**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 | $\eta^2$ |
| 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, $p < 0.01$).

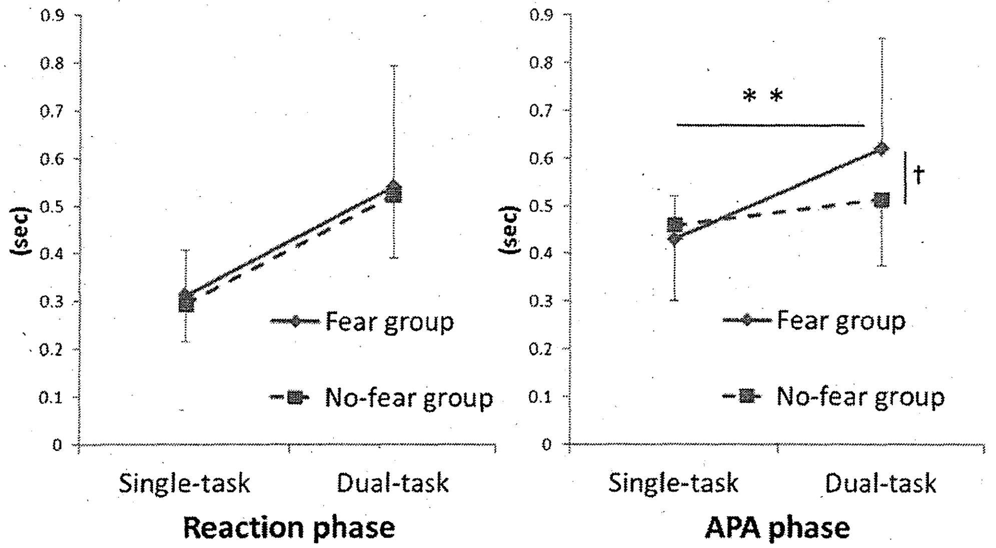

**Fig. 2.** Average of measurement parameters for both groups of participants in both task conditions: single-task condition and dual-task condition. *Note.* †Significant difference between No-fear and Fear groups in the individual-task condition (Bonferroni, $p < 0.05$). **Significant difference between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

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

## 4. Discussion

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

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

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

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

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

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### Conflicts of interest statement

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

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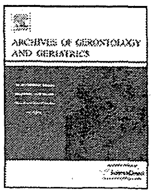

# Effects of dual-task switch exercise on gait and gait initiation performance in older adults: Preliminary results of a randomized controlled trial

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A B S T R A C T

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).

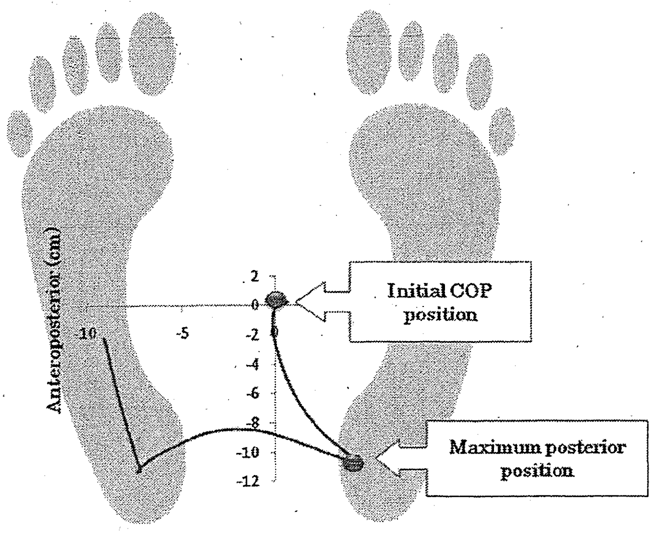

**Fig. 1.** Overhead view of the COP trajectory at gait initiation. Measurement parameters comprised reaction time from cue to step initiation and backward displacement of COP in the anteroposterior direction from the initial position to the maximum posterior position.

### 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 $\eta^2$ 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

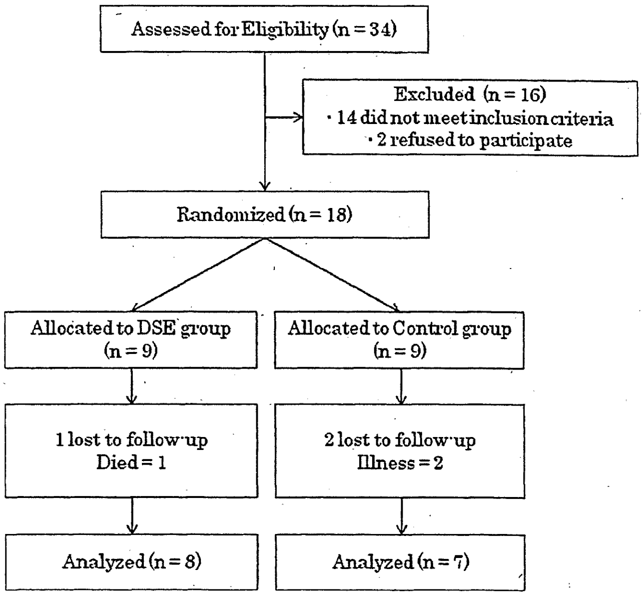

**Fig. 2.** Flow diagram of participant progress through phases of the randomized controlled trial.

**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 $\eta^2$ | $F$-Value | $p$-Value | Partial $\eta^2$ |
| 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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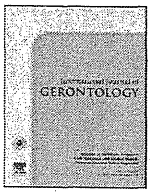

Original Article

# Development of a New Fall Risk Assessment Index for Older Adults☆

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S U M M A R Y

*Background:* Falls are the third-leading cause of a bedridden state and are a major cause of morbidity in elderly people. Therefore, it is important to determine an older person's risk of falling using a simple and reliable method. The aim of the present study was to examine whether our newly developed index for the assessment of complex-task locomotion can predict falls in robust elderly people.
*Methods:* The new index consisted of four items (stand-up, turn, walk and trip tests). It was used to assess 780 community-dwelling elderly Japanese people (mean age 76.0 ± 7.4 years, 300 men and 480 women) who could complete a Timed Up and Go test in less than 13.5 seconds. We used receiver operating characteristic curves (ROC) to validate the index and to determine its cut-off point to predict falls.
*Results:* The area under the curve was 0.15 ($p < 0.001$, 95% CI: 0.675-0.755). The ROC curve analysis enabled the best cut-off (1 point) to discriminate fallers from non-fallers (sensitivity 80.8%, specificity 60.6%).
*Conclusion:* We have demonstrated that the new index is a reliable indicator for falls in elderly people who have higher levels of functional capacity. Our data suggest that a score of more than 1 point by the new index can predict falls in robust elderly people.

## 1. Introduction

In Japan, falls are the third-leading cause of a bedridden state and are a major cause of morbidity in older people[1]. Falls are relatively common among the elderly, with approximately 30% of individuals aged 65 years or older falling at least once a year[2]. Because falls tend to occur as a result of the activities of daily living, previous research has focused on identifying age-related changes in locomotive function[3]. Several performance measures, such as walking speed[4], Timed Up and Go (TUG) test[5], one-leg stand (OLS)[6], functional reach[7], five times chair stand[8], and Tinetti balance[9], have been used to evaluate the physical performance of community-dwelling older people.

Several studies have suggested that a cut-off point of 13.5 seconds in a TUG test is a useful indicator that an individual has an increased risk of falling[10]. However, some older adults who have higher levels of functional capacity can complete a TUG test in less than 13.5 seconds but remain susceptible to falls, so it is important to develop accurate prediction systems for these individuals. In daily-life situations, the requirements for locomotion typically occur under complicated circumstances with cognitive attention focused on a particular task. In recent years, numerous studies have evaluated complex-task locomotion for fall prediction in older adults[11–13]. However, more simple and reliable methods are necessary for elderly people living in the community.

The aim of the present study was to examine whether our newly developed index to assess complex-task locomotion was related to falls in the robust elderly population.

## 2. Methods

### 2.1. Participants

We recruited 780 community-dwelling elderly Japanese people (mean age 76.0 ± 7.4 years, 300 men and 480 women) for this study. We excluded participants based on the following exclusion criteria: the presence of severe cardiac, pulmonary or musculoskeletal disorders, co-morbidities associated with an increased risk of falls (i.e., Parkinson's disease or stroke), and a TUG score greater than 13.5 seconds. The simple TUG test was developed to screen

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☆ All contributing authors declare no conflicts of interest.

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basic mobility performance and has been shown to be significantly associated with activities of daily living function in frail older adults[5]. It has been reported that elderly people with a TUG score greater than 13.5 seconds are at increased risk of falling[10].

### 2.2. *Questionnaire*

The new index was developed in our university by a working group of medical doctors, physical therapists, occupational therapists, public health nurses and an epidemiologist. It consisted of four questions, rated as 0 or 1 by self-report as follows:(1) "Can you stand up without a support?" No = 1; (2) "Can you turn in the opposite way, while holding an empty glass?" No = 1; (3) "Can you walk without dropping a glass of water?" No = 1; and (4) "Have you ever tripped over an obstacle while going to the bathroom or picking up the telephone?" Yes = 1. The test–retest reliability for each item and the total points using the Kappa coefficient (k-value) and the inter-trial correlation coefficient (ICC [1.1]) between the two measurements with a 2-week interval in a sample of 312 participants were calculated as follows: Question 1 (k-value = 0.881); Question 2 (k-value = 0.816); Question 3 (k-value = 0.881); Question 4 (k-value = 0.882); and total point (ICC [1,1] = 0.941).

### 2.3. *Data collection for other physical performance tests*

The participants were subjected to five other physical performance tests that are widely used to identify high-risk elderly adults: 10 m walk under a single-task condition (ST walking)[4]; 10 m walk under a dual-task (DT) condition (comfortable walking while counting numbers aloud in reverse order starting from 50) (DT walking)[14]; a TUG test[5]; functional reach (FR)[7]; one-leg stand (OLS)[6]; and five times chair stand tests[8]. The tests were performed in a random order. For each performance task, the participants performed two trials and the average score was calculated.

### 2.4. *Falls*

Information on fall incidents within the past year was collected from participants by interview. A fall was defined as an event that resulted in a person unintentionally coming to rest on the ground, floor, or other lower level with or without loss of consciousness or injury[15]. We excluded falls resulting from extraordinary environmental factors (e.g., traffic accidents or falls while riding a bicycle).

### 2.5. *Statistical analysis*

Differences in the data between the falls and non-falls were analyzed by Student t test or Chi-square test. To compare physical performance in the two groups, effect sizes were calculated as follows: (faller mean − non-faller mean)/standard deviation. The relationship between the total point and the six previously validated tests was assessed using Spearman's correlation coefficient. The utility of the total points used to distinguish fallers from non-fallers was tested using receiver operating characteristic (ROC) curves for cut-off points on the index. Data were registered and analyzed using the Statistical Package for Social Science (Windows version 18.0).

## 3. Results

Of the 780 study participants, 203 (26%) reported at least one or more falls within 1 year of administering the new index. Based on these self-reported incidences of falling, the participants were divided into two groups: fallers and non-fallers. The demographic characteristics of the two groups are summarized in Table 1. No significant differences were observed between the groups for age, body weight, height and gender. Fallers scored significantly more points in "Question 1" (odds ratio = 2.79, 95% CI; 1.94–4.03), "Question 2" (odds ratio = 3.20, 95% CI; 1.64–6.24), "Question 3" (odds ratio = 2.14, 95% CI; 1.46–3.15), "Question 4" (odds ratio = 3.46, 95% CI; 2.50–4.87), and total points than non-fallers ($p < 0.001$).

**Table 1**
Comparison of demographic characteristics and measurements in fallers and non-fallers.

| | Faller (n = 203) | Non-faller (n = 577) | Odds (95% CI) | *E/S* | *p* value |
|---|---|---|---|---|---|
| Age | 76.8 ± 8.1 | 75.0 ± 8.3 | | | 0.180 [a] |
| Weight, kg | 57.9 ± 9.9 | 54.3 ± 11.6 | | | 0.406 [a] |
| Height, cm | 155.7 ± 10.3 | 157.4 ± 11.6 | | | 0.071 [a] |
| Gender, female | 122 (60.1%) | 358 (62.0%) | | | 0.560 [a] |
| Q1 (0,1) [c] | 70 (34.5%) | 91 (15.8%) | 2.79 (1.94–4.03) | | <0.001 [b] |
| Q2 (0, 1) [c] | 19 (9.4%) | 18 (3.1%) | 3.20 (1.64–6.24) | | <0.001 [b] |
| Q3 (0, 1) [c] | 55 (27.1%) | 85(14.7%) | 2.14 (1 .46–3.15) | | <0.001 [b] |
| Q4 (0, 1) [c] | 115 (56.7%) | 157 (27.2%) | 3.46 (2.50–4.87) | | <0.001 [b] |
| Total points (0–4) | 1.27 ± 0.86 | 0.61 ± 0.88 | | 0.77 | <0.001 [a] |
| ST walking time, sec | 10.45 ± 2.46 | 9.48 ± 2.59 | | 0.39 | <0.001 [a] |
| DT walking time, sec | 14.17 ± 4.73 | 12.75 ± 4.76 | | 0.30 | <0.001 [a] |
| TUG, sec | 9.90 ± 2.26 | 9.05 ± 2.22 | | 0.37 | <0.001 [a] |
| OLS, sec | 6.43 ± 8.67 | 9.82 ± 12.60 | | 0.39 | <0.001 [a] |
| Functional reach, cm | 23.83 ± 6.98 | 26.06 ± 7.90 | | 0.32 | <0.001 [a] |
| Five chair stand, sec | 11.45 ± 5.94 | 9.92 ± 3.63 | | 0.26 | <0.001 [a] |

[a] Student t test.

[b] Chi-square test.

[c] Q1: "Can you stand up without a support?" Yes = 0, No = 1; Q2: "Can you turn in the opposite way, while holding an empty glass?" Yes = 0, No = 1; Q3: "Can you walk without dropping a glass of water?" Yes = 0, No = 1; Q4: "Have you ever tripped over an obstacle while going to the bathroom or picking up the telephone?" Yes = 1, No = 0.

DT = manual-task; OLS = one-leg standing; ST = single-task; TUG test = Timed Up and Go test.

All physical performance tests demonstrated that the elderly participants in the non-faller group had significantly lower scores than those in the faller group. The largest effect size was the total point in all measurements. The results for total points was weakly, but significantly, correlated with those for ST walking time ($r = 0.179$, $p < 0.001$), DT walking time ($r = 0.421$, $p < 0.001$), OLS ($r = -0.154$, $p < 0.001$), and functional reach ($r = -0.083$, $p = 0.021$).

The ROC curve for the total points for the classification of fall incidents is shown in Fig. 1. The area under the curve was 0.715 ($p < 0.001$, 95% CI; 0.675–0.755). The ROC curve analysis enabled us to indicate the positive value of 1 point (sensitivity 80.8%, specificity 60.6%) and negative value of 2 points (sensitivity 0.394%, specificity 83.4%).

## 4. Discussion

In this study we have demonstrated that our new index is a reliable indicator for falls in elderly people who have higher levels of functional capacity. The results of the total score on the new index were moderately correlated with those of DT walking time. Moreover, the total new index score demonstrated statistically significant difference between faller and non-faller groups. Therefore, the new index may be considered a measurement that is related to walking ability under DT conditions. These results implicate the role of the total score in the fall risk assessment. A

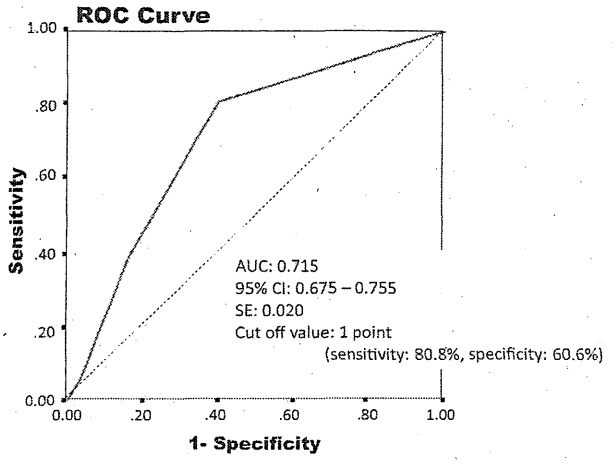

**Fig. 1.** The receiver operating characteristic (ROC) curve for the total points used for the classification of fall risk. The area under the curve (AUC) was 0.715. Concerning the total points, the cut-off value was determined at 1 point (sensitivity, 80.8%; specificity 60.6%).

score of 1 point by the new index was considered to represent the fall-related cut-off value. In addition, the total score on the new index had the largest effect size in the other screening tool for falls. Therefore, the index may be useful as a screening tool for fall prediction in robust community-dwelling elderly people.

The total points on the new index were weakly correlated with previous validated performance tests. The concept of the new index was assessed to complex-task locomotion related to falls. Therefore, it is not surprising that the new index was weakly correlated with simple performance tests.

In addition to the benefits of the new index as a clinical assessment tool[4–8], we assessed whether this index could be used as a tool for fall risk screening. The new index has a number of advantages over conventional fall risk screening tests. First, it takes a shorter time for the measurement. Second, it is easy to do the assessment in non-clinical settings. However, there is a limitation in this study. The new index could not predict falling in older adults as this study was based on the participants having experienced falls in the previous year. A prospective cohort study to further evaluate the relationship between fall incidents and the new index, in addition to a comparison with existing indices, is being planned.

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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:

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

$I_{\mathrm{ant}}$ 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.

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

$$I_{\text{total}} = \int_{t_1}^{t_2} \left[\text{EMG}_{\text{agon}} + \text{EMG}_{\text{ant}}\right](t)\mathrm{d}t.$$

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 $\text{ICC}_{1,1}$. The $\text{ICCs}_{1,1}$ 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 $\text{ICC}_{1,1}$ 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 $\chi^2$ 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

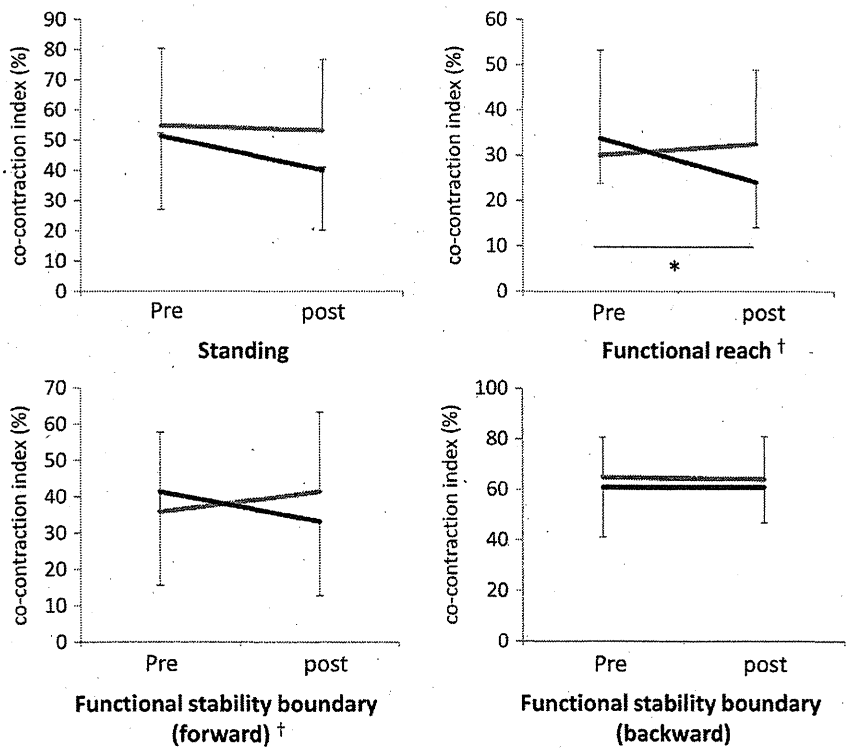

Figure 1. Pre- and posttraining comparisons of coactivation during postural control tasks. Significance was tested using mixed design analysis of covariance and post hoc Bonferroni tests. The black lines indicate the intervention group, and the gray lines indicate the control group. Interaction by analysis of covariance, $\dagger p < .0125$ 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 $\eta^2$ |
|---|---|---|---|---|---|---|
| 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. $\eta^2$, effect size ($\eta^2$) 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 $\eta^2$ |
|---|---|---|---|---|---|
| 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. $\eta^2$, effect size ($\eta^2$) 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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Original Study

# Community-Based Exercise Program is Cost-Effective by Preventing Care and Disability in Japanese Frail Older Adults

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*Keywords:*
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## ABSTRACT

*Background:* In Japan, older adults are assessed by frailty checklist for care prevention. However, the effect of care prevention programs in community-dwelling frail older adults is still unclear.
*Objectives:* The purpose of this study was to investigate whether the care prevention program would reduce care and disability and to measure its cost-effectiveness in frail older adults.
*Design:* This is a prospective study using propensity score matching.
*Setting and subjects:* A total of 610 community-dwelling older adults were recruited in 2 cities of Japan.
*Intervention:* Subjects in the exercise group (n = 305) attended physical exercise sessions once a week for 16 consecutive weeks. The exercise sessions were in a standardized format consisting of moderate-intensity aerobic exercise, progressive strength training, flexibility and balance exercises, and cool-down activities. The control group (n = 305) received only screening evaluation.
*Measurements:* Primary outcome was long term care insurance requirement certification during the 1-year follow-up period. Secondary outcome measurements were changes of frailty checklist, and care and medical cost.
*Results:* Twenty-five subjects (8.1%) in the exercise group and 55 (18%) in the control group were newly certified for long-term care insurance service requirement in 1 year after the intervention (RR = 2.16, 95% CI = 1.46–3.20). Consequently, the health care cost for the subjects in the exercise group was significantly lower than in the control group ($P < .001$). Moreover, subjects in the exercise group had significant improvements in total scores of the frailty checklist compared with the control group that worsened after 1 year (exercise group: from 7.41 ± 3.98 to 7.11 ± 4.00, control group: from 7.34 ± 4.27 to 8.02 ± 4.81, F = 12.84, $P < .001$).
*Conclusion:* These results suggested that physical exercise is effective in preventing the progression of frailty and further disability in older adults living in the community. We could save heath care costs by our care prevention program.

The aged population in Japan is increasing faster than in any other country. Frailty in older adults is a serious problem in aged countries, such as in Japan. In general, frailty can be defined as a vulnerable state that places older adults at high risk for adverse health outcomes, such as falls, hospitalization, and mortality.[1] Therefore, to prevent the adverse outcomes of frailty, multicomponent exercise programs have been implemented and provided a beneficial effect on activities of daily living (ADLs) and instrumental ADL disability for community-dwelling moderately frail older adults.[2]

Japan implemented a long term care insurance (LTCI) system in April 2000 to deal with the extremely rapid aging process of our population. Before 2000, long term care services were provided under a tax-based social welfare system targeting seniors with limited economic resources and family support.[3] After LTCI implementation, however, LTCI services have been provided to the elderly who are certified, as a support requirement or care requirement according to their care needs and certification assessment.[4] The selection process for classifying dependent older adults is first based on a questionnaire that evaluates a person's current mental and physical condition (74 items), and then the first decision is reached by computerized algorithm. The second decision is made by a long term care approval board based on the first computer decision, doctor's recommendation, and the home-visit report. Finally, people who are certified as dependent older adults are subdivided into 7 levels (requiring support levels 1 and 2 and care levels 1 to 5) depending on their conditions. They are provided home- and community-based or institutional services according to the care needs. Individuals who are not eligible for long term care or support care may use preventive care services.

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The authors declare no conflicts of interest.

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