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Original Article

# Age-related Differences in the Influence of Cognitive Task Performance on Postural Control Under Unstable Balance Conditions☆

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SUMMARY

*Background:* Poor multitask performance is commonly used as an indicator of age-related changes in attentional capacity. An inability to allocate sufficient attention to postural control under multitask conditions is thought to be a contributing factor to the risk of falling in older adults. This study examined age-related differences in the influence of cognitive task performance on postural sway and muscle activity on unstable balance conditions.
*Methods:* Thirty healthy younger adults (22.2 ± 1.5 years of age, 15 men and 15 women) and 27 healthy older adults (71.3 ± 3.4 years of age, 13 men and 14 women) participated in the study. Participants performed a reaction time task under three conditions during standing on a compliant foam surface: holding a glass full of sand (control task), holding a glass of water (dual-manual task), and performing a control task while simultaneously performing a verbal fluency task (dual-cognitive task).
*Results:* Both younger and older adults had a longer reaction time for the dual-cognitive task compared to the other two tasks ($p < 0.01$). Older participants exhibited decreased lower limb muscle activity and increased anterior–posterior trunk acceleration during the dual-cognitive task, while these effects were not observed in younger adults.
*Conclusion:* Increasing attentional demand by implementing a cognitive task concomitant with a balance task had a greater influence on postural control in older compared to younger adults.


## 1. Introduction

Many activities of daily living require the integration of multiple physical and cognitive functions, including common tasks such as walking on unlevel ground and talking at the same time. To produce appropriate behavior in these situations, attentional resources must be divided to enable multiple tasks to be performed simultaneously. The dual-task paradigm allows the extent of attentional resource-sharing to be examined. Dual-task methods have been successfully applied to the measurement of postural control[1] and poor multitask performance is commonly used as an indicator of age-related changes in attentional capacity[2]. The results of several previous studies have indicated age-related declines in dual-task performance[3–5]. The simultaneous performance of postural and cognitive tasks has been found to have a deleterious effect on balance control, particularly in older adults, owing to a reduction in or misallocation of attentional resources[1]. In addition, poor multitask performance has been found to constitute a risk factor for falling in older people[5–10].

In experimental paradigms using reaction time (RT) as a dependent variable, measures of the relative cost of performing concomitant tasks can provide a conservative estimate of age-related changes in dual-task performance[11]. For example, Sparrow et al reported that RTs in older adults under dual-task conditions were significantly longer than those of a younger group, but RTs did not differ between age groups under single-task conditions[12]. Moreover, concomitant cognitive tasks have been found to substantially decrease postural stability because of increased attentional demands. Importantly, several previous studies indicated that an inability to allocate sufficient attention to postural control under multitask conditions is a contributing factor to the risk of

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falling in older adults[5,8]. Pellecchia reported that postural sway in young participants while standing on a compliant surface increased with the difficulty of a concurrent cognitive task[13].

Brauer et al reported that in older adults, both healthy and balance-impaired individuals showed reduced activity in the lower muscles under dual-task compared to single-task conditions[14]. In addition, frail older adults who demonstrated poor dual-task performance with a manual task (i.e., carrying a glass of water) exhibited a high risk of falling[15]. These findings support the notion that cognition and motor performance are related. However, few studies have shown age-related differences between healthy younger and older adults in the influence of cognitive demands on postural sway and muscle activity during the performance of postural tasks under unstable balance conditions.

We hypothesized that the additional attentional demand under challenging balance conditions, such as standing on a compliant foam surface, would result in a greater decrease in postural stability with any changes in lower-extremity muscle activity in older adults compared to younger adults. Previous studies have postulated that the relationships between postural control and cognitive demand in dual-task situations could be U-shaped[16,17]. In these opinions, postural control performance is either improved or attenuated, depending on whether the cognitive demand of the secondary task is low or high, respectively. In a previous study, when performing more demanding cognitive tasks, older adults showed increased body-center pressure displacements measured by a force platform, in line with the predicted U-shaped function, whereas young adults did not[18]. However, to the best of our knowledge, there are few data regarding differences in the effects of additional manual and cognitive tasks on postural sway and lower muscle activity under unstable balance conditions in older adults. Thus, the aim of the current study was to examine age-related differences in dual task performance and to determine age-related differences in the influence of concurrent manual and cognitive tasks on postural sway and lower muscle activity under unstable balance conditions between younger adults and community-dwelling healthy older adults.

## 2. Methods

### 2.1. Participants

Fifty-seven volunteers participated in the current study, divided into two age groups: 30 healthy younger participants aged between 20 and 25 years (22.2 ± 1.5 years, 15 men and 15 women) and 27 healthy older participants aged 65–78 years (71.3 ± 3.4 years, 13 men and 14 women). All older participants were community-dwelling volunteers who lived independently without assistance. We confirmed general cognitive status in older participants using the Mental Status Questionnaire (MSQ)[19]; all of them exhibited normal general cognitive functioning (less than one error on the MSQ). Young volunteers were a mixture of undergraduate university students, postgraduate students, and employees of the university. We excluded participants with a history of serious neurological or musculoskeletal diagnoses, abnormal hearing, or an inability to stand on their preferred leg with eyes open for 15 seconds. Demographic characteristics and physical performance test scores for the 57 participants are presented in Table 1. The Sapporo Medical University ethics committee approved the experimental protocols. All participants provided written informed consent.

### 2.2. Materials and apparatus

Participants were instructed to press a handheld button as quickly as possible in response to the presentation of an auditory stimulus. RT was measured using a time counter (PTS-010, DKH Inc., Tokyo, Japan) and displayed in milliseconds. RT in each trial was defined as the temporal interval between presentation of an auditory stimulus and the onset of a button-press response.

**Table 1**
Participant characteristics.

| | Younger ($n = 30$) | Older ($n = 27$) |
|---|---|---|
| Age (y) | 22.2 ± 1.5 | 71.3 ± 3.4 |
| Female (%) | 50.0 | 51.9 |
| Body height (cm) | 166.7 ± 9.8 | 157.7 |
| Body mass (kg) | 57.8 ± 9.9 | 58.8 |
| Education (y) | 15.5 | 12.7 |
| Fallen at least once in past 6 mo (%) | 0.0 | 3.7 |
| Exercised at least three times per wk (%) | 13.3 | 77.8 |
| TUG score (s) | 3.8 ± 0.5 | 4.5 ± 0.5 |
| OLS time (s) | 60.0 ± 0.0 | 54.8 ± 11.3 |

OLS = one-legged standing; TUG = timed up-and-go test (maximum pace).

Surface electromyographic (EMG) signals were recorded from the tibialis anterior (TA) and medial gastrocnemius (MGAS) muscles of the right leg. Bipolar surface EMG sensors (SX230, Biometrics Ltd, United Kingdom; interelectrode distance 20 mm) were placed on the skin over the TA and MGAS muscles for EMG recording. Before recording, unilateral (right leg) maximum isometric voluntary contraction (MVC) of the TA and MGAS muscles was measured during 5-second maximal contractions. EMG signals were digitized at a sampling frequency of 1000 Hz (full-wave-rectified and low-pass-filtered-50 Hz signal), and root mean square (RMS) voltages of the EMG signal (rEMG) were calculated. For each subject, we normalized rEMG activity to the individual MVC, resulting in a percentage MVC (%MVC) value for each muscle.

We used a triaxial accelerometer (MA3-04Ac, Micro Stone Inc., Nagano, Japan; fluency range 0.8–1000 Hz) to measure postural sway. A triaxial accelerometer was placed on the lower back of the subject at the level of the third lumbar vertebra. Acceleration signals (measured in G, where 1 G = 9.8 m/s$^2$) were used to determine anterior–posterior sway during the postural response. Sway variability was quantified by calculating the RMS of anterior–posterior acceleration. We used acceleration signals as a measure of postural sway because previous studies reported that trunk accelerometry could quantify the stochastic–dynamic structure of postural sway[20] and discriminate between populations and conditions during quiet standing[21]. In addition, trunk acceleration has been used as a measure of sway responses to differing conditions in older people[22]. To clarify the interaction between postural sway and muscle activity while standing in an unstable balance condition, we measured anterior–posterior sway and EMG activity of the ankle musculature, which contributes to anterior–posterior postural control.

Surface EMG and triaxial accelerometer data were acquired and analyzed using a PowerLab system with Chart v5.0 software (ADInstruments, Castle Hill, Australia).

### 2.3. Procedure

After exclusion criteria were applied, vital signs were assessed and information about education, falling incidents in the previous 6 months, and the amount of exercise per week was collected in face-to-face interviews. All participants performed the timed up-and-go test (TUG) and one-legged standing test (OLS) as clinical measures of gait and balance to exclude serious balance impairments. The TUG is generally used to assess mobility performance. In this task, participants are instructed to rise from a chair, walk 3 meters, turn around, walk back to the chair, and sit down at their usual pace[23]. In this study, participants were asked to perform the TUG at their maximum pace, because we sought to assess mobility performance under conditions with a high risk of falling due to challenging balance conditions.

In the experimental session, participants performed the RT task under three conditions:

(1) standing with feet close together (Romberg stance) on a compliant foam surface (Airex Balance Pad Plus, Airex AG, Sins, Switzerland; $50 \times 41 \times 6$ cm$^3$, weight 0.7 kg, apparent density 55 kg/m$^3$, tensile strength 240 kPa) with a glass full of sand (250 g) in the left hand (control task);
(2) standing on a compliant foam surface in the Romberg stance with a glass of water (250 g) in the left hand (dual-manual task); and
(3) performing the control task condition while simultaneously performing a verbal fluency task (dual-cognitive task).

In all task conditions, participants were asked to stand under unstable balance conditions. We defined the lowest cognitive and physical demands of the secondary task as a control task. In the dual-manual task, to increase the physical demand, participants held a glass full of water instead of sand, with the surface of the water 1 cm from the top edge of the glass. We added a verbal fluency task to the control task to increase cognitive demand in the dual-cognitive task. The verbal fluency task was selected from two categories at random from the following four categories: animals, vegetables, countries, and Japanese prefectures. For each trial in the dual-cognitive task, participants were instructed to think of as many examples in each category as possible, but not to verbalize their answers. Immediately after the recording session, participants then had to verbally name as many item names in each category as possible within a 40-second response period. The number of item names was used as a measure of cognitive demand.

Each participant practiced at least twice before data collection. The experimenter confirmed that the participants were standing quietly in a stable position and then issued the verbal command “ready” as a starting signal to the participants before RT measurement began. An assessor (a physical therapist) explained the details of the test protocols to each participant and conducted practice sessions of RT measurement to ensure that participants understood the test protocols. RT was then measured for each participant under the three task conditions (control, dual-manual, and dual-cognitive tasks), randomly presented to avoid any learning or task effects, to measure the speed of response to an auditory stimulus. Each condition was tested in two sessions and a single session comprised five trials. Five auditory stimuli were presented at randomly generated intervals of 6, 7, 8, 9, or 10 seconds in a session for a total of 40 seconds. Thus, in total we recorded each variable in each task condition in 10 trials. Surface EMG and triaxial accelerometer data were recorded from 5 seconds before the stimulation was presented. In each task condition, the average of each variable over eight trials (excluding the single fastest and single slowest RT trial to exclude accidental responses) was used for statistical analysis. Fig. 1 shows the experimental methods.

### *2.4. Statistical analysis*

Differences between younger and older adults in RT, %MVC of EMG, and RMS values of anterior−posterior acceleration in the different tasks were examined using repeated-measures two-way analysis of variance (ANOVA; subject group × task condition). *Post hoc* tests of coefficients with Bonferroni correction for multiple comparisons were conducted for main effects that were statistically significant. Unpaired Student *t* tests were used to compare verbal fluency (number of words) between younger and older adults. Statistical results were assumed to be significant at $p < 0.05$. All statistical analyses were performed using SPSS 17.0 for Windows (SPSS Inc., Chicago, IL, USA).

## 3. Results

ANOVA revealed significant effects of the group × task condition interaction on RT [$F_{(2,110)} = 5.167$, $p = 0.001$] and EMG of the TA [$F_{(2,110)} = 9.766$, $p < 0.001$] (Fig. 1A,C). By contrast, no significant interaction effects were found for RMS values of anterior−posterior acceleration [$F_{(2,110)} = 1.760$, $p = 0.177$] or EMG of the MGAS

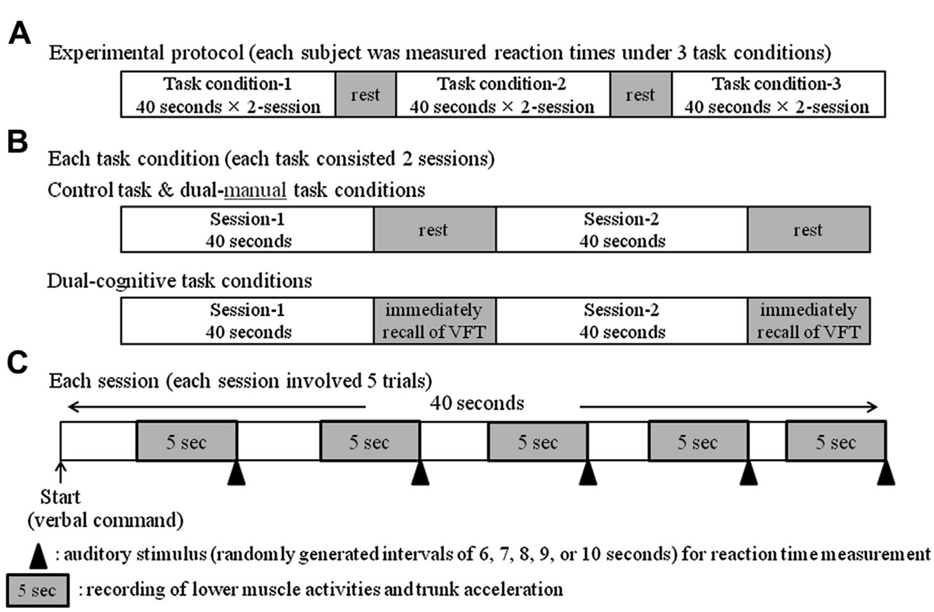


**Fig. 1.** (A) Experimental protocol, (B) each task condition, and (C) each session condition. Each task condition was randomly selected from control task, dual-manual task, and dual-cognitive task conditions. Each task consisted of two sessions and each session involved five trials of reaction time measurements. VFT = verbal fluency test.

[$F_{(2,110)} = 1.043$, $p = 0.356$] (Fig. 1B,D). As shown in Fig. 1A, a *post hoc* analysis of the main effect for task condition with Bonferroni correction indicated that RTs during the dual-cognitive task were significantly longer than those during the control and dual-manual tasks for both groups ($p < 0.001$). Although there was no significant difference in RMS values of anterior–posterior acceleration between task conditions in younger adults, anterior–posterior acceleration in older adults was significantly increased during the dual-cognitive task compared with the control and dual-manual tasks ($p < 0.05$; Fig. 1B). No significant difference in TA muscle activity was found in younger adults, but a significant decrease was observed in older adults in the dual-cognitive compared to the control and dual-manual tasks ($p < 0.01$; Fig. 1C). We also found a significant decrease in MGAS activity in older adults while performing the dual-cognitive task compared with the control task ($p < 0.05$; Fig. 1D). Table 2 shows the number of immediate recall words after the dual-cognitive task in the verbal fluency task. Significant differences in the number of responses and correctly answered words were found between younger and older adults, with younger adults reporting a significantly greater number of words compared to older adults ($p < 0.01$).

## 4. Discussion

The goal of this study was to examine age-related differences in the influence of manual and cognitive tasks on postural sway and muscle activity under unstable balance conditions. In all three task conditions (control task, dual-manual task, and dual-cognitive task) all participants were able to maintain the task while avoiding a loss of balance, which could lead to falling or tripping. The results revealed that both younger and older adults exhibited longer RTs under dual-cognitive compared to control and dual-manual task conditions. Anterior–posterior trunk acceleration significantly increased in the dual-cognitive task for older adults, while no similar increase was observed in younger adults. EMG measurements revealed that older adults exhibited decreased TA and MGAS muscle activity during the dual-cognitive task, but these effects were not observed in younger adults. Older adults showed a substantial reduction in their ability to maintain posture when a cognitive task was performed simultaneously, but younger adults did not.

As shown in Fig. 2A, a significant interaction effect was found on RT, and this result revealed an age-related increase in RT under dual-cognitive task conditions, in agreement with the results of a number of earlier studies[11,12,24–26]. Furthermore, our results reveal age-related differences in the influence of cognitive tasks on postural control in the unstable balance condition. Olivier et al confirmed that the interference between mental activity and postural control could be attributed mainly to attentional limitations[27]. In our dual-cognitive task condition, addition of a verbal fluency task concomitant to the challenging balance condition (standing in the Romberg stance on a compliant foam surface), older participants exhibited a significant increase in anterior–posterior trunk acceleration and a decrease in TA and MGAS muscle activity. Younger participants did not exhibit either of these changes. The decrease in muscle activity and increase in postural sway exhibited by older participants during the verbal fluency task may indicate that fewer attentional resources were available for balance control in the cognitively demanding dual-task condition. The results also indicate that performing balance and cognitive tasks concurrently has a greater impact on the interaction between body posture and muscle activity for balance control in older compared to younger adults. Simoneau et al demonstrated that during complex posture, postural instability, as well as EMG activity of the ankle joint muscles, was decreased in older adults when a difficult memory task was added[28]. Our results are partly in accord with previous studies reporting a decrease in TA and MGAS muscle-response amplitudes when older participants performed a cognitive task simultaneous to standing platform perturbations[14,29].

Redfern et al reported that performance of an RT task was associated with an increase in postural sway in older but not younger participants[30]. These findings suggest that attentional processes may be affected by inhibitory balance control in older adults when sensory integration requirements are high, and that aging may modify the interference between postural and cognitive tasks in the adjustment of behavior in complex situations. Performance of cognitively demanding tasks diminishes central nervous system resources that govern self-regulation of physical tasks requiring maximal voluntary effort[31]. In our study, even when standing under unstable balance conditions, younger adults were able to divide attention into concurrent cognitive tasks while maintaining postural stability without changing trunk sway and lower-limb muscle activity during a control task. However, in older adults, divided attention for cognitive tasks might lead to failure to activate lower limb muscles to control posture. On the basis of these findings, we hypothesize that older adults cannot help but increase body sway to perform dual-cognitive tasks under unstable balance conditions, as in our experimental situations.

Previous studies reported that a combination of sufficiently challenging motor and postural tasks and concurrent cognitive tasks could be used to reveal early signs of deterioration in the ability of older people to control posture[32,33]. In the present study, we measured RT, activity in the lower muscles, and body sway while dual-cognitive tasks were being performed during quiet standing under unstable balance conditions. The results revealed age-related differences in the influence of cognitive tasks on postural sway and lower-limb muscle activity, as well as slower RT responses. The current findings thus indicate that multitask performance had a greater impact on balance control in older compared to young adults. Although quiet standing is a relatively simple postural task, it is now well established that it requires some level of cognitive resources[34]. Recent studies using randomized controlled trials have demonstrated that multitask training in older adults has an effect on the performance of physical activities (e.g., gait speed, cadence, and balance tasks) under dual-task conditions[35–37]. Our findings indicate that further research should be undertaken to determine whether a multitask intervention program could improve balance control in the interaction between muscle activation and body sway under multitask conditions involving cognitive demand in older adults.

We assessed the impact of increased cognitive demand during dual-cognitive task conditions by instructing participants to immediately recall words after the measurement period in the dual-cognitive task condition. A previous study reported a mean (SD) category fluency score of 18.3 (5.3) words (mean 3.1 words per 10 seconds) in the animal naming test (animals named within 1 minute) in a group of 117 healthy older adults with no cognitive impairments[38]. Another study in Brazil reported a similar mean category fluency score in the animal naming task in older adults with no cognitive impairments[39]. In the present study, the mean (SD) score in the category fluency task (calculated as the scores for

**Table 2**
Number of recall words in the verbal fluency task immediately after the dual-cognitive task period.

| | Younger ($n = 30$) | Older ($n = 27$) |
|---|---|---|
| Total number of responses (words) | 41.7 ± 8.2 | 32.4 ± 11.2 ** |
| Number of correct responses (words) | 41.3 ± 8.2 | 29.7 ± 11.5 *** |

** $p < 0.01$, *** $p < 0.001$, Student *t* tests.

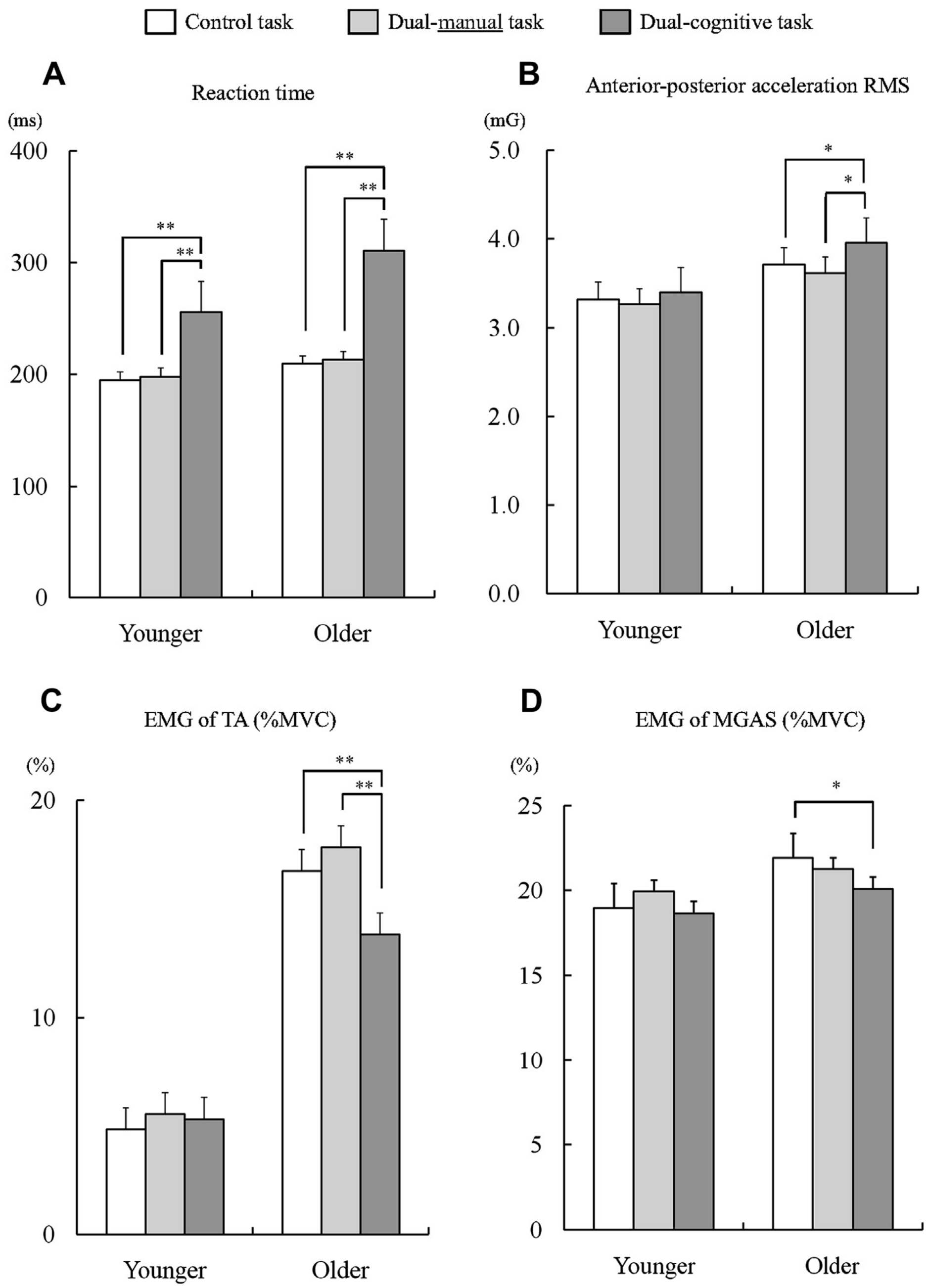


**Fig. 2.** Group means and standard errors in each task condition for younger adults ($n = 30$) and older adults ($n = 27$). *$p < 0.05$; **$p < 0.01$; the Bonferroni *post hoc* test was used to test the significance of differences between task conditions. Error bars represent one standard error. EMG = electromyographic; MGAS = medial gastrocnemius; MVC = maximum isometric voluntary contraction; RMS = root mean square; TA = tibialis anterior.

two category fluency trials selected randomly from animals, vegetables, countries, and Japanese prefectures, and the score in each trial counted as the total number of correct items named within 40 seconds) completed immediately after the dual-cognitive task in older adults was 29.7 (11.5) (total number of correct answers named within 80 seconds, mean 3.7 words per 10 seconds). Our sample of older adults thus exhibited similar category fluency scores to those reported in previous studies, although we used four categories (animals, vegetables, countries, and Japanese prefectures). The results indicated that the older adults in our study were able to focus despite the cognitive demand in the RT measurement period in the dual-cognitive task condition. However, we found that older adults named significantly fewer items than younger adults, and exhibited a significant decrease in lower muscle activity and an increase in anterior–posterior trunk acceleration in the dual-cognitive task. This pattern was not shown by younger adults. These results suggest that performance of a dual-cognitive task has a greater influence on postural control in older compared to younger adults.

Some limitations of this study should be noted. Although we confirmed that all older participants exhibited normal general cognitive functioning (less than one error on the MSQ), we did not perform other standardized cognitive tests to examine the influence of cognitive functioning on the dual-task performance. In addition, there was no quantitative measure of the cognitive demand associated with the dual-cognitive task condition. In the dual-cognitive task condition, participants were instructed to think of as many examples as possible in a particular category in the recording period and then name them immediately after the recording period finished. However, the number of immediate recall words did not necessarily reflect an increase in cognitive demand in the dual-cognitive task condition. In addition, 77.8% of our older sample exercised three times per week and exhibited higher levels of physical activity than our younger sample and general aged populations. Thus, it is unclear whether our findings can be applied to elderly people in general.

In conclusion, our findings indicate that cognitive task performance has a greater influence on postural control in older compared to younger adults. Although both younger and older adults exhibited longer RTs under the dual-cognitive compared to the control and dual-manual task conditions, we found a significant effect of the group $\times$ task condition interaction on RT. In addition, we found age-related differences in the influence of cognitive task performance on postural sway and muscle activity. A significant decrease in lower-limb muscle activity and an increase in anterior–posterior trunk acceleration under dual-cognitive task conditions were exhibited by older adults, but not by younger adults. Overall, we found that increasing attentional demand by implementing a cognitive task concomitant to a balance task had a greater influence on postural control in older compared to younger adults.

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