater co-contraction of antagonists with resultant ankle joint stiffness as a strategy to maintain postural stability.

In the present study, TA activation during standing was greater in the older adults than in the young adults. During normal standing, the planter flexor muscles are recruited mainly as antigravity muscles at the ankle joint (Kendall and MacCreary, 1983) while the activity of the TA usually remains low. The greater TA activity in the older adults probably caused the observed increase in muscle coactivation in this study.

The results of the dynamic postural control tasks, i.e., functional reach and functional stability boundary, suggest that muscle coactivation becomes stronger in older adults who cannot sufficiently move their COP within their base of support. Hortobagyi and DeVita (2000), have reported increased coactivation of antagonistic muscles during stair descending in older adults compared with young adults, which they interpreted as an indication that the older adults had increased muscle coactivation in order to stiffen the joints of their lower limbs. Functional reach and the functional stability boundary during forward motion involve a forward movement of the COP, which requires increased plantar flexor torque at the ankle joint to control posture. Therefore, the TA plays the role of antagonist in these tasks. In the present study, during functional reach and functional stability boundary for forward motion, the EMG activity of the TA reached almost 20% of MVC in the older adults, probably to increase the stiffness of their ankle joint. The elevated TA activity may have caused the increase in muscle coactivation in a similar manner as during static postural control.

Our gait measurements showed higher muscle coactivation during walking in the older adults than in the young adults. This

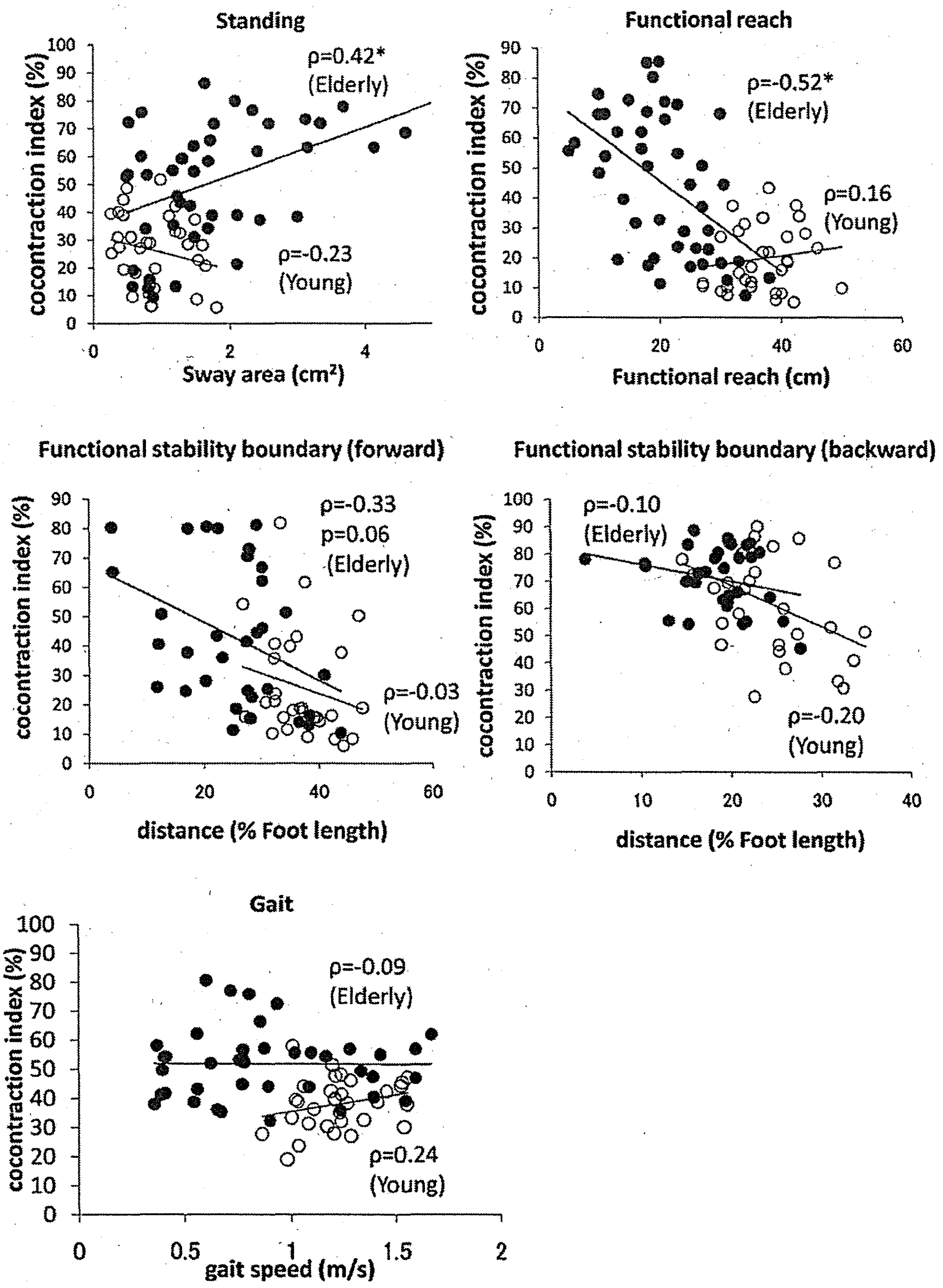

Fig. 2. Correlations between postural control ability and CI. Filled circles show older adults and open circles show young adults. Spearman rank correlation was used for statistical analysis (ρ: correlation coefficient, $^*p < 0.05$).

difference indicates that aging induces not only a decline in walking ability (e.g., decrease in gait velocity, increase in step variability) but also a change in central nervous system control of dynamic movement. Recent studies have also reported higher muscle coactivation at the ankle joint during walking in older adults than in young adults (Schmitz et al., 2008; Hortobagyi et al., 2009). In these studies, high muscle coactivation during walking was interpreted as being a means of enhancing ankle joint stability. Chambers and Cham (2007) have investigated the relationship between muscle co-contraction and slips during gait measurements. The subjects who walked with higher ankle muscle co-contraction were predisposed to experience less severe slips when encountering an unexpected slippery floor (Chambers and Cham, 2007). Additionally, anticipation of a slippery surface resulted in more muscle co-contraction at the ankle and knee. These observations support the hypothesis that the elderly have enhanced muscle coactivation to compensate for an age-associated decline in postural control ability.

Our study also found no significant correlation between gait velocity and muscle coactivation during walking. Muscle coactivation during walking seems to be independent from gait velocity. Hortobagyi et al. (2009) have investigated muscle coactivation during walking at different velocities and reported that muscle coactivation was not affected by gait velocity in older people. This finding suggests that older adults probably can utilize a high muscle coactivation strategy during walking regardless of gait velocity.

In previous studies, high muscle co-contraction has been described as a strategy to stiffen the joint and enhance stability (Hortobagyi and DeVita, 2000; Hortobagyi et al., 2009). The purpose of increasing joint stiffness is to compensate for the many neuromotor impairments associated with aging, including reduced muscle strength (Hortobagyi et al., 1995), slower rate of tension development (Thelen et al., 1996), reduced proportion of fast muscle fibers (Larsson et al., 1979), miscued limb positioning (Skinner et al., 1984), and fear of falling (Okada et al., 2001). Carolan and Cafarelli (1992) have measured muscle activation in the biceps femoris during knee extension and found that as knee extensor strength increased, biceps femoris activity also increased. This finding indicates that greater effort to extend the knee joint induces increased muscle coactivation in the antagonist muscle. In the present study, the elderly showed higher muscle activity than the young adults in most of the measured tasks. Because of age-related decreases in their muscular strength, older adults need to recruit more muscle fibers to accomplish a specific postural task. This increased muscle effort possibly led to the higher muscle coactivation that we observed.

Increased muscle coactivation may be a necessary change to compensate for the poor postural control accompanying healthy aging. However, strong coactivation of agonist and antagonist muscles should reduce the performance of agonist muscles (Carolan and Cafarelli, 1992; Pereira and Goncalves, 2010) as well as increasing the energetic cost of transport (Mian et al., 2006), thereby inducing fatigue and potentially increasing the risk of falling (Hortobagyi et al., 2009). If older adults employ the coactivation strategy for postural control, probable consequences would include poor performance and increased risk of falling, especially in situations difficult to deal with by this strategy. In clinical settings, efforts to determine the proper level of coactivation, corresponding to personal and environmental situations, should be targeted especially toward those older patients who have suffered deterioration in their postural control ability.

Limitations of our study include that our study data did not clarify the relationship between muscle coactivation and joint kinematics. In addition, our study provided no information on a postural strategy for the knee or hip joint because it focused on the ankle joint. Finally, the lack of longitudinal data precludes an examination of the causal relationship between deterioration in postural control and muscle coactivation. Further studies are needed to examine muscle coactivation strategy in postural tasks for the elderly in greater detail.

5. Conclusions

Our study clarified that older adults show greater muscle coactivation during postural control compared with young adults. Moreover, muscle coactivation was significantly higher in older adults with low postural control ability than in older adults with high postural control ability. Increased muscle coactivation could be a necessary change to compensate for the deterioration in postural control accompanying healthy aging. However, further research is needed to clarify in greater detail the positive and negative effects of muscle coactivation on postural control.

Conflict of interest statement

None.

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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

Kazuki Uemura, Minoru Yamada, Koutatsu Nagai, and Noriaki Ichihashi

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

Address correspondence to Kazuki Uemura, PT, BS, Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan. Email: k.uemura@kw7.ecs.kyoto-u.ac.jp

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.

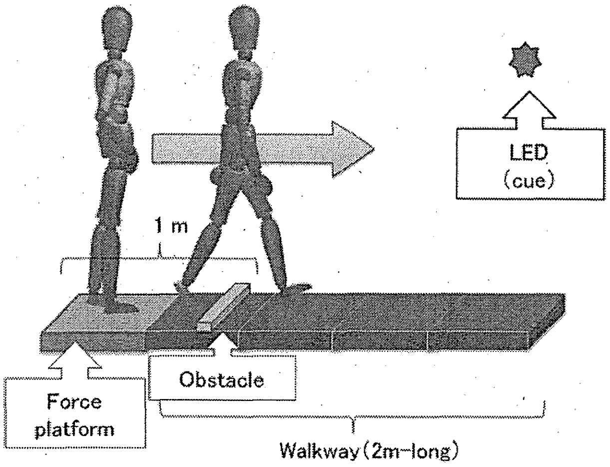

Figure 1. Schematic representation of the gait initiation test under the obstructed condition. Each participant initially stood upright on a force platform. Participants were instructed to execute the first step as quickly as possible after a visual cue. The obstacle was placed at 1 m from the initial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

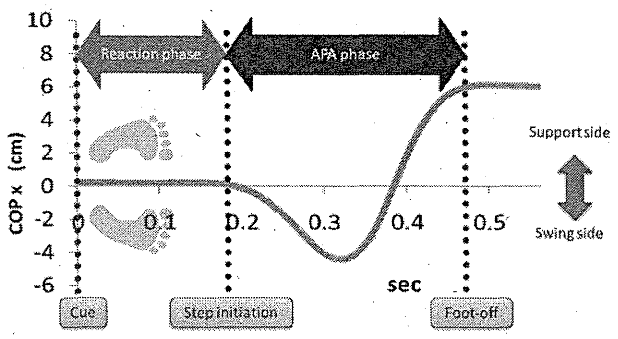

Figure 2. An example of gait initiation data. The following events are marked: onset of the visual cue (cue), the first mediolateral deviation of the center of pressure (COP) toward the swing leg (step initiation), and the end of the mediolateral shift of the COP toward the stance leg (foot-off). See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

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*].

^{a}p values are based on t test or chi-square.

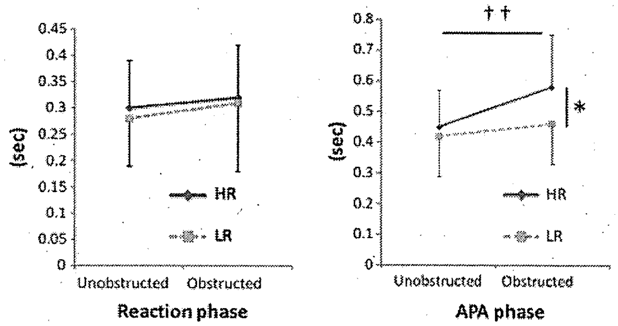

Figure 3. Average measurement parameters for both groups of participants in unobstructed and obstructed conditions. *Significant difference between high-risk (HR) and low-risk (LR) participants in the individual task condition (Bonferroni, $p < .0125$). ††Significant difference between unobstructed and 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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Fear of falling is associated with prolonged anticipatory postural adjustment during gait initiation under dual-task conditions in older adults

Kazuki Uemura [a,*], Minoru Yamada [b], Koutatsu Nagai [b], Buichi Tanaka [c], Shuhei Mori [b], Noriaki Ichihashi [b]

[a] *Department of Physical Therapy, Graduate School of Medicine, Nagoya University, Japan*
[b] *Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto University, Japan*
[c] *Centor for Rehabilitation, Tenri Yorodu Soudansho Hospital, Japan*

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ABSTRACT

Little is known about dynamic balance control under dual-task conditions in older adults with fear of falling (FoF). The purpose of this study was to examine the effect of FoF on anticipatory postural adjustment (APA) during gait initiation under dual-task conditions in older adults. Fifty-seven elderly volunteers (age, 79.2 [6.8] years) from the community participated in this study. Each participant was categorised into either the Fear ($n = 24$) or No-fear ($n = 33$) group on the basis of the presence or absence of FoF. Under single- and dual-task conditions, centre of pressure (COP) data were collected while the participants performed gait initiation trials from a starting position on a force platform. We also performed a 10-m walking test (WT), a timed up & go test (TUG), and a functional reach test (FR). The reaction and APA phases were measured from the COP data. The results showed that under the dual-task condition, the Fear group had significantly longer APA phases than the No-fear group, although no significant differences were observed between the 2 groups in the reaction and APA phases under the single-task condition and in any clinical measurements (WT, TUG, and FR). Our findings suggest that specific deficits in balance control occur in subjects with FoF during gait initiation while dual tasking, even if their physical functions are comparable to subjects without FoF.

1. Introduction

Fear of falling (FoF) refers to the lack of self-confidence that normal activities can be performed without falling [1]. Its prevalence varies between 21% and 85%, is higher in women, and increases with age [2,3]. While FoF is a major component of the 'post-fall syndrome', such fears can also develop in individuals who have not experienced any falling episodes [4]. Although FoF may contribute to the risk of falling, it cannot be assumed that it represents the actual risk of falling [5]. FoF is associated with anxiety, depressive symptoms, and reduced quality of life [6], and may lead to unnecessary avoidance of specific activities in older adults, even though they may be able to perform such activities without falling [7,8].

Some gait adaptations secondary to FoF – e.g. decreased step length and speed and prolonged double support – are interpreted as attempts at stabilisation to reduce the risk of falling [9]. On the basis of Gage's study on the influence of anxiety on attentional demands during walking, FoF may be assumed to reduce the amount of attention resources available for gait and balance control [10]. The effect of FoF on gait and balance may therefore be more apparent when individuals perform a second task during walking, as happens often in daily life. However, little is known about dynamic balance control under dual-task conditions in older adults with FoF. Only one study has reported that FoF does not influence the ability to attend to a secondary cognitive task during a steady-state gait [11].

Many older adults fall while walking short distances [12], suggesting that they have difficulty in maintaining balance during the transition phase, including gait initiation and termination, which are frequently repeated during daily activities. Gait initiation is believed to require more attentional resources than steady state walking does [13,14]. Gait initiation is a voluntary transition from a condition of a static stable support to a continuously unstable posture during locomotion, which requires anticipatory postural adjustment (APA) serving to shift the centre of mass (COM) towards the supporting side so that the leg can be raised [15]. Prolonged duration of APA during step initiation while dual tasking is reported to be associated with increased risk of falling in older adults [16]. Therefore, the duration of APA is considered an indicator of balance control ability during movement initiation [16,17]. However, no study has thus far reported the effect of FoF on balance control during gait initiation.

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* Corresponding author at: Graduate School of Medicine, Nagoya University, 1-1-20 Daikouminami, Higashi-ku, Nagoya 461-8673, Japan. Tel.: +81 527 19 1365; fax: +81 527 19 1365.
E-mail address: uemura.kazuki@a.mbox.nagoya-u.ac.jp (K. Uemura).

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The purpose of this study was to examine the effect of FoF on APA during gait initiation while dual tasking in older adults. We hypothesised that older adults with FoF need more time for APA than those without FoF because of dual-task interference between postural and cognitive tasks.

2. Methods

2.1. Participants

Fifty-seven community-dwelling older adults (mean age [standard deviation, SD], 79.2 [6.8] years; height, 156.1 [10.6] cm; weight, 55.8 [11.6] kg) participated in this study. Participants were recruited through advertisements in various local papers. Inclusion criteria were as follows: age ≥65 years, minimal hearing and visual impairments (can see the visual cue used during the experiment), and ability to ambulate independently at the time of measurement.

Exclusion criteria were as follows: severe cardiac, pulmonary, or musculoskeletal disorders; diseases associated with a high risk of falling (e.g. Parkinson disease); inability to execute arithmetic tasks; serious visual impairment not correctable with spectacles; and inability to follow multiple commands by a physical therapist. Written informed consent was obtained from the participants 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.

FoF was assessed by an ordered-choice, closed-ended question about fear of falling. The question was phrased as follows: 'Are you afraid of falling now?' Participants who responded 'somewhat' or 'very much' were assigned to the Fear group; those who responded 'little' or 'not at all' were assigned to the No-fear group [18]. We recorded the subjects' demographic and medical variables, such as number of drugs used and mental status (Rapid Dementia Screening Test [19]).

The subjects also completed a standardised questionnaire, which recorded the number of times they had fallen in the past year. A fall was defined as an event that a person unintentionally comes to rest on the ground, floor, or another lower level [20]. Falls resulting from extraordinary environmental factors (e.g. traffic accidents or falls while riding a bicycle) were excluded from the count. On the basis of their responses, participants were divided into 2 groups: Fallers (one or more falls) and Non-fallers (zero falls).

2.2. Task and protocol

In the gait initiation test, the participants initially stood upright on a force platform on their both legs, with their feet abducted at 10° and their heels separated mediolaterally by 6 cm. Participants were instructed to start walking along the walkway as quickly as possible after a visual cue of LED illumination and to continue walking—that is, take at least 5 steps on the walkway (2 m). The participants were allowed to select the first stepping leg (right or left). An LED was set 2.5 m ahead of the participants, at eye level. The test was performed under single- and dual-task conditions. Under the dual-task condition, the participants were instructed to count aloud backward by 1 starting from 100 while they waited for the visual cue. The order of the tasks was randomised. Before experimental data were collected, the participants performed at least 3 trials to familiarise themselves with the equipment.

All participants underwent 3 clinical measurements – a 10-m walking test (WT) [21], a timed up & go test (TUG) [22], and a functional reach test (FR) [23] – in the presence of an experienced physiotherapist.

2.3. Instrumentation and data analysis

COP data during gait initiation tests were collected with a portable Kister 9286 Force Platform (Kistler Instrument Corp., Winterthur, Switzerland). The 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, USA). The following events were extracted from the COP data: (1) step initiation, which was defined as the first mediolateral deviation of the COP towards the swing leg (COP excursion >3 SD away from the initial COP position defined as the mean amplitude in the 1500-ms period prior to the onset of the visual cue), and (2) foot-off, which was defined as the end of the mediolateral shift of the COP towards the stance leg (absolute COP slope <100 mm/s, 2 samples in a row) [17]. 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 (Fig. 1). The means and SDs were determined using data from 3 trials.

2.4. Statistical analysis

Two-way repeated-measures ANOVA (group [Fear vs. No-fear]) × (task condition [single vs. dual]) was used in the statistical analysis of all variables. A probability of $p < 0.05$ was considered statistically significant. When interaction effects were detected, separate ANOVA and post hoc comparisons were performed to assess group and task differences. Additional 2-way repeated-measures ANOVA, (group [Fallers vs. Non-fallers]) × (task condition [single vs. dual]), and post hoc comparisons were performed in a similar manner. Student's t-test for independent measures was used to evaluate the differences between Fear and No-fear groups in the WT, TUG, and FR tests. Partial η^2 and Cohen's d values were calculated as measures of effect size. Data analysis was performed using SPSS 11.0J for Windows (SPSS Inc., Chicago, IL, USA).

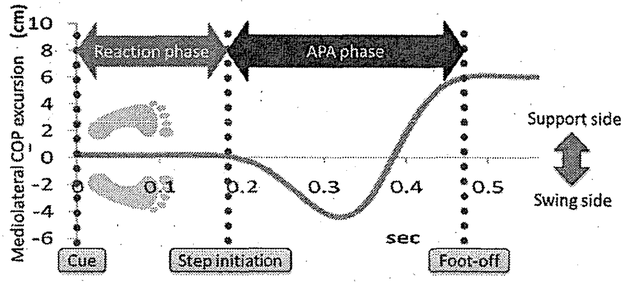

Fig. 1. An example of gait initiation data. The following events are marked: onset of the visual cue (Cue), the first mediolateral deviation of the COP towards the swing leg (Step initiation), the end of the mediolateral shift of the COP towards the stance leg (Foot-off); see text for details.

3. Results

3.1. Participant characteristics

Of the 57 subjects (age, 65–93 years) who participated in the study, 24 (42%) were classified into the No-fear group and 33 (58%) were classified into the Fear group on the basis of the presence or absence of FoF. Table 1 shows the demographic and medical variables and performance characteristics of the 57 participants, as well as the differences in performance test scores between the Fear and No-fear groups. No significant differences were found in age, height, weight, gender, number of medications, or Rapid Dementia Screening Test score between the 2 groups, while the number of Fallers among the Fear group was significantly higher than those among the No-fear group ($p = 0.039$). In clinical measurements, no significant differences were detected in the WT ($p = 0.69$, $d = 0.12$), TUG ($p = 0.99$, $d = 0$), or FR ($p = 0.29$, $d = 0.31$) tests.

3.2. Performance of gait initiation test

Table 2 shows all variables for the No-fear and Fear group participants in the single- and dual-task conditions. No interaction effects between group and task conditions were detected in the reaction phase ($p = 0.99$, F1, 55 = 0, $\eta^2 = 0$; Fig. 2). The reaction phase was longer for the dual-task condition for both the Fear and No-fear groups ($p < 0.001$, F1, 55 = 52.2, $\eta^2 = 0.49$), but no significant main group effect was found ($p = 0.63$, F1, 55 = 0.24, $\eta^2 = 0.004$).

Table 1
Participant characteristics.

	No-fear (n=33)	Fear (n=24)	p-value
Age, years	79.9 [7.5] (65–93)	79.7 [6.9] (65–87)	0.31
Height, cm	156.8 [10.9]	155.1 [10.4]	0.55
Weight, kg	54.6 [9.8]	57.5 [13.7]	0.38
Gender, % males	38.1%	44.4%	0.64[a]
No. of medications	4.9 [5.2]	6.5 [5.6]	0.38
Faller, %	27.2%	54.1%	0.039[a]
RDST	4.9 [3.3]	6.1 [3.1]	0.17
WT, s	12.9 [5.7]	12.3 [3.9]	0.69
TUG, s	13.0 [5.9]	13.0 [4.6]	0.99
FR, cm	19.0 [7.7]	21.2 [6.8]	0.29

RDST: rapid dimentia screening test; WT: walking test; TUG: timed up & go test; FR: functional reach test. Values are shown as mean [SD].

[a] p-value are based on t-test or chi-square.

Table 2
Two-way repeated measures ANOVA findings on measurement parameters in No-fear and Fear group.

	Single-task		Dual-task		Interaction		
	No-fear	Fear	No-fear	Fear	*F*-value	*p*-value	η^2
Reaction phase, s	0.29 [0.11]	0.31 [0.09]	0.52 [0.27]	0.54 [0.15]	0	0.99	0
APA phase, s	0.46 [0.16]	0.43 [0.09]	0.51 [0.14]†	0.62 [0.23]**	7.21	0.01	0.12

Values are shown as mean [SD].
† Significant difference between No-fear and Fear groups in individual task condition (Bonferroni, $p < 0.05$).
** Significant difference between single- and dual-task condition in individual groups (Bonferroni, $p < 0.01$).

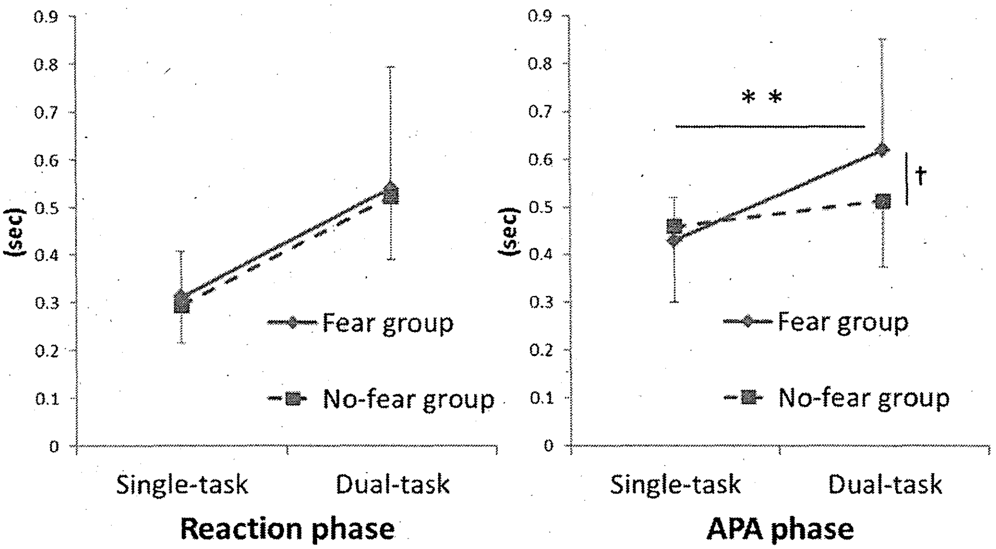

Fig. 2. Average of measurement parameters for both groups of participants in both task conditions: single-task condition and dual-task condition. *Note.* †Significant difference between No-fear and Fear groups in the individual-task condition (Bonferroni, $p < 0.05$). **Significant difference between the single- and dual-task conditions in individual groups (Bonferroni, $p < 0.01$).

Interaction effects between group and task conditions were detected in the APA phase ($p = 0.01$, F1, 55 = 7.21, $\eta^2 = 0.12$; Fig. 2). The APA phase was longer for the dual-task condition for both the Fear and No-fear groups ($p < 0.001$, F1, 55 = 23.1, $\eta^2 = 0.29$), but no significant main group effect was found ($p = 0.26$, F1, 55 = 1.3, $\eta^2 = 0.023$). The main effect was qualified by the interaction. A post hoc comparison showed that the APA phases of the Fear group were significantly longer than those of the No-fear group under the dual-task condition ($p = 0.036$, $d = 0.62$) and that there was no statistical difference between groups under the single-task condition ($p = 0.041$, $d = 0.23$). The Fear group 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 the No-fear participants ($p = 0.11$, $d = 0.33$).

Table 3 shows all variables for Non-fallers and Fallers in the single- and dual-task conditions. Interaction effects between group and task conditions were detected in the reaction phase ($p = 0.004$, F1, 55 = 9.07, $\eta^2 = 0.14$). The reaction phase was longer for the dual-task condition for both Fallers and Non-fallers ($p < 0.001$, F1, 55 = 70.1, $\eta^2 = 0.56$), and longer for Fallers under both the single- and dual-task conditions ($p = 0.006$, F1, 55 = 8.11, $\eta^2 = 0.13$). The main effect was qualified by the interaction. A post hoc comparison showed that the reaction phases of the Fallers were significantly longer than those of the Non-fallers under the dual-task condition ($p = 0.002$, $d = 0.88$), and that there was no statistical difference between groups under the single-task condition ($p = 0.67$, $d = 0.2$). Both Fallers and Non-fallers had significant increases in the reaction phase under the dual-task condition compared with the single-task condition ($p < 0.001$, $d = 1.84$; $p < 0.001$, $d = 1.27$).

Interaction effects between group and task conditions were detected in the APA phase ($p = 0.005$, F1, 55 = 8.39, $\eta^2 = 0.13$). The APA phase was longer for the dual-task condition for both Fallers and Non-fallers ($p < 0.001$, F1, 55 = 25.2, $\eta^2 = 0.31$), and longer for Fallers under both the single- and dual-task conditions ($p = 0.01$, F1, 55 = 7.08, $\eta^2 = 0.11$). The main effect was qualified by the interaction. A post hoc comparison showed that the APA phases of the Fallers were significantly longer than those of the Non-fallers

Table 3
Two-way repeated-measures ANOVA findings on measurement parameters in non-fallers and fallers.

	Single-task		Dual-task		Interaction		
	Non-fallers	Fallers	Non-fallers	Fallers	*F*-value	*p*-value	η^2
Reaction phase, s	0.29 [0.10]	0.31 [0.11]	0.46 [0.18]††,**	0.65 [0.27]**	9.07	0.004	0.14
APA phase, s	0.44 [0.13]	0.46 [0.13]	0.49 [0.14]††	0.66 [0.22]**	8.39	0.005	0.13

Values are shown as mean [SD].
†† Significant difference between non-fallers and fallers in the individual-task condition (Bonferroni, $p < 0.01$).
** Significant difference between single- and dual-task conditions in individual groups (Bonferroni, $p < 0.01$).