through the body. Participants lay supine with their arms and legs extended and relaxed during bioelectrical impedance measurement. Leg muscle mass adjusted by their whole-body weight (LLM) was used for analysis (25).

Fall experience and fear of falling

We assessed fear of falling by asking a single yes or no question "Are you afraid of falling?",which has a high test-retest reliability (26). This question was asked at the pre- and post-intervention. The test-retest reliability using the Kappa coefficient was 0.960.

Measurement of physical activities

Measurement of step counts was conducted between October 2010 and May 2011. Participants were instructed to wear the pedometer in their pocket of dominant leg for 14 consecutive days except bathing, sleeping, and performing water-based activities. This pedometer has a 30-day data storage capacity. We calculated the averages of their daily step counts for 2 weeks.

Required sample size

Previous pedometer-based walking program showed a significant improvement in average daily steps from 7,220 to 10,410 (effect size = 0.77) (27). We designed the effect size of the current study to be 0.7. With a significance level of 0.05, a power of 80%, and a moderate effect size (0.7), a minimum of 34 participants were needed in both intervention and control groups. Accounting for a potential 20% attrition rate, a total of 82 participants were recruited for this study, which was deemed large enough to detect statistically significant differences.

Statistical analysis

Baseline characteristics of intervention and control groups were compared to examine the comparability of the 2 groups. Differences in the demographic variables between the 2 groups were analysed using the Student's t-test or chi-square test.

Relative risk was then calculated, and the chi-square test was used to evaluate the effect of interventions on fear of falling. The effect of exercise on outcome measures was analyzed using a mixed 2 × 2 (group (intervention and control groups) × time (pre-intervention, post-intervention)) analysis of variance. Post hoc Tukey tests were used to assess whether group or time periods showed significant differences.

In the intervention group, the relationship between the percent change of daily steps and percent change of other measures was investigated with the Spearmann correlation coefficient.

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

Results

Overall, 103 people were screened, and 87elderly (84.5%) who met the inclusion criteria for the trial and agreed to participate were enrolled (Fig. 1). Among the individuals who did not meet the inclusion criteria (n = 16), most were excluded because they had exercised regularly in the 6 months before screening. Four people who were eligible for the study withdrew their consent after telephone screening. Of 87 individuals selected for the study, 82 (94.3%) completed the 12-month follow-up: 40 in the intervention group (93.0%) and 42 in the control group (95.5%).

All 24 scheduled intervention sessions were completed. The median relative adherence was 100% (25th–75th percentile, 95.6–100%) in the intervention group. No health problems, including cardiovascular or musculoskeletal complications, occurred during daily walking or testing. Minor problems such

Figure 1
Flow chart showing the distribution of participants throughout the trial

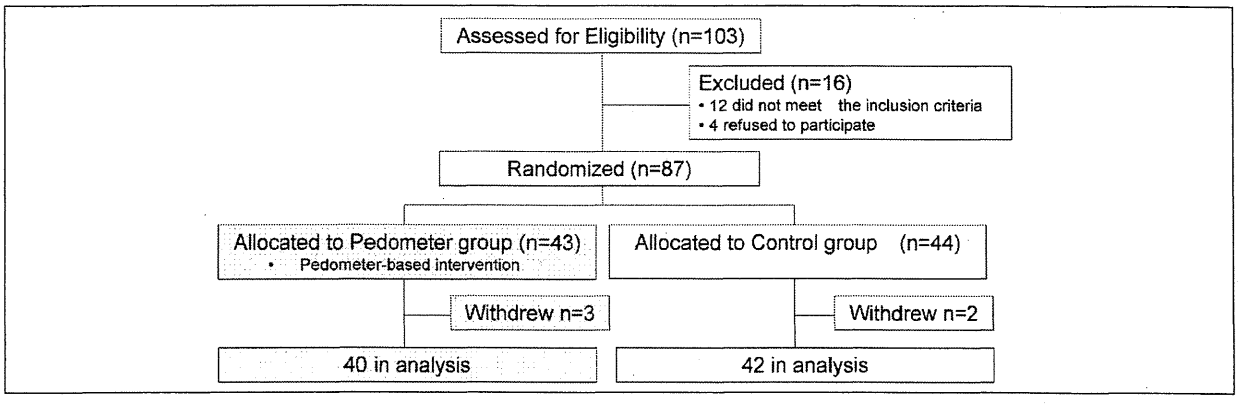

Tableau 1
Comparison of demographic characteristics and measurements in intervention and control groups

	Mean	SD	Mean	SD	P-value
Age (year)	75.5	5.9	75.8	7.6	0.83
Gender, female	20 (50.0%)		20 (47.6%)		0.50
Height (cm)	159	10.7	157.2	8.9	0.28
Weight (kg)	57.6	9.1	59.1	10.9	0.42
BMI (kg/m²)	22.7	2.5	24.1	5.1	0.10
Number of Medications	4.6	1.9	5.0	1.9	0.29
RDST	8.3	1.9	8.0	2.2	0.61
Walking aids	6 (15.0%)		5 (11.9%)		0.47
Falls in the last 1 year	10 (25.0%)		14 (33.3%)		0.28

BMI: body mass index; RDST: rapid dementia screening test

Table 2
Functional fitness in each group at pre- and post-intervention

			Baseline		Post-intervention			Time X group effect	
measures		**group**	**Mean**	**SD**	**Mean**	**SD**		**F-value**	**P-value**
Lean leg mass	(kg/weight)	I	0.154	0.016	0.168	0.027 *	#	5.01	0.03
		C	0.158	0.018	0.159	0.020			
Walking time	(sec)	I	11.7	3.2	10.8	2.7 **	#	5.90	0.02
		C	11.7	2.9	11.7	3.3			
Timed up & go test	(sec)	I	12.0	4.1	11.4	3.1 *	#	6.10	0.02
		C	12.3	3.3	12.6	4.2			
Functional reach	(cm)	I	20.2	8.8	23.7	7.2		3.00	0.09
		C	20.3	6.1	20.7	6.7			
Five chair stand	(sec)	I	12.0	5.0	12.2	6.0		0.06	0.81
		C	13.3	4.1	13.3	4.9			
Physical activity	(steps)	I	2031	1323	3726	1607	##	51.66	<0.01

I: Intervention group; C: Control group; * P<0.05, ** P<0.01: As calculated by comparing pre-intervention value; # P<0.05, ## P<0.01: As calculated by group comparison

as muscle pain after the first training sessions and fatigue were observed in the intervention group. All problems were managed easily using adjustment of the intervention, and they improved during the intervention.

Participants in intervention and control groups were comparable and well matched with regard to their baseline characteristics (Table1). There were no significant differences in age, body weight, height, gender, RDST scores, number of medications, users of walking aids, or experiences of falls in the previous year.

In the intervention group, average daily steps were increased by 83.4% (from 20311323 to 3726 1607) during the study period, but not in the control group (from 20471698 to 22671837). Participants in the intervention group had significantly greater improvements in secondary outcome measures such as LLM, walking time, TUG, and physical activity ($P < 0.05$). However, other secondary outcome measures were not significantly different between the 2 groups ($P > 0.05$) (Table2).

In the pre-intervention period, fear of falling was 55.0% and 47.6% in the intervention and control groups, respectively. The relative risk was calculated as 0.865 (95% CI: 0.566 - 1.322) for fear of falling for participants in the control group compared with those in the intervention group ($p = 0.327$). After the intervention, fear of falling was decreased to 30.0% in the intervention group, while that was not changed in the control group (52.4%). Relative risk was calculated as 1.746 (95% CI: 1.003 – 3.039) for fear of falling for participants in the controlgroup compared with those in the intervention group ($p = 0.033$).

To determine the association of percent change in daily steps withthatin other outcome measures, we analysed Spearmann's

correlation coefficients in the intervention group. The percent change of daily steps was correlated with that of leg muscle mass (r=0.476, P=0.014), walking time (r=-0.789, P<0.01), TUG (r=-0.441, P=0.009), and functional reach (r=0.450, P=0.006). The percent change of daily steps was not significantly correlated with that of 5CS (r=-0.234, P=0.295).

Discussion

In this 6-month pilot RCT to address the role of pedometer-based intervention for older adults, we have shown that the average daily steps were successfully increased by 83.4%in the intervention group, and that the pedometer-based behavior change program was very effective for the improvement of physical activity, fear of falling, locomotive function, and leg muscle mass. These results suggested that pedometer-based behavioral change programs can be applied to sedentary older adults to prevent the progression of frailty and disability.

We showed that the pedometer-based behavioral change program was very effective for the improvement of average daily steps. Goal setting and self-monitoring of behavior are crucial for behavioral change. In this study pedometers were primarily used as a motivational tool and our behavioral support seemed to have mainly affected the behavioral change toward increasing physical activity.

We found that there was moderate correlation between percent change of daily steps and that of other physical functions. These results suggest that the promotion of physical activity is potentially beneficial for a wide spectrum of health-related outcomes in older adults. Due to such benefits, physical activity should be indicated to prevent sarcopenia, frailty and disability. Recent study suggested that the physical activity is correlated with leg muscle mass (18) and the lower extremity function such as walking speed and knee extension torque (28) in the elderly aged 75 years and above. As an underlying mechanism, Tissandier et al. reported that regular physical activity could maintain higher levels of insulin-like growth factor-1 (29). Further, improvement of inflammation, oxidative damage, and insulin resistance may be related to higher physical activity and could mediate the improvement of the health status and protection from negative health-related events. However, in spite of its simple and inexpensive applicability, few studies have addressed the relationship between physical activity and physical function by pedometer-based intervention in older adults. In 12-week pedometer-based trial of older with knee osteoarthritis, Talbot et al showed increased daily steps, walking speed, and knee extension strength (30). A 4-week trial of a pedometer-based walking program in older adults shows an improvement in number of daily steps, lower limb endurance, and locomotive function (16). These reports and ours indicated that increased physical activity (daily steps) is associated with improvements in numerous physical functions.

The pedometer-based behavioral change program was effective in improving leg muscle mass and fear of falling. These results suggest that the pedometer-based behavioral change program is effective for the prevention of sarcopenia and reducing falls in community-dwelling older adults. A pedometer is very small and relatively inexpensive, and may be useful as a large population approach for the prevention of dependency. However, not only increased physical activity, but also better nutrition such as sufficient protein intake is important for the prevention of sarcopenia (31).

There are several limitations to this study. First, these findings should be considered as preliminary because of the relatively small sample size (n=82). Second, statistical analyses were performed for each of the four outcome measures separately, including the physical performance tests, which increased the possibility of false-positive findings (type 1 error). Finally, as indicated by their willingness to participate in this study, 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 pedometer-based behavior change program is useful in improving physical activity, fear of falling, physical performance, and leg muscle mass in sedentary older adults. A larger study is needed to confirm the present results and to evaluate the most effective exercises for the prevention of dependency.

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Sponsor's Role: None

References

1. Aoyagi Y, Katsuta S (1990) Relationship between the starting age of training and physical fitness in old age. Can J Sport Sci 15: 65–71.
2. Aoyagi Y, Shephard RJ (1992) Aging and muscle function. Sports Med 14: 376–396.
3. Aoyagi Y, Shephard RJ (2009) Steps per day: the road to senior health? Sports Med 39: 423–438.
4. Ishikawa-Takata K et al (2003) Relationship of lifestyle factors to bone mass in Japanese women. J Nutr Health Aging 7: 44-53.
5. Nelson ME, Rejeski WJ, Blair SN et al (2007) Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. Med Sci Sports Exerc 39: 1435–1445.
6. Singh NA, Clements KM, Singh MA (2001) The efficacy of exercise as a long-term antidepressant in elderly subjects: a randomized controlled trial. J Gerontol A BiolSci Med Sci 56: M497- M504.
7. Mazzeo RS, Cavanagh P, Evans WJ et al (1998) American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. Med Sci Sports Exerc 30: 992-1008.
8. Simons LA, Simons J, McCallum J et al (2006) Lifestyle factors and risk of dementia: Dubbo study of the elderly. Med J Aust 184: 68-70.
9. Spirduso WW, Cronin DL (2001) Exercise dose-response effects on quality of life and independent living in older adults. Med Sci Sports Exerc 33: S598-S608.

10. Craig P, Dieppe P, Macintyre S et al (2008) Developing and evaluating complexinterventions: The new Medical Research Council guidance. BMJ 337: a1655.
11. Abraham C, Michie S (2008) A taxonomy of behavior change techniques used ininterventions. Health Psychol 27:379–387.
12. Marteau T, Dieppe P, Foy R et al (2006) Behavioural medicine: Changing our behaviour. BMJ 332: 437–438.
13. Bravata DM, Smith-Spangler C, Sundaram V et al (2007) Using pedometers to increase physical activity and improve health: a systematic review. JAMA 21; 298: 2296-304.
14. Dakin LE et al (2010) Promoting walking amongst older patients in rehabilitation: Are accelerometers the answer? J Nutr Health Aging 14: 863-865.
15. Farmer B, Croteau K, Richeson N et al (2006) Using pedometers as a strategy to increase the daily steps of older adults with chronic illness: From research to practice. Home Healthc Nurse 24:449-456.
16. Snyder A, Colvin B, Gammack JK (2011) Pedometer use increases daily steps and functional status in older adults. J Am Med Dir Assoc 12: 590-594.
17. Kalbe E, Calabrese P, Schwalen S et al (2003) The Rapid Dementia Screening Test (RDST): a new economical tool for detecting possible patients with dementia. Dement Geriatr Cogn Disord 16: 193-199.
18. Park H, Park S, Shephard RJ, et al (2010) Yearlong physical activity and sarcopenia in older adults: the Nakanojo Study. Eur J Appl Physiol 109: 953-61.
19. Crouter SE, Schneider PL, Karabulut M et al (2003) Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. Med Sci Sports Exerc 35: 1455-1460.
20. Lopopolo RB, Greco M, Sullivan D et al (2006) Effect of therapeutic exercise on gait speed in community-dwelling elderly people: a meta-analysis. PhysTher 86: 520-540.
21. Podsiadlo D, Richardson S (1991) The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 39: 142–148.
22. Duncan PW, Weiner DK, Chandler J et al (1990) Functional reach: a new clinical measure of balance. J Gerontol 45: M192-M197.
23. Guralnik JM, Simonsick EM, Ferrucci L et al (1994) A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol 49: M85-M94.
24. Miyatani M, Kanehisa H, Msuo Y et al (2001) Validity of estimating limb muscle volume by bioelectrical impedance. J Appl Physiol 91: 386-394.
25. Estrada M, Kleppinger A, Judge JO, et al (2007). Functional impact of relative versus absolute sarcopenia in healthy older women. J Am Geriatr Soc 55: 1712-1719.
26. Reelick MF, van Iersel MB, KesselsRP et al (2009) The influence of fear of falling on gait and balance in older people. Age Ageing 38:435-440.
27. Araiza P, Hewes H, Gashetewa C, et al (2006) Efficacy of apedometerbased physical activity program on parameters of diabetes cont rol in type2 diabetes mellitus. Metabolism. 55: 1382-1387.
28. Aoyagi Y, Park H, Watanabe E, et al (2009) Habitual physical activity and physical fitness in older Japanese adults: the Nakanojo Study. Gerontology. 55: 523-531.
29. Tissandier O, Péres G, Fiet J, et al (2001) Testosterone, dehydroepiandrosterone, insulin-like growth factor 1, and insulin in sedentary and physically trained aged men. Eur J Appl Physiol. 85: 177-1784.
30. Talbot LA, Gaines JM, Huynh TN et al (2003) A home-based pedometer-driven walking program to increase physical activity in older adults with osteoarthritis of the knee: a preliminary study. J Am Geriatr Soc 51: 387-392.
31. Boirie Y (2009) Physiopathological mechanism of sarcopenia. J Nutr Health Aging 13: 717-23

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Effects of dual-task switch exercise on gait and gait initiation performance in older adults: Preliminary results of a randomized controlled trial

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ABSTRACT

Few studies have reported the effect of exercise intervention for improving postural control deficit in older adults at high risk of falling. We have developed a "Dual-task Switch Exercise (DSE)" program that focuses on gait initiation performance under the dual-task condition. The purpose of this study was to evaluate whether gait initiation performance could be improved by a specific exercise intervention. Eighteen participants were randomly assigned to either DSE or control groups. The DSE group received focused training to improve the ability to initiate movements quickly under the dual-task condition. The control group received steady-state walking training. After 30-min of seated training sessions, participants received 5-min individualized training sessions once a week for 24 weeks. In the pre- and post-training period, performance of the steady-state gait (10-m walking time) and gait initiation (reaction time, backward center of pressure (COP) displacement) were measured under the single- and dual-task conditions. The results of a randomized clinical trial showed that both groups showed improvement of steady-state walking time under the dual-task condition (main effect of time; $p = 0.018$). However, DSE was more effective in improving both the reaction time and backward COP displacement during gait initiation under the dual-task condition than control (interaction effect of time × group; reaction time, $p = 0.015$; COP displacement, $p = 0.011$). There were no significant differences in steady-state gait and gait initiation performance under the single-task condition between pre- and post-training in both groups. Only the specific exercise intervention improved gait initiation performance under the dual-task condition.

1. Introduction

More than 30% of community-dwelling people over the age of 65 fall each year (Campbell et al., 1990). Falls cause fractures and head injuries (Dargent-Molina et al., 1996) and are associated with a decline in function and mobility (Marottoli et al., 1992). A wide range of preventative strategies have been studied, including psychotropic medication withdrawal, treatment of cardiovascular disorders, and domestic hazard assessment (Tinetti et al., 1996). The 2009 Cochrane review addressed the effectiveness of exercise interventions in preventing falls (Gillespie et al., 2009). It was reported that exercise intervention was particularly effective for previous fallers (Buchner et al., 1997). This suggests that exercise intervention should be more accurately targeted to this group (Lord et al., 2003).

There are few studies that focus on improving the postural control deficit of older adults who are at high risk of falling through exercise intervention. In older adults, gait speed under the dual-task condition, which was considered as postural performance associated with the risk of falling (Beauchet et al., 2008a,b; Hofheinz and Schusterschitz, 2010), could only be improved by dual-task training (Silsupadol et al., 2009b). However, some research studies have reported no significant differences in dual-task-gait performance between fallers and non-fallers (Stalenhoef et al., 2002; Hyndman and Ashburn, 2004; Andersson et al., 2006). Therefore, improving gait speed under the dual-task condition may not necessarily reduce the risk of falling in older adults. Because gait speed under the dual-task conditions is not always a sensitive indicator of fall risk, it is necessary to focus on specific aspects of gait, and develop more sensitive indices for dynamic balance control associated with fall risk.

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As such, we focused on gait initiation by examining several aspects of gait, including gait termination and turning, because these enable fundamental and vital transitions from a condition of a static stable support to a continuously unstable posture during locomotion (Crenna and Frigo, 1991). Gait initiation is a voluntary destabilizing behavior that requires decoupling between COP and center of gravity (COG) to accelerate the COG (Halliday et al., 1998; Mbourou et al., 2003). The backward displacement of COP during gait initiation decreases with advancing age and disability (e.g., neurological disorders and vestibular hypofunction) (Halliday et al., 1998; Chang and Krebs, 1999). These previous findings suggest that forward acceleration during gait initiation is a unique and challenging task for the neuromuscular system. Further, gait initiation requires more attentional resources (Suzuki et al., 2004) and may cause more dual-task interference with a cognitive task than steady-state walking does.

We previously investigated the relationship between the risk of falling and backward displacement of COP during gait initiation, which is considered to be a sensitive indicator of balance dysfunction (Chang and Krebs, 1999; Hass et al., 2004). Limiting backward displacement of COP could function as an adjustment strategy to prevent a large disequilibrium between COG and COP (Tokuno et al., 2003). We found that the gait initiation performance of elderly fallers was poorer (i.e., reduction in backward displacement of COP) under the dual-task condition than that of non-fallers even if the steady-state walking time was identical under both the single- and dual-task conditions between the groups (Uemura et al., in press). In addition, the ability to initiate and execute a quick voluntary step was impaired in older adults at high risk of falling when their attention was divided by a secondary cognitive task (St George et al., 2007).

Gait initiation performance under dual-task conditions may be a better discriminator between fallers and non-fallers than steady-state gait speed. Thus, we developed a "Dual-task Switch Exercise (DSE)," which focuses on improving the ability to initiate and switch movements quickly under the dual-task condition. This preliminary randomized controlled trial aimed to evaluate whether gait initiation performance could be improved by a specific exercise intervention (DSE) in order to assess the effectiveness of DSE for fall prevention primarily in older adults. We hypothesized that DSE would improve gait initiation performance under dual-task conditions, and that training of steady-state gait under dual-task conditions would not be associated with gait initiation performance.

2. Materials and methods

2.1. Participants

Participants were recruited using an advertisement in local press. The following criteria were used to screen participants in the initial interview: aged 65 and older, community-dwelling, able to walk independently or with a cane, minimal hearing and vision impairments (i.e. participants were able to hear the instructions in a normal voice, and were able to easily see the visual cues used in the experiment), and no regular exercise in the previous 12 months. Exclusion criteria were as follows: severe cardiac, pulmonary, or musculoskeletal disorders; pathologies associated with increased risk of falling (e.g., Parkinson disease); inability to execute arithmetic tasks; serious visual impairment not correctable with spectacles; and the inability to follow multiple commands by a physical therapist. We recorded mental status (Rapid Dementia Screening Test) (Kalbe et al., 2003). Written informed consent was obtained from the participants in accordance with the guidelines approved by the XXX University Graduate School of Medicine (approval number, E-844) and the Declaration of Human Rights, Helsinki, 1975.

2.2. Study design and randomization

Participants were randomized using block randomization in blocks of 4. Using this sequence, the participants were then randomly assigned to the DSE ($n = 9$) or control ($n = 9$) group.

2.3. Intervention

All participants received 30 min of seated group training sessions once a week for 24 weeks. Each exercise class included a standardized format: (1) stretching of upper limb muscles, (2) stretching of trunk muscles, (3) stretching of lower limb muscles, (4) agility training of lower limb (e.g., rapid stepping, ankle pumping), (5) strength training of lower limb (e.g., knee extension, calf raise, toe raise). Strength training was executed by one's own weight and training equipment was not used. After these exercises, participants in both the DSE and control groups performed individual exercises for 5 min.

2.4. Dual-task switch exercise

In order to train the ability to initiate and switch movements quickly under the dual-task condition, participants in the DSE group were instructed to execute the following motor tasks while performing a cognitive task: (a) the COP shift exercise was to shift weight laterally from one foot to the other, and anterior-posterior weight shifting, performed in a position similar to a fencing posture. This was the basic exercise used to decouple the COP and COG quickly on a fixed support base. (b) The Start-and-Stop exercise was to start walking from a static standing position and stop walking repeatedly. This second exercise focused on training postural control abilities during the transition phase from a static stable support to a continuously unstable posture during locomotion. (c) The Switch exercise was to switch the direction of movement in reverse without turning around; for example, from walking forward to walking backward. This was the last applied exercise that focused on switching ability during continuous movement. In the Start-and-Stop and Switch exercises, participants were instructed to initiate or switch movements by reacting to an auditory cue as quickly as possible.

2.5. Control exercise

Participants in the control group were instructed to execute a steady-state walking (forward, backward, and laterally) exercise while performing a cognitive task on a straight walkway at least 10 m long, without stopping or turning. In this exercise, quick initiation and switching movements were not required.

In both the DSE and control groups, the cognitive load was progressively increased during the 24-week program. The participants of both groups were asked to execute only the motor task without a cognitive task during weeks 1–6 and then to execute individual exercises under the dual-task condition by simultaneously performing simple cognitive tasks, such as forward counting and reciting letters of Japanese alphabet, during weeks 7–12. From week 13, a more difficult cognitive task, such as reciting as many names of animals, vegetables, or professions as possible, was added. In addition, in the DSE group, the cue was changed from verbal instructions (i.e., start or stop) to the sound of clapping hands. Backward counting was not used as a cognitive task in both group exercises because it was used as a secondary task in outcome measures.

2.6. Outcomes

Gait initiation and steady-state gait performance were measured under single- and dual-task conditions as outcome measures. In the gait initiation test, the participants initially stood upright on a force platform on both legs, with their feet abducted 10° and their heels separated mediolaterally by 6 cm. Participants were instructed to initiate walking along the walkway as quickly as possible after a visual LED illumination cue and to continue walking, i.e., 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 in front 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 backward aloud starting from 100 in decrements of 1 while they waited for the visual cue. The order of the tasks was randomized. Before the experimental data were collected, the participants performed at least 3 trials to familiarize themselves with the equipment.

The COP data during the gait initiation tests were collected with a portable force platform (Kistler 9286). The force platform data were sampled at a frequency of 1 kHz and low-pass-filtered at 6 Hz. The initial COP position was defined as the mean amplitude in the 1500-ms period prior to the onset of the visual cue. 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). Measurement parameters comprised reaction time and backward displacement of COP. Reaction time was calculated as the time from the cue to step initiation (Uemura et al., 2011). Backward displacement of COP was calculated as the distance from the initial position to the maximum posterior position in the anteroposterior direction (Fig. 1) (Hass et al., 2004). Backward displacements of COP were standardized by the longitudinal diameters of the support base (Tateuchi et al., 2011). The mean was determined using data from 3 trials.

In the steady-state gait test, the 10-m steady-state walking time (s) was measured under the single- and dual-task conditions. Under the dual-task condition, participants were instructed to count backward aloud starting from 90 by a decrement of 1 (Beauchet et al., 2008a). Walking time was calculated using a stopwatch to measure the time taken to cover the central 10 m of the 14-m walkway (van Loo et al., 2004).

2.7. Statistical analysis

Baseline characteristics were compared among groups using Student's *t*-test for quantitative variables and the chi-square test for qualitative variables. The intervention effects on all outcome measures were determined using two-way repeated measures ANOVA with group (DSE, control) as a between-subjects factor and time (pre-training, post-training) as within-subjects factors. When interaction effects were detected, post hoc comparisons were performed to test the differences in physical function variables between pre- and post-training at each group. The significance level of multiple comparisons was adjusted using the Bonferroni correction ($p < 0.025$). Partial η^2 were reported as measures of effect size. Data analysis was performed using SPSS version 11.0 for Windows (SPSS Inc, Chicago, IL).

3. Results

Of the 34 participants that were screened, 14 did not meet the inclusion criteria and 2 refused to participate. Eighteen participants completed the pre-intervention assessment and were randomly assigned to one of the two training groups; 15 completed the training program and were included in the analysis (one DSE group participant died; two control group participants were excluded because of illness; Fig. 2). There were no significant group differences in any baseline characteristics ($p > 0.05$; Tables 1 and 2). There were no adverse events associated with participation in the study.

3.1. Steady-state walking time on a 10-m walkway

Table 2 depicts all variables for the DSE and control groups at pre- and post-training. No interaction effects between group and time were detected for walking time under the single- and dual-task conditions ($p = 0.79$, $F_{1,13} = 0.075$, and $\eta^2 = 0.006$; $p = 0.093$, $F_{1,13} = 3.28$, and $\eta^2 = 0.2$, respectively). There was no significant main effect of time in walking time under the single-task condition

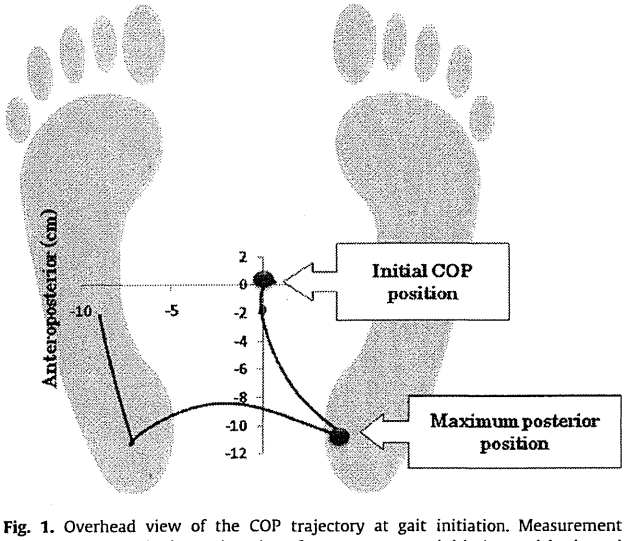

Fig. 1. Overhead view of the COP trajectory at gait initiation. Measurement parameters comprised reaction time from cue to step initiation and backward displacement of COP in the anteroposterior direction from the initial position to the maximum posterior position.

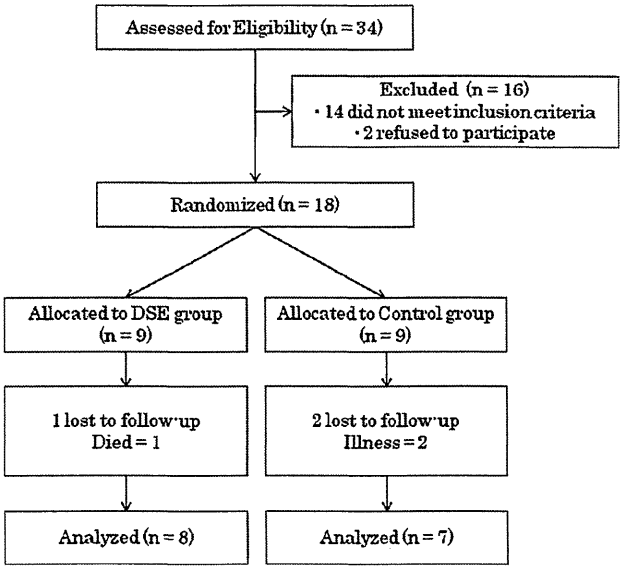

Fig. 2. Flow diagram of participant progress through phases of the randomized controlled trial.

Table 1
Baseline characteristics of both groups of participants.

	DSE group ($n=8$)	Control group ($n=7$)	p-Value
Age (years)	82.4 ± 5.9 (75–93)	82.4 ± 6.8 (76–92)	0.99
Height (cm)	154.7 ± 9.7	149.5 ± 9.1	0.36
Weight (kg)	50.8 ± 6.8	48.3 ± 9.4	0.57
Gender (% males)	28.6%	12.5%	0.43
RDST	4.6 ± 3.0	3.3 ± 3.1	0.45

Note: Values are shown as mean ± SD (range). p-Values are based on t-test or chi-square.
RDST: Rapid Dementia Screening Test.

($p = 0.22$, $F_{1,13} = 1.65$, and $\eta^2 = 0.11$), while there was a significant main effect of time in walking time under the dual-task condition ($p = 0.018$, $F_{1,13} = 7.3$, and $\eta^2 = 0.36$).

3.2. Reaction time

No interaction effects between groups and time were detected in reaction time under the single-task condition ($p = 0.92$, $F_{1,13} = 0.01$, and $\eta^2 = 0.001$). There was no significant main effect of time ($p = 0.92$, $F_{1,13} = 0.01$, and $\eta^2 = 0.001$). Significant interaction effects between groups and time were detected for reaction time under the dual-task condition ($p = 0.015$, $F_{1,13} = 7.8$, and $\eta^2 = 0.38$). The DSE group demonstrated significantly improved reaction time under the dual-task condition (i.e., reacted faster) after training ($p = 0.007$). However, no significant improvement was found for the control group ($p = 0.411$).

3.3. Backward displacement of COP

No interaction effects between groups and time were detected in backward displacement of COP under the single-task condition ($p = 0.31$, $F_{1,13} = 1.1$, and $\eta^2 = 0.079$). There was no main effect of time ($p = 0.17$, $F_{1,13} = 2.1$, and $\eta^2 = 0.14$). Significant interaction effects between groups and time were detected for the backward displacement of COP under the dual-task condition ($p = 0.011$, $F_{1,13} = 8.7$, and $\eta^2 = 0.4$). Moreover, the DSE group showed an inclination toward improvement, while the control group showed an inclination toward deterioration on the backward displacement of COP. However, there were no significant differences between pre- and post-training in both the DSE ($p = 0.029$) and control ($p = 0.114$) groups.

4. Discussion

The goal of this study was to evaluate whether gait initiation performance under the dual-task condition could be improved by a specific exercise intervention (DSE). The DSE group received training that focused on improving the ability to initiate and switch movements quickly under a dual-task condition, while the control group received steady-state walking training under a dual-task condition. Our results indicate that the type and magnitude of the benefits vary by training type. Both the DSE and control groups showed improvement of steady-state walking time under the dual-task condition. However, DSE was more effective in improving both reaction time and backward displacement of COP during gait initiation under the dual-task condition than the control exercise.

Gait initiation performance under the dual-task condition (i.e., reaction time and backward displacement of COP) was improved by DSE only, which is a specific exercise intervention that more accurately targets previous fallers. Oddsson et al. (2007) emphasized the importance of overload and specificity principles, suggesting that it is crucial to maintain a progressive and specific training load, as in any type of training, for improvement to occur. Changes in performance under the dual-task condition are considered to depend mainly on one's capacity to properly allocate attention between the 2 tasks (Beauchet et al., 2009). In addition, it is thought that gait initiation, which needs voluntary control, requires more attention resources than steady-state walking, which is highly automated (Bardy and Laurent, 1991; Suzuki et al., 2004). Therefore, DSE strengthened the capacity of attention allocation and information processing during the transition phase of movement under the dual-task condition and led to specific improvement in gait initiation performance. The control exercise, including steady-state gait, failed to add sufficient loads for training attention capacity.

Post hoc comparison revealed significant improvement of the reaction time in the DSE group under the dual-task condition after training. Melzer and Oddsson (2004) reported that a short-term learning effect was observed for the step initiation reaction time under the dual-task condition in older adults. It appeared that the reaction time under the dual-task condition was highly trainable and showed significant improvement in response to 24-week DSE training schedule. Moreover, in the DSE group, a significant interaction effect between groups and time was detected for backward displacement of COP under the dual-task condition, as was an inclination for improvement. However, our sample size and statistical power are not sufficient to reveal significance in the post hoc comparison.

Both steady-state gait and gait initiation performance under the single-task condition did not improve by DSE or the control exercise. One reason might be the low frequency and short duration of the exercise interventions in the present study, which were 30-min training sessions once a week. These were smaller than those in a previous report, which executed 45-min training sessions 3 times a week (Silsupadol et al., 2009a,b).

The major limitation of this study was the small sample size. Thus, the present study may be better characterized as a preliminary study. It remains unclear whether improvement of gait initiation performance under the dual-task condition could

Table 2
Findings on outcome measures at pre-training (Pre), the end of training (Post) by intervention group.

	DSE group ($n=8$)		Control group ($n=7$)		Interaction effect (time × group)			Main effect (time)		
	Pre	Post	Pre	Post	F-Value	p-Value	Partial η^2	F-Value	p-Value	Partial η^2
Reaction time (s)										
ST	0.35 ± 0.12	0.35 ± 0.12	0.39 ± 0.24	0.39 ± 0.12	0.01	0.92	0.001	0.01	0.92	0.001
DT	0.71 ± 0.23	0.44 ± 0.2*	0.56 ± 0.23	0.64 ± 0.32	7.8	0.015	0.38	2.4	0.14	0.16
Backward displacement of COP (%)										
ST	12.3 ± 12.2	15.3 ± 12.1	15.2 ± 10.8	15.7 ± 8.9	1.1	0.31	0.079	2.1	0.17	0.14
DT	11.9 ± 10.7	14.8 ± 10.5	13.4 ± 8.9	9.0 ± 6.4	8.7	0.011	0.40	0.41	0.53	0.03
Steady-state walking time (s)										
ST	13.4 ± 3.2	12.6 ± 3.2	12.7 ± 4.2	12.2 ± 2.9	0.075	0.79	0.006	1.65	0.22	0.11
DT	18.5 ± 7.2	13.9 ± 4.7	16.9 ± 8.9	16.0 ± 7.7	3.28	0.093	0.20	7.3	0.018	0.36

* Significant difference between pre- and post-training at individual group (Bonferroni, $p < 0.025$).

reduce the incidence of falls in the future. A larger study with sufficient statistical power is needed to conclusively determine the specific improvements of gait initiation performance associated with DSE, and the training effect on preventing accidental falls. Another limitation of this study was that only walking time was used to quantify steady-state gait performance. There are several other measures that could have been used. For example, the COG and COP inclination angles have been shown to be a sensitive measure of balance control during gait in older adults (Lee and Chou, 2006).

5. Conclusions

This is the first study that examined the effect of a specific exercise targeting impaired gait initiation performance under the dual-task condition in older adults who were at high risk of falling. The results of the present study suggest that older adults are able to improve their gait initiation performance under the dual-task condition only after specific types of training (DSE), and that training of steady-state gait under the dual-task condition may not associate with gait initiation performance. This finding would give new insight into developing exercise programs for fall prevention.

Conflict of interest statement

None.

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References

Andersson, A.G., Kamwendo, K., Seiger, A., Appelros, P., 2006. How to identify potential fallers in a stroke unit: validity indexes of 4 test methods. J. Rehabil. Med. 38, 186–191.

Bardy, B.G., Laurent, M., 1991. Visual cues and attention demand in locomotor positioning. Percept. Mot. Skills 72, 915–926.

Beauchet, O., Allali, G., Annweiler, C., Berrut, G., Maarouf, N., Herrmann, F.R., Dubost, V., 2008a. Does change in gait while counting backward predict the occurrence of a first fall in older adults? Gerontology 54, 217–223.

Beauchet, O., Annweiler, C., Allali, G., Berrut, G., Herrmann, F.R., Dubost, V., 2008b. Recurrent falls and dual task-related decrease in walking speed: is there a relationship? J. Am. Geriatr. Soc. 56, 1265–1269.

Beauchet, O., Annweiler, C., Dubost, V., Allali, G., Kressig, R.W., Bridenbaugh, S., Berrut, G., Assal, F., Herrmann, F.R., 2009. Stops walking when talking: a predictor of falls in older adults? Eur. J. Neurol. 16, 786–795.

Buchner, D.M., Cress, M.E., de Lateur, B.J., Esselman, P.C., Margherita, A.J., Price, R., Wagner, E.H., 1997. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. J. Gerontol. A. Biol. Sci. Med. Sci. 52, M218–M224.

Campbell, A.J., Borrie, M.J., Spears, G.F., Jackson, S.L., Brown, J.S., Fitzgerald, J.L., 1990. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. Age Ageing 19, 136–141.

Chang, H., Krebs, D.E., 1999. Dynamic balance control in elders: gait initiation assessment as a screening tool. Arch. Phys. Med. Rehabil. 80, 490–494.

Crenna, P., Frigo, C., 1991. A motor programme for the initiation of forward-oriented movements in humans. J. Physiol. 437, 635–653.

Dargent-Molina, P., Favier, F., Grandjean, H., Baudoin, C., Schott, A.M., Hausherr, E., Meunier, P.J., Breart, G., 1996. Fall-related factors and risk of hip fracture: the EPIDOS prospective study. Lancet 348, 145–149.

Gillespie, L.D., Robertson, M.C., Gillespie, W.J., Lamb, S.E., Gates, S., Cumming, R.G., Rowe, B.H., 2009. Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev, CD007146.

Halliday, S.E., Winter, D.A., Frank, J.S., Patla, A.E., Prince, F., 1998. The initiation of gait in young, elderly, and Parkinson's disease subjects. Gait Posture 8, 8–14.

Hass, C.J., Gregor, R.J., Waddell, D.E., Oliver, A., Smith, D.W., Fleming, R.P., Wolf, S.L., 2004. The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults. Arch. Phys. Med. Rehabil. 85, 1593–1598.

Hofheinz, M., Schusterschitz, C., 2010. Dual task interference in estimating the risk of falls and measuring change: a comparative, psychometric study of four measurements. Clin. Rehabil. 24, 831–842.

Hyndman, D., Ashburn, A., 2004. Stops walking when talking as a predictor of falls in people with stroke living in the community. J. Neurol. Neurosurg. Psychiatry 75, 994–997.

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

Lee, H.J., Chou, L.S., 2006. Detection of gait instability using the center of mass and center of pressure inclination angles. Arch. Phys. Med. Rehabil. 87, 569–575.

Lord, S.R., Castell, S., Corcoran, J., Dayhew, J., Matters, B., Shan, A., Williams, P., 2003. The effect of group exercise on physical functioning and falls in frail older people living in retirement villages: a randomized, controlled trial. J. Am. Geriatr. Soc. 51, 1685–1692.

Marottoli, R.A., Berkman, L.F., Cooney Jr., L.M., 1992. Decline in physical function following hip fracture. J. Am. Geriatr. Soc. 40, 861–866.

Mbourou, G.A., Lajoie, Y., Teasdale, N., 2003. Step length variability at gait initiation in elderly fallers and non-fallers, and young adults. Gerontology 49, 21–26.

Melzer, I., Oddsson, L.I., 2004. The effect of a cognitive task on voluntary step execution in healthy elderly and young individuals. J. Am. Geriatr. Soc. 52, 1255–1262.

Oddsson, L., Boissy, P., Melzer, I., 2007. How to improve gait and balance function in elderly individuals-compliance with principles of training. Academic literature review. Eur. Rev. Aging Phys. Act. 4, 15–23.

Silsupadol, P., Lugade, V., Shumway-Cook, A., van Donkelaar, P., Chou, L.S., Mayr, U., Woollacott, M.H., 2009a. Training-related changes in dual-task walking performance of elderly persons with balance impairment: a double-blind, randomized controlled trial. Gait Posture 29, 634–639.

Silsupadol, P., Shumway-Cook, A., Lugade, V., van Donkelaar, P., Chou, L.S., Mayr, U., Woollacott, M.H., 2009b. Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. Arch. Phys. Med. Rehabil. 90, 381–387.

St George, R.J., Fitzpatrick, R.C., Rogers, M.W., Lord, S.R., 2007. Choice stepping response and transfer times: effects of age, fall risk, and secondary tasks. J. Gerontol. A. Biol. Sci. Med. Sci. 62, 537–542.

Stalenhoef, P.A., Diederiks, J.P., Knottnerus, J.A., Kester, A.D., Crebolder, H.F., 2002. A risk model for the prediction of recurrent falls in community-dwelling elderly: a prospective cohort study. J. Clin. Epidemiol. 55, 1088–1094.

Suzuki, M., Miyai, I., Ono, T., Oda, I., Konishi, I., Kochiyama, T., Kubota, K., 2004. Prefrontal and premotor cortices are involved in adapting walking and running speed on the treadmill: an optical imaging study. Neuroimage 23, 1020–1026.

Tateuchi, H., Ichihashi, N., Shinya, M., Oda, S., 2011. Anticipatory postural adjustments during lateral step motion in patients with hip osteoarthritis. J. Appl. Biomech. 27, 32–39.

Tinetti, M.E., McAvay, G., Claus, E., 1996. Does multiple risk factor reduction explain the reduction in fall rate in the Yale FICSIT Trial? frailty and injuries cooperative studies of intervention techniques. Am. J. Epidemiol. 144, 389–399.

Tokuno, C.D., Sanderson, D.J., Inglis, J.T., Chua, R., 2003. Postural and movement adaptations by individuals with a unilateral below-knee amputation during gait initiation. Gait Posture 18, 158–169.

Uemura, K., Yamada, M., Nagai, K., Ichihashi, N., 2011. Older adults at high risk of falling need more time for anticipatory postural adjustment in the precrossing phase of obstacle negotiation. J. Gerontol. A. Biol. Sci. Med. Sci. 66, 904–909.

Uemura, K., Yamada, M., Nagai, K., Shinya, M., Ichihashi, N. Effect of dual-task on the center of pressure trajectory at gait Initiation in elderly fallers and non-fallers. Aging Clin. Exp. Res., in press.

van Loo, M.A., Moseley, A.M., Bosman, J.M., de Bie, R.A., Hassett, L., 2004. Test-re-test reliability of walking speed, step length and step width measurement after traumatic brain injury: a pilot study. Brain Inj. 18, 1041–1048.

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Effects of Balance Training on Muscle Coactivation During Postural Control in Older Adults: A Randomized Controlled Trial

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Background. Recently, several studies have reported age-associated increases in muscle coactivation during postural control. A rigid posture induced by strong muscle coactivation reduces the degree of freedom to be organized by the postural control system. The purpose of this study was to clarify the effect of balance training on muscle coactivation during postural control in older adults.

Methods. Forty-eight subjects were randomized into an intervention (mean age: 81.0 ± 6.9 years) and a control group (mean age: 81.6 ± 6.4 years). The control group did not receive any intervention. Postural control ability (postural sway during quiet standing, functional reach, and functional stability boundary) was assessed before and after the intervention. A cocontraction index was measured during the postural control tasks to assess muscle coactivation.

Results. Cocontraction index values in the intervention group significantly decreased following the intervention phase for functional reach ($p < .0125$). Cocontraction index values had a tendency to decrease during functional stability boundary for forward and quiet standing tasks. Functional improvements were observed in some of the tasks after the intervention, that is, functional reach, functional stability boundary for forward, one-leg stance, and timed up and go ($p < .05$).

Conclusions. Our study raised the possibility that balance training for older adults was associated with decreases in muscle coactivation during postural control. Postural control exercise could potentially lead older adults to develop more efficient postural control strategies without increasing muscle coactivation. Further research is needed to clarify in greater detail the effects of changes in muscle coactivation.

Key Words: Coactivation—Postural control—Electromyography.

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BOTH static and dynamic postural controls are fundamental components of human activity. Aging has been associated with deterioration in postural control manifesting itself by an increase in postural sway (1,2) and a decrease in the voluntary movement capacity of the body's center of gravity (3,4). Deterioration in these functions leads to a higher risk of falling, which in turn may increase the number of people with high levels of disability (4,5).

Recently, several studies have reported age-associated increases in muscle coactivation during dynamic movements (ie, walking and stair climbing; 6,7) and postural control (8,9), although evidence on whether coactivation is elevated during maximal effort contraction is inconclusive (10). Increased muscle coactivation in older adults is most commonly described as a compensatory mechanism to increase joint stiffness, which thereby enhances stability (6,7,8,9,11).

However, some researchers have pointed out negative effects of coactivation on postural control and movement, observing that excessive muscular coactivation increases postural rigidity (12,13). A rigid posture induced by strong muscle coactivation reduces the degrees of freedom to be organized by the postural control system (14) and may actually compromise the execution of voluntary or compensatory responses (12,15).

In an effort to prevent deterioration in postural control ability, patients undergo balance training in clinical settings. Multiple studies have reported on the effect of balance training on postural control ability. A systematic review of these studies has documented improvements in the ability to stand on one leg and to reach forward without losing balance in postural control tasks (16).

However, the effect of balance training on muscle coactivation during postural control in older adults remains unclear. Investigation of muscle coactivation changes after balance training thus could be an important step toward clarifying the mechanisms by which balance training might

improve postural control. In addition, this information could serve as a useful reference for optimizing rehabilitation strategies in older people. The purpose of this study was to clarify the effect of balance training on muscle coactivation during postural control in older adults. In our previous cross-sectional study, muscle coactivation was negatively correlated with postural control ability in older adults (9). This result raises the possibility that the improvement in postural control after balance training correlates with decreased muscle coactivation.

We hypothesized that muscle coactivation during postural control in older adults would decrease after balance training.

Methods

Participants

Resident subjects were recruited using advertising literature from three nursing homes. The inclusion criteria were set as follows: aged 65 or older, dwelling in a nursing home, able to walk independently (or with a cane), willing to participate in group exercise classes, and with minimal, if any, auditory or visual impairment. Oral and written explanations of the study were offered to the 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 of four points or less; 17), persistent joint pain, or severe musculoskeletal impairment (inability to participate in the training regimen). Any subjects who were willing to participate and met the entry criteria were accepted into the study. Written informed consent was obtained from each participant in the trial in accordance with the Declaration of Human Rights, Helsinki, 1975. This research was approved by the Ethical Review Board of Kyoto University Graduate School of Medicine, Kyoto, Japan.

Study Design and Randomization

Randomization via computer-generated random numbers was performed in blocks of four subjects stratified according to 10 m walking time. The 48 subjects were randomly assigned to the intervention group (n = 24) or the control group (n = 24). The subject assignments were not blinded to the research staff members who performed measurements during the postural control tasks.

Sample Size

Our pilot study investigated the immediate effect of repetitive balance training on muscle coactivation during wobble board standing in young adults and demonstrated that muscle coactivation during standing on the wobble board decreased 12% (cocontraction index; CI), which is accompanied by significant improvement in balance ability (18). The longer intervention period would provoke greater reduction of muscle coactivation in older adults. Therefore, we aimed to detect a 15% (CI) reduction in muscle coactivation in the intervention group compared with the control group. Furthermore, based on the data from our pilot study, we estimated the standard deviation of this degree of change in coactivation to be 14% (CI; 18). Based on these assumptions, a total sample size of 34 participants would be required with alpha set at 0.05, beta at 0.2, and a given power of 0.8. We increased the sample size to a minimum of 44 to account for an anticipated dropout rate of 20%.

Intervention

Subjects assigned to the intervention group received 40 minutes of group balance training sessions twice a week for 8 weeks focused on improving postural control ability. There were three subgroups in the intervention group. Each subgroup consisted of 4–10 people. Exercise classes, which were supervised by a physical therapist, consisted of 10 minutes of warm-up and stretching exercises followed by 30 minutes of balance training. Subjects with a risk of falling during the exercise session were permitted to hold the back of a chair to ensure their postural stability. The level of exercise difficulty was adjusted according to the ability of each subject by altering reach distance or base of support. Subjects who held a chair during exercise were instructed to decrease the assistive level when they were able to acquire postural ability without losing balance during the tasks.

The control group did not receive any intervention but were simply instructed to spend their time as usual during the intervention phase. In order to avoid contamination during the exercise period, the training location was set at a place where the subjects in the control group were not usually visiting when the training session was under way. Subjects assigned to the control group were offered the same exercise program after the conclusion of the study period.

Warm-up and Stretching

Before training, subjects participated in warm-up and stretching exercises consisting of finger joint movement, bending fingers backward, shoulder rotation, waist rotation, upward stretching, lateral bending of the trunk, forward bending, and lower leg stretching. Lower leg stretching was targeted on the hamstrings (bending trunk forward with extended knee) and gluteus maximus (hip flexion using arms) in a sitting position.

Balance Training

Balance training consisted of standing on one leg, tandem standing, shifting weight laterally from one foot to another (19), anterior–posterior or lateral weight shifting, and reaching forward and laterally (20). Subjects were instructed to

maintain their position for 5 or more seconds during each task and performed three sets of these exercises during each training session. The training sessions also included stepping forward and sideways in which the instructor called out each stepping direction. Subjects were provided a wall or chair for safe support as needed.

Testing Procedures and Protocol

The postural control tasks selected for testing consisted of postural sway during quiet standing, functional reach (4,21), and functional stability boundary (forward and backward; 3) because similar movements are performed frequently during activities of daily living.

Postural Sway

Postural sway during quiet standing was measured by 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 stood on the force plate with their feet together and then were asked to gaze at a mark at eye level while maintaining a stationary posture as symmetrically as possible. Quiet standing balance was registered for a period of 10 seconds, from which the root mean square area was calculated. Electromyography (EMG) activity was also recorded for the first 3 seconds of quiet standing. The intraclass correlation coefficient ($ICC_{1,1}$) for the root mean square area was .72 in this study, which indicates "substantial" reliability (22).

Functional Reach

Functional reach was defined as the difference between arm's length and maximal forward reach (4). The position of the fingertip was determined with the shoulder flexed at 90° along a wall. 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, and to maintain this maximal forward reach position for 3 seconds for EMG measurements.

Functional Stability Boundary

Functional stability boundary tasks were performed on the force plate (3). Standing with their heels on a line 10 cm anterior to the posterior edge of the plate, subjects were instructed to standstill for 5 seconds and then to shift their body weight first toward their toes and then toward their heels over the largest possible amplitude while maintaining 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 seconds for EMG measurements, from which the averaged peak center of pressure displacement from the initial position was calculated. The center of pressure displacement for each subject was normalized by the length of that subject's foot.

Additional Physical Function Characteristics

To calculate the 10 m walking time, which we utilized as the stratification variable, we had subjects perform walking trials at their preferred speed over a 12-m walkway, during which we measured the walking time for the middle 10 m (23). The timed up and go test (24) 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 seconds.

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, and soleus (25) and then washed with alcohol. Bipolar surface electrodes (Ambu, Blue sensor M, Denmark) with a 2.0-cm interelectrode distance were placed on the skin around the probable motor point of the muscles (26). 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 soleus and tibialis anterior while the subjects were performing maximal voluntary contractions (MVC; 27). The MVC of the soleus was obtained during maximal isometric plantar flexion, and maximal tibialis anterior 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 (percent MVC) during the postural tasks. The MVCs were recalculated for the posttraining measurement.

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 cocontraction of the tibialis anterior and soleus muscles, the CI was calculated using the method of Falconer and Winter (28). Specifically, the following equation was used:

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

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 tibialis anterior EMG is less than the soleus EMG, and t_2 to t_3 denotes the period during which the soleus EMG is less than the tibialis anterior EMG.

I_{total} is the integral of the sum of tibialis anterior and soleus EMG during performance of the task, calculated in accord with the following equation:

$$I_{total} = \int_{t_1}^{t_2} \left[EMG_{agon} + EMG_{ant} \right](t)dt.$$

The CI calculation was done by a staff member who was blinded to the subject assignments.

Testing Reliability

The test–retest interday reliability of EMG measurements related to electrode positioning was estimated by calculating $ICC_{1.1}$. The $ICCs_{1.1}$ for the CI were as follows: 0.68 (95% CI: 0.36–0.86) for quiet standing, 0.75 (95% CI: 0.47–0.89) for functional reach, 0.86 (95% CI: 0.66–0.94) for functional stability boundary (forward), and 0.91 (95% CI: 0.78–0.96) for functional stability boundary (backward). These ICC values indicated substantial to "almost perfect" reliability for all measurements of CI (22). The $ICC_{1.1}$ for CI without electrode repositioning during quiet standing was 0.93 (95% CI: 0.72–0.98), which indicates almost perfect reliability (22).

Statistics

The results were analyzed using an intention to treat analysis. Baseline characteristics of the intervention and control groups were compared to examine comparability of the two. The Kolmogorov–Smirnov Test was used to test the normality of distributions. Differences between groups were analyzed using the chi-square test for categorical variables, Student's *t* test for continuous variables with normal distribution, and the Mann–Whitney *U* test for nonnormally distributed variables.

The effect of exercise on outcome measurements was analyzed using mixed design 2 × 2 group (intervention and control groups) × time (pretraining and posttraining) analysis of covariance. Baseline values were used as covariates in the analysis of covariance. Statistical significances in CI and muscle activation (percent MVC) were set at 0.0125 (0.05/4) because four tasks measured by EMG were included to assess the muscle coactivation. Post hoc Bonferroni tests were used to assess which group or time periods showed significant differences. Statistical significance in post hoc Bonferroni tests was also set at 0.0125 (0.05/4). $P < .05$ was considered statistically significant in analysis of covariance for physical functions. Data were entered and analyzed using SPSS (Windows version 12.0, SPSS, Inc., Chicago, IL). For all outcome measures, missing data values were imputed using mean values for each corresponding group.

RESULTS

Study Population

Our initial pool of study subjects comprised 108 residents from three nursing homes, of whom 51 refused to participate in the study and nine did not meet the inclusion criteria. The remaining 48 individuals (mean age 83.0 ± 6.8 years) agreed to participate in the study and provided written consent. Of the 48 subjects who enrolled in the study, 40 (83%) completed the 8-week intervention phase and postintervention assessment: 20 in the intervention group (83%) and 20 in the control group (83%). The other eight subjects dropped out because of hospitalization due to chronic illness (two subjects) or absence on the day of the assessment for personal reasons (six subjects). After the imputation of missing data, we performed an intention to treat analysis on the 48 subjects.

Adherence to the Study Protocol

During the 8-week intervention phase, 16 exercise sessions were scheduled and all took place. Excluding the four who dropped out, the intervention group subjects attended an average of 14 sessions and had an overall attendance rate of 82% over the 8 weeks. No health problems, including cardiovascular or musculoskeletal complications, occurred during training sessions or testing.

Baseline Characteristics

Table 1 summarizes baseline data for the 48 subjects who completed the study. No significant differences between the intervention and control groups were observed in any of the characteristics examined, including age, height, and weight.

Effects of Intervention on Muscle Coactivation and Muscle Activity

After the 8-week intervention phase, CI values in the intervention group showed a significant decrease compared with preintervention values for functional reach (pre: 33.8% ± 21.4%, post: 24.1% ± 15.9%, group × time interaction: $F[1,46] = 10.311$, $p = .002$, $\eta^2 = 0.186$). Although there was a significant group-by-time interaction in CI during functional stability boundary (forward; pre: 41.3% ± 25.7%, post: 33.2% ± 20.4%, group × time interaction: $F[1,46] = 7.226$, $p = .010$, $\eta^2 = 0.138$), no significant decrease was found in CI during this task by post hoc test ($p \geqq .0125$; Figure 1).

CI did not significantly change in standing (pre: 51.3% ± 24.4%, post: 40.1% ± 19.9%, interaction: $F[1,46] = 4.975$, $p = .031$, $\eta^2 = 0.100$) or functional stability boundary

Table 1. Baseline Characteristics (mean ± *SD*) of Subjects

	Intervention Group (n = 24)	Control Group (n = 24)	p Value
Age, y	81.0 ± 6.9	81.6 ± 6.4	.762
Body weight, kg	51.3 ± 8.4	52.4 ± 7.6	.680
Height, cm	150.7 ± 6.8	153.1 ± 6.5	.247
Female, %	83.0	92.0	.620
Medication, n (%)	20 (83)	20 (83)	1.000
Number of comorbidities, n (%)			.604
≦3	20 (83)	18 (75)	
4–6	4 (17)	5 (21)	
≧7	0 (0)	1 (4)	
Falls in the last year, n (%)	4 (17)	6 (25)	.613
Postural sway area, cm^2	1.7 ± 0.9	1.8 ± 1.0	.684
Functional reach, cm	21.3 ± 4.6	19.8 ± 6.3	.365
Functional stability boundary for forward, %	19.5 ± 6.8	18.8 ± 7.1	.877
Functional stability boundary for backward, %	13.1 ± 5.4	11.7 ± 5.8	.161
10 m walking time, s	11.3 ± 2.5	11.5 ± 2.9	.843
TUG, s	8.3 ± 2.2	9.2 ± 2.2	.150
One-leg stance, s	14.4 ± 11.5	10.1 ± 9.9	.168

Notes: Significance was tested using the χ^2 test for categorical variables, Student's t test for continuous variables, and the Mann–Whitney U test for nonnormally distributed variables. TUG = timed up and go.
*$p < .05$.

(backward) in the intervention group (pre: 60.8% ± 19.7%, post: 60.9% ± 14.1%, interaction: $F[1,46] = 0.099$, $p = .754$, $\eta^2 = 0.002$).

Significant group-by-time interactions in tibialis anterior activity were observed during functional stability boundary (backward), but not during functional reach ($p = .055$; Table 2). Although there was no significance across the board, tibialis anterior activity remained constant or decreased, and soleus activity increased during the tasks such as standing, functional reach, and functional stability boundary for forward in the intervention group (Table 2). Tibialis anterior activity increased during functional stability boundary (backward) in the intervention group ($p < .0125$).

Effects of Intervention on Physical Function

Functional reach, functional stability boundary (forward and backward), timed up and go, and one-leg stance significantly improved after the 8-week intervention (group × time interaction: $p < .05$; Table 3). No significant improvements in other postural control abilities or physical functions were observed.

Discussion

Our study results provided evidence partially supportive of our hypothesis that muscle coactivation during postural control would decrease after balance training. Specifically, we found that balance training decreased muscle coactivation in dynamic postural control tasks (ie, functional reach and functional stability boundary for forward), although no

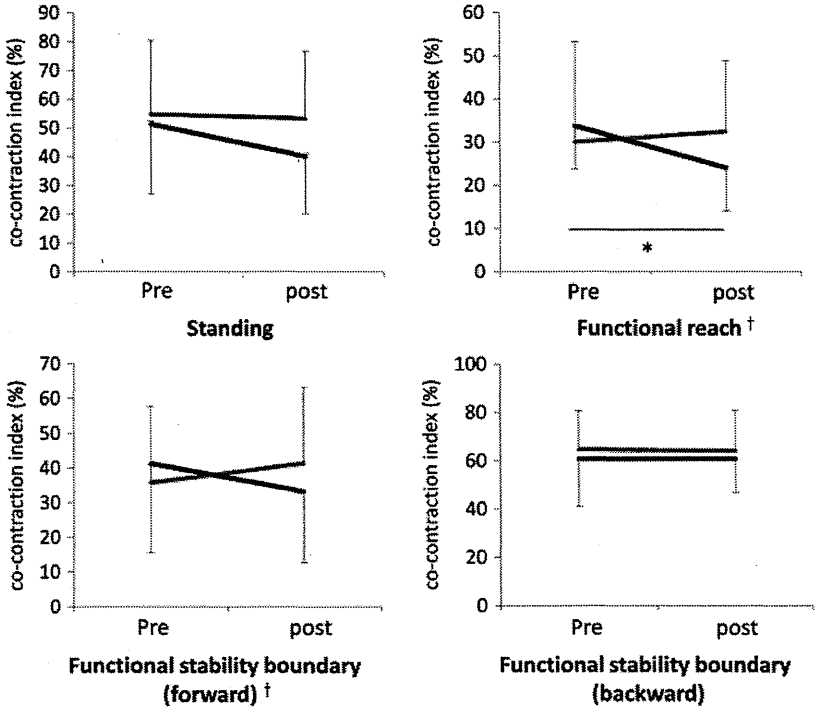

Figure 1. Pre- and posttraining comparisons of coactivation during postural control tasks. Significance was tested using mixed design analysis of covariance and post hoc Bonferroni tests. The black lines indicate the intervention group, and the gray lines indicate the control group. Interaction by analysis of covariance, †$p < .0125$ post hoc test, *$p < .0125$.

Table 2. Mean Normalized Electromyographic Activity (% maximal voluntary contractions: mean ± *SD*) During Tasks

Tasks	Muscle		Pre (n = 24)	Post (n = 24)	Group × Time *F* Value	Effect Size η^2
Standing	TA	Intervention group	12.4 ± 10.5	9.8 ± 8.7	1.806	0.039
		Control group	12.6 ± 11.3	12.3 ± 11.0		
	SOL	Intervention group	21.5 ± 9.2	24.9 ± 9.9	0.368	0.008
		Control group	19.3 ± 15.3	21.9 ± 13.7		
Functional reach	TA	Intervention group	12.3 ± 14.6	11.7 ± 14.2	3.938	0.080
		Control group	8.2 ± 8.6	11.0 ± 8.7		
	SOL	Intervention group	46.3 ± 16.5	58.8 ± 17.6	1.982	0.042
		Control group	42.3 ± 19.6	50.2 ± 19.3		
Functional stability boundary for forward, %	TA	Intervention group	16.0 ± 15.0	16.4 ± 14.5	0.513	0.011
		Control group	13.2 ± 12.0	17.3 ± 12.1		
	SOL	Intervention group	48.6 ± 19.2	61.1 ± 13.2	2.706	0.057
		Control group	45.3 ± 19.0	52.9 ± 19.7		
Functional stability boundary for backward, %	TA	Intervention group	35.6 ± 18.0	64.7 ± 16.6	21.223*	0.320
		Control group	39.3 ± 16.9	46.1 ± 17.1		
	SOL	Intervention group	22.3 ± 11.2	30.6 ± 12.6	1.072	0.023
		Control group	23.0 ± 12.6	27.6 ± 14.1		

Notes: Significance was tested using mixed design analysis of covariance. SOL = soleus; TA = tibialis anterior.

*$p < .0125$ *F* value; *F* value is a test statistic to decide whether the sample means are within sampling variability of each other. The null hypothesis is rejected when the *F* value is large. η^2, effect size (η^2) is a measure of the strength of the relationship between two variables.

significance was seen in functional stability boundary for forward in post hoc test. These findings suggest that exercise may be able to modify redundant muscle coactivation during dynamic postural control in older adults.

Previous studies have reported that older adults showed greater muscle coactivation during postural control in static or dynamic conditions compared with young adults (9,25,29). A previous study of ours showed that muscle coactivation was significantly higher in older adults with low postural control ability than in older adults with high postural control ability (9). All these studies described coactivation with resultant ankle joint stiffness as a compensatory strategy to maintain postural stability. The result of our current study suggests that trained subjects could maintain dynamic postural stability without the stiffening of their ankle joint associated with higher muscle coactivation.

Functional reach, functional stability boundary (forward), timed up and go, and one-leg stance time significantly improved in the intervention group. The improvements we observed in functional reach and functional stability boundary were associated with decreased muscle coactivation after the intervention. Our previous cross-sectional study showed that balance ability is negatively related to muscle coactivation during postural control in older adults (9). The result of the present study suggested that changes in muscular coactivation are related with changes in postural control ability. However, the postural sway area and CI during standing did not improve in the intervention group. The lack of the effect on postural sway might be attributable to training frequency and duration. The training program in this study was 40-minute balance sessions conducted twice a week for 8 weeks. A previous study proposed an effective

Table 3. Pre- and Posttraining Comparison of Postural Control Abilities and Physical Function

		Preintervention (n = 24)	Postintervention (n = 24)	Group × Time *F* Value	Effect Size η^2
Postural sway area, cm^2	Intervention group	1.7 ± 0.9	1.3 ± 1.0	0.001	<0.001
	Control group	1.8 ± 1.0	1.43 ± 0.87		
Functional reach, cm	Intervention group	21.3 ± 4.6	25.2 ± 4.0	19.808*	0.306
	Control group	19.8 ± 6.3	19.6 ± 6.0		
Functional stability boundary for forward, %	Intervention group	19.5 ± 6.8	25.2 ± 6.8	28.777*	0.390
	Control group	18.8 ± 7.1	17.9 ± 7.4		
Functional stability boundary for backward, %	Intervention group	12.7 ± 5.2	15.7 ± 6.2	3.886	0.079
	Control group	11.7 ± 5.8	12.3 ± 4.6		
10 m walking time, s	Intervention group	11.3 ± 2.5	10.5 ± 2.1	3.926	0.080
	Control group	11.5 ± 2.9	11.7 ± 3.4		
One-leg stance, s	Intervention group	14.4 ± 11.5	16.1 ± 10.0	9.737*	0.178
	Control group	10.1 ± 9.9	8.3 ± 6.8		
TUG, s	Intervention group	8.3 ± 2.2	7.5 ± 1.7	7.420*	0.142
	Control group	9.2 ± 2.2	9.2 ± 2.3		

Notes: TUG = timed up and go. Significance was tested using mixed design analysis of covariance.

*$p < .05$ *F* value; *F* value is a test statistic to decide whether the sample means are within the sampling variability of each other. The null hypothesis is rejected when the *F* value is large. η^2, effect size (η^2) is a measure of the strength of the relationship between the two variables.

balance training program conducted three times per week for 1 hour for 3 months (16). Longer programs may produce greater effects on physical function and muscle coactivation. If postural control ability in functional stability boundary for backward had improved in the present study, coactivation during this task might also have changed after training.

Our study found that tibialis anterior activity during postural sway, functional reach, and functional stability boundary for forward had a tendency to remain constant or decrease modestly in the intervention group. On the other hand, soleus activity was subject to increase especially in the intervention group. Functional reach and functional stability boundary (forward) involve a forward movement of the center of pressure, which requires increased plantar flexor torque at the ankle joint to control posture, while the tibialis anterior plays a role of antagonist. The results of the study suggest that the balance training led to an increase in agonist (soleus) activity and a decrease or maintenance in antagonist (tibialis anterior) activity. Carolan and Cafarelli (30) 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 recruit agonist induces increased muscle coactivation in the antagonist. In the present study, after balance training, subjects could recruit the agonist (soleus) without enhancement of the antagonist (tibialis anterior). This decrease or conservation in the antagonist activity, in turn, could help optimize the work of the agonist (soleus) during postural control. Postural control exercise therefore could potentially lead older adults to more efficient postural control strategies without increasing muscle coactivation.

Not much has been done to define the contribution of muscle coactivation during physical activity or in falls in older adults, although the change of muscle coactivation strategy has been reported during postural control or joint movements (6,8,31,32). The present study showed decreased muscle coactivation during postural control after training. However, it remains unclear from our study how neural adaptation (ie, decrease of muscle coactivation) contributes to fall avoidance or changes with increased physical activity. Further studies should investigate the effect of decreased muscle coactivation after training on functional outcomes other than balance ability.

This study has several limitations. First, our study examined only the ankle joint and thus provides no information on postural strategies for the knee or hip joint. Second, our data did not measure changes in kinematics, which therefore did not enable us to evaluate any possible relationship between muscle coactivation and kinematics during postural tasks in older adults. It is a matter of further study to clarify the effect of kinematic change on muscle coactivation with information from multiple joints. Third, the information on subject assignment was not blinded to the research staff members during the postural control tasks. Possible bias cannot be ruled out in this study design. However, the effect of bias on coactivation, which is the main outcome in this study, is not considered significant because it would be difficult for the research staff members to manipulate the coactivation intentionally. Also, the CI calculation process was done in a blinded way. Finally, the ICC for postural control ability (sway area) during quiet standing was not very high (0.72) because of the short measurement time (10 seconds). This might have had an effect on the results of the postural sway area. However, ICC for CI without electrode repositioning during quiet standing was very high (0.93). We conclude that the results for muscle coactivation were not influenced very much by the measurement time in quiet standing.

Conclusions

Our study found that coactivation during postural control decreases after balance training in older adults, which can be associated with improvement of postural control ability. Postural control exercise could potentially lead older adults to develop more efficient postural control strategies without increasing muscle coactivation. Further research is needed to clarify the contribution decreased muscle coactivation makes to balance ability and to other functional outcomes such as fall prevention or increased physical activity.

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References

1. Era P, Heikkinen E. Postural sway during standing and unexpected disturbance of balance in random samples of men of different ages. *J Gerontol.* 1985;40:287–295.
2. Shumway-Cook A, Baldwin M, Polissar NL, Gruber W. Predicting the probability for falls in community-dwelling older adults. *Phys Ther.* 1997;77:812–819.
3. Slobounov SM, Moss SA, Slobounova ES, Newell KM. Aging and time to instability in posture. *J Gerontol A Biol Sci Med Sci.* 1998;53: B71–B78.
4. Duncan P, Studenski S, Chandler J, Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. *J Gerontol.* 1992; 47:M93–M98.
5. Lord SR, Clark RD, Webster IW. Physiological factors associated with falls in an elderly population. *J Am Geriatr Soc.* 1991;39:1194–1200.
6. Hortobagyi T, Solnik S, Gruber A, et al. Interaction between age and gait velocity in the amplitude and timing of antagonist muscle coactivation. *Gait Posture.* 2009;29:558–564.
7. Schmitz A, Silder A, Heiderscheit B, Mahoney J, Thelen DG. Differences in lower-extremity muscular activation during walking between healthy older and young adults. *J Electromyogr Kinesiol.* 2009;19: 1085–1091.
8. Laughton CA, Slavin M, Katdare K, et al. Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. *Gait Posture.* 2003;18:101–108.
9. Nagai K, Yamada M, Uemura K, Yamada Y, Ichihashi N, Tsuboyama T. Differences in muscle coactivation during postural control between healthy older and young adults. *Arch Gerontol Geriatr.* 2011;53: 338–343.

10. Clark DJ, Fielding RA. Neuromuscular contributions to age-related weakness. *J Gerontol A Biol Sci Med Sci.* 2011; doi:10.1093/gerona/glr041.
11. de Boer MD, Morse CI, Thom JM, de Haan A, Narici MV. Changes in antagonist muscles' coactivation in response to strength training in older women. *J Gerontol A Biol Sci Med Sci.* 2007;62:1022–1027.
12. Wu G. Age-related differences in Tai Chi gait kinematics and leg muscle electromyography: a pilot study. *Arch Phys Med Rehabil.* 2008; 89:351–357.
13. Tang PF, Woollacott MH. Inefficient postural responses to unexpected slips during walking in older adults. *J Gerontol A Biol Sci Med Sci.* 1998;53:M471–M480.
14. Tucker MG, Kavanagh JJ, Barrett RS, Morrison S. Age-related differences in postural reaction time and coordination during voluntary sway movements. *Hum Mov Sci.* 2008;27:728–737.
15. Allum JH, Carpenter MG, Honegger F, Adkin AL, Bloem BR. Age-dependent variations in the directional sensitivity of balance corrections and compensatory arm movements in man. *J Physiol.* 2002; 542:643–663.
16. Howe TE, Rochester L, Jackson A, Banks PM, Blair VA. Exercise for improving balance in older people. *Cochrane Database Syst Rev.* 2011;11:CD004963.
17. Kalbe E, Calabrese P, Schwalen S, Kessler J. The Rapid Dementia Screening Test (RDST): a new economical tool for detecting possible patients with dementia. *Dement Geriatr Cogn Disord.* 2003;16:193–199.
18. Nagai K, Yamada M, Uemura K, et al. Effect of repetitive postural control exercise on muscular coactivation at the ankle joint. *J Jpn Phys Ther Ass.* 2011;38:84–89.
19. Suzuki T, Kim H, Yoshida H, Ishizaki T. Randomized controlled trial of exercise intervention for the prevention of falls in community-dwelling elderly Japanese women. *J Bone Miner Metab.* 2004;22:602–611.
20. Vogler CM, Sherrington C, Ogle SJ, Lord SR. Reducing risk of falling in older people discharged from hospital: a randomized controlled trial comparing seated exercises, weight-bearing exercises, and social visits. *Arch Phys Med Rehabil.* 2009;90:1317–1324.
21. Duncan P, Weiner D, Chandler J, Studenski S. Functional reach: a new clinical measure of balance. *J Gerontol.* 1990;45:M192–M197.
22. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull.* 1979;86:420–428.
23. Lopopolo RB, Greco M, Sullivan D, Craik RL, Mangione KK. Effect of therapeutic exercise on gait speed in community-dwelling elderly people: a meta-analysis. *Phys Ther.* 2006:86:520–540.
24. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc.* 1991;39: 142–148.
25. Melzer I, Benjuya N, Kaplanski J. Age-related changes of postural control: effect of cognitive tasks. *Gerontology.* 2001;47:189–194.
26. Hermens H. SENIAM. http://www.seniam.org/. Accessed June 4, 2010.
27. Kendall FP, McCreary EK, Provanoe PG, Rodgers M, Romani W. *Muscles: Testing and Function, With Posture and Pain.* North American ed. Baltimore, MD: Lippincott Williams & Wilkins; 2005.
28. Falconer K, Winter DA. Quantitative assessment of co-contraction at the ankle joint in walking. *Electromyogr Clin Neurophysiol.* 1985;25: 135–149.
29. Manchester D, Woollacott M, Zederbauer-Hylton N, Marin O. Visual, vestibular and somatosensory contributions to balance control in the older adult. *J Gerontol.* 1989;44:M118–M127.
30. Carolan B, Cafarelli E. Adaptations in coactivation after isometric resistance training. *J Appl Physiol.* 1992;73:911–917.
31. Simoneau E, Martin A, Van Hoecke J. Muscular performances at the ankle joint in young and elderly men. *J Gerontol A Biol Sci Med Sci.* 2005;60:439–447.
32. Tsang WW, Lee KY, Fu AS. Effects of concurrent cognitive task on pre-landing muscle response latency during stepping down activity in older adults with and without a history of falls. *Disabil Rehabil.* 2008;30:1116–1122.

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Fear of falling is associated with prolonged anticipatory postural adjustment during gait initiation under dual-task conditions in older adults

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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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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).

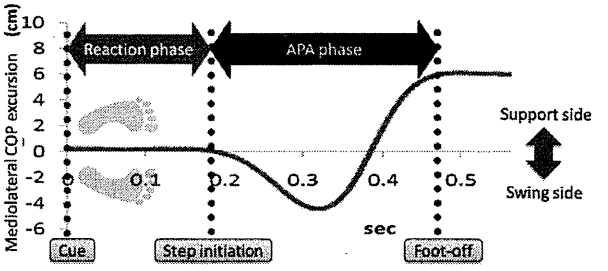

Fig. 1. An example of gait initiation data. The following events are marked: onset of the visual cue (Cue), the first mediolateral deviation of the COP towards the swing leg (Step initiation), the end of the mediolateral shift of the COP towards the stance leg (Foot-off); see text for details.

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, $p < 0.01$).

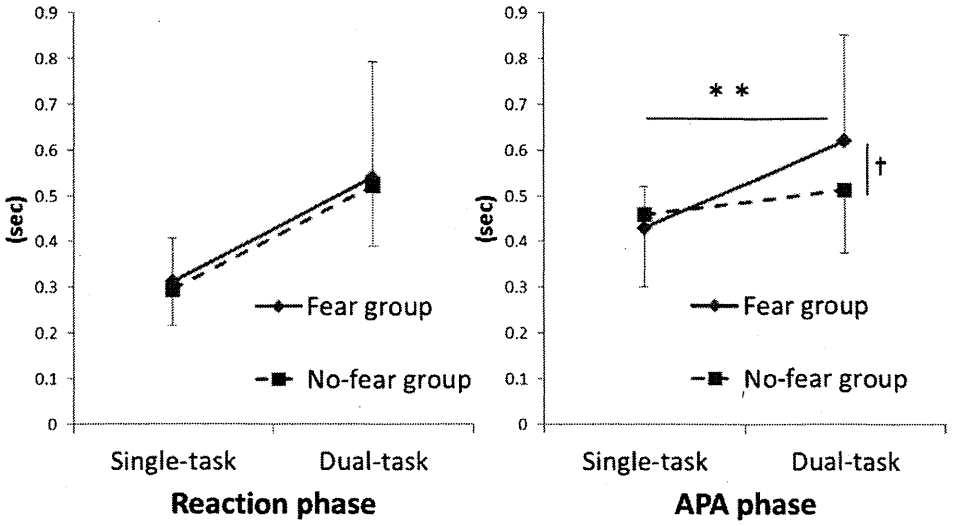

Fig. 2. Average of measurement parameters for both groups of participants in both task conditions: single-task condition and dual-task condition. *Note.* †Significant difference between No-fear and Fear groups in the individual-task condition (Bonferroni, $p < 0.05$). **Significant difference between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