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Original Article

The effects of cognitive tasks on the frequency of non-MTC gait cycle during walking in healthy older and young adults

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Abstract. [Purpose] To investigate the effects of cognitive tasks on the non-minimum toe clearance gait cycles (nMTC) frequency during walking in healthy older and young adults. [Participants and Methods] This study included 20 healthy older and 20 young adults. The participants performed 3 min preferred-speed walking under a single-task and three dual-tasks (DTs) consisting of verbal, subtraction, and recall tasks. We determined the nMTC, which could not detect a trough in the toe trajectory during the swing phase. We evaluated the nMTC frequency (the cases of nMTC / total gait cycles) and compared them among the tasks and between groups. [Results] The results of the two-way analysis of variance revealed that there were no differences among the tasks, while the nMTC frequency in the older group was higher than that in the young group. The DT cost (DTc), which was used as an indicator of cognitive-motor interference (CMI), was higher in the subtraction and recall tasks in the older group than those in the young group. [Conclusion] This study showed that adding a cognitive task while walking increased in the nMTC frequency in older adults. These results suggest that the nMTC frequency under DT would reflect the increased CMI in healthy older adults.
Key words: Non-MTC gait cycle, Dual-task walking, Cognitive-motor interference

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INTRODUCTION

The gait cycle is composed of the stance phase and the swing phase, which require different motor strategies to achieve the purpose of each[1)]. The swing phase task involves the progression of the foot of the swing limb from the previous to the next support position, providing the basis for the forward progression of the body[1)]. The toe trajectory in the sagittal plane during the normal swing phase of the gait cycle follows a bimodal pattern. When the swing toe is elevated after toe-off, it reaches its first peak. After the first peak, the swing toe is descended closer to the ground. Subsequently, the swing toe is elevated again and reaches its second peak at the highest vertical point from the ground during the swing phase. Finally, the swing toe is dropped vertically when the heel of the swing limb strikes the ground. The swing phase is subdivided into three periods: initial swing, mid swing, and terminal swing. The swing foot exhibits the described first and second peaks during the initial and terminal swings, respectively. Conventionally, these are represented graphically by the terms Mx1 and Mx2 for the first

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and second peaks, respectively. The trough between Mx1 and Mx2 at mid swing is termed minimum toe clearance (MTC), at approximately 50% of the swing phase[2)]. MTC is defined as the minimum vertical distance between the lowest point of the toes of the swing leg and the walking surface, during the swing phase of the gait cycle. The swing toe is closest to the ground at MTC[3)]. The MTC is reported to be 10–30 mm to minimize metabolic cost (muscle activity) and to avoid the occurrence of toe-ground contact events[4, 5)].

Since tripping occurs when the MTC is reduced to zero, it is well recognized as an indicator of the risks of tripping-related falls[3)]. The forward velocity of the swing toe reaches a maximum at or near the MTC point[6)]. Then, if the swing toe contacts the walking surface or objects, an external force unexpectedly interrupts the progress of the swing foot during walking, and the body center of mass shifts in the anterior direction causing forward rotation of the body. The center of mass moves outside the base of the single support foot. Hence, when tripping at or near the MTC point, stability cannot be regained without rapid and safe placement of the swing foot, and tripping must be halted to prevent balance loss and falling[2–4, 6, 7)].

Considering that there is a strong association between tripping frequency and falling[8, 9)], it is important to control the swing leg at or near the MTC point to avoid tripping-related falls. A systematic review of MTC during level walking revealed that the mean or median values of MTC did not differ between healthy older and young adults, although MTC variability was greater in older adults than that in young adults[3)]. Furthermore, MTC variability was greater in older fallers than that in non-fallers[7)]. Studies have established that the increase in variability of both MTC and stride length[10)] or stride time[11)] is related to falls in older people. Springer et al.[12)] showed a negative relationship between swing time variability and performance on the tests of executive functions (Stroop test) in older fallers, but not in young or non-fallers. Additionally, this relationship intensifies during walking while performing a complex cognitive task, as compared to usual walking or walking while performing a simple cognitive task[12)].

The dual-task (DT) paradigm, measured as a walking task with additional cognitive tasks, is effective in examining an individual's capacity for executive functions and attentional resources[13)]. The performance of a concurrent task requires executive controls and increases attentional demands. It often leads to cognitive-motor interference (CMI) between tasks if the task is complex or exceeds an individual's processing capacity, and is manifested as a decreased performance in one or both tasks[14)]. Executive functions supervised by prefrontal cortex deficits are associated with declines in gait performance[15–17)]. Considering these findings, the decline in executive functions would contribute to the increase in variability of gait parameters, such as MTC, thereby leading to falls.

Santhiranayagam et al.[4, 9)] described the 'non-MTC' gait cycle (nMTC) as a gait cycle without a trough between Mx1 and Mx2 during the swing phase. Simply put, nMTC do not exhibit MTC events. They reported two important findings on the nMTC frequency increase in 1) the older group compared to that in the young group; 2) DT walking compared with preferred-speed walking. We expect that the main causal factor of the increase in the nMTC frequency would be contributed by the decline in executive functions. When the decline in executive functions makes it difficult to walk, while simultaneously performing a cognitive task, the person first gives priority to the safety of walking (shorter steps or slower walking speed) and then copes with a cognitive task. In the nMTC, the swing toe is higher than that in the MTC[4)], and this helps to secure the safety margin to the walking surface. We expect that the nMTC would be a compensatory strategy for prioritizing safety such that tripping-related falls in complex or challenging situations that induce greater CMI can be avoided. Therefore, we hypothesized that the nMTC frequency under DT would reflect the increase in CMI in older people. There are no reports on whether the nMTC frequency would increase under DT in physically and mentally healthy older people. Santhinarayagam et al.[4, 9)] evaluated the nMTC frequency in study participants who were walking on motorized treadmills and assigned holding a glass-of-water task as a secondary task. However, we believe that it would be more valid to evaluate this during ground-level walking to predict tripping-related balance loss or falls in the real world. Some researchers have reported kinematic differences between treadmill and ground-level walking[2, 18)]. This study aimed to explore whether nMTC frequency would increase under DT in healthy older adults on ground-level walking.

PARTICIPANTS AND METHODS

The participants included 20 healthy young adults (10 females and 10 males; aged 21.2 ± 0.8 years, mean ± SD) and 20 healthy older adults (10 females and 10 males; aged 70.2 ± 3.1 years, mean ± SD). The eligibility criteria were as follows: 1) no subjective symptoms related to locomotive organs; 2) normal cognitive function (Mini-Mental State Examination [MMSE] score of 24 or higher and Frontal Assessment Battery [FAB] score of 11 or higher); 3) not applicable to 'Sarcopenia' specified by the Asian Working Group for Sarcopenia in 2019[19)] and to physical 'Frail' specified by the revised Japanese version of the Cardiovascular Health Study criteria in 2020[20)]; and 4) living independently at home. We identified people by interviewing, measuring, and verifying. Those who met all the criteria were included in the older group and those who met one criterion were included in the young group. Written informed consent was obtained from all participants prior to the conduct of the study. This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Research Ethics Committee of Kinjo University (Ethics approval No. 2019-03).

A three-dimensional motion analyzer (Vicon Motion Systems Ltd., Oxford, UK) was used to trace the toe trajectory during walking. The location information of the four infrared reflective markers on both the big toenails and heels (2 cm height from ground level) during walking was measured using nine infrared cameras. Participants performed a 3-min preferred-speed walking barefoot on a circuit (total distance was 26 m) with two parallel 10-m long straights, and the distance between parallel straights was 3 m.

We set up four tasks as the conditions for performing 3-minute preferred walking. The four tasks were as follows: walk with no cognitive task (single-task: ST); DT_walk with a verbal task to count numbers from 1; DT_walk with a subtraction task to perform serial-3 subtractions from a predefined 3-digit number shown by the examiner; and DT_walk with a recall task to recall an item that belongs to a certain category [such as fruits or vegetables] presented by the examiner[21]. As for the timing to start each task, the verbal task was started after the start of walking, while the subtraction and recall tasks were given by the examiner after the start of walking. For the three DT tasks, the participants were instructed not to stop walking and to use a conversational tone of voice to answer. The subtraction and recall tasks were recorded using a voice recorder, and the numbers of correct/wrong answers were checked after measurements. When a reflective marker came off during measurement, the task was considered failed and moved to the last. The participant then proceeded to perform the next task. Walking direction on the circuit (clockwise or counterclockwise) and tasks for each participant were predetermined by a random draw. Participants took a 3-minute break between each session to relieve physically and mentally fatigue and to wash out the effect of the task before a break.

The measurable volume and the accuracy limit of the measuring devices were taken into consideration. To ensure data collection on the orientation of the reflective markers with an infrared camera and to eliminate errors in MTC, due to the slight inclination of the walkway surface, measurements were taken in a segment extending ± 1,000 mm from the origin of the three-dimensional coordinate space (a 4–6-m segment of a linear walkway). The origin was defined as a point located 5 m into the 10-m length and the center of the width of the straight walkways.

In the assessment procedure, the toe-off point and the heel-contact point were first determined from the longitudinal data on the vertical distance between the big toenail markers and the heel marker attached to the swinging limb. The interval between these points was regarded as the swing phase. Next, from the longitudinal data on the big toenail markers, the first peak observed in the toe trajectory of the swinging limb during the first half of the swing phase was identified and referred to as Mx1; the point where the toe was at the highest point during the second half was identified and referred to as Mx2. We determined whether there was a trough between Mx1 and Mx2[4]. In this study, because the reflective markers were directly attached to the body surface, the wobbling of the reflective markers during the swing phase was taken into consideration. The presence of a trough measuring 0.2 mm or greater from the height at Mx1 for 0.02 seconds or longer was assumed to be MTC gait cycle. Cases not meeting these conditions were determined to be nMTC in this study.

The longitudinal data on the big toenail markers were plotted on a graph. Cases in which the toe-off, Mx1, and Mx2 points could not be identified visually on the toe trajectory were excluded from the assessment data. The number of cases classified as MTC or nMTC was counted, and the frequency was calculated under each condition using the following formula: (cases of nMTC / total cases of nMTC and MTC gait cycles) × 100%. In addition, we calculated the DT costs (DTcs) of 3-min walking distance (3MWD) and nMTC frequency. DTc is used as an indicator of cognitive-motor interference under a DT condition[22]. DTc is used to be calculated as a percentage calculated as (DT−ST) / ST × 100%. In this study, however, DTc could not be calculated when nMTC frequency of ST was zero; therefore, this study used DTcs of 3MWD and nMTC frequency computed by subtracting ST value from DT value.

In statistical investigation, we first confirm whether there were differences of body composition and the total number of cases of swing phases which we could judge MTC or nMTC. We also compared the 3MWD, nMTC frequency in ST and DTc of verbal task between older and young group using Welch's t-test if the results of Shapiro–Wilk test showed normally distributed data in both groups to be compared; otherwise, Mann–Whitney U-test was performed.

Next, we performed the two-way analysis of variance (ANOVA) to examine whether differences were seen in 3MWDs, nMTC frequencies and DTcs among the elements of each task and between groups. Tukey test was used to compare 3MWD and nMTC frequency among the tasks if the results of Shapiro–Wilk test showed normally distributed data in all the tasks to be compared; otherwise, Steel-Dwass test was performed. The comparisons between groups were made using Mann–Whitney U-test.

We also compared three DTcs of 3MWD and three DTcs of nMTC frequency in each task between groups. The comparisons were made using Welch's t-test if the results of Shapiro–Wilk test showed normally distributed data in both groups; otherwise, Mann–Whitney U-test was used.

Regarding the subtraction task and recall task, the percentage of correct answers was obtained based on the numbers of responses and correct answers, and comparisons were made between two groups using Mann–Whitney U-test if the results of Shapiro-Wilk test showed not normally distributed data in both groups.

The statistical software IBM SPSS 26 (IBM Corp., Armonk, NY, USA) and the EZR version 1.54. were used. The significance level was set at 5% for all analyses.

RESULTS

Compared to the body composition data between groups, body mass index ($p<0.05$), percent of body fat ($p<0.05$) were higher value in older group than in young group although skeletal muscle mass index were not different (Table 1).

There were no differences in the total number of cases of swing phases that could judge MTC or nMTC in the four tasks between the two groups (Table 2). There were also no differences in the 3MWD and nMTC frequency in the ST (Table 3) and DTc of the verbal task (Table 4) between the two groups.

Table 1. The demographic characteristics in older and young group

	Older group	Young group
Age (years)	70.2 ± 3.1	21.2 ± 0.8
Male:Female	10:10	10:10
Body mass index (kg/m^2)*	22.0 ± 1.5	20.3 ± 2.6
Percent of body fat (%)*	25.3 ± 6.5	21.2 ± 5.5
Skeletal muscle mass index (kg/m^2)	7.1 ± 0.9	7.3 ± 0.9

The values of body mass index, percent body fat, skeletalmuscle mass index represents mean ± SD.
*p<0.05.

Table 2. The comparison of the number of swing phases which could judge in four tasks between two groups

	ST	DT		
		Verbal task	Subtraction task	Recall task
Older group	32.9 ± 4.4	30.4 ± 3.6	31.9 ± 4.3	32.4 ± 4.4
Young group	30.5 ± 5.0	30.8 ± 4.8	31.9 ± 3.7	31.3 ± 4.5

Mean ± SD.
ST: single-task; DT: dual-task.

Table 3. The comparison of 3MWD and nMTC frequency in four tasks between two groups

	ST		DT					
			Verbal task		Subtraction task		Recall task	
	Older group	Young group	Older group	Young group	Older group	Young group	Older group	Young group
3MWD (m)*	215.5 ± 24.9	205.3 ± 22.3	198.5 ± 36.8	193.5 ± 26.8	185.1 ± 37.9	178.6 ± 24.9	181.5 ± 38.5	182.4 ± 24.2
nMTC frequency (%)**	9.3 ± 14.6	9.5 ± 16.9	10.3 ± 16.3	6.8 ± 12.5	18.5 ± 25.2	8.0 ± 13.9	17.7 ± 20.6	8.6 ± 15.9

Mean ± SD.
ST: single-task; DT: dual-task; 3MWD: 3-minute walking distance; nMTC frequency: non-MTC gait cycle frequency.
nMTC frequency was caluculated using the formula: (cases of nMTC gait cycles / total cases of MTC and nMTC gait cycles) × 100%.
*two-way ANOVA: ST vs. subtraction p<0.001.
ST vs. recall p<0.001.
** two-way ANOVA: older vs. young p<0.05.

Table 4. The comparison of DTcs of 3MWD and nMTC frequency in DTs between two groups

	Verbal task		Subtraction task		Recall task	
	Older group	Young group	Older group	Young group	Older group	Young group
3MWD*	−17.0 ± 25.3	−11.9 ± 14.3	−30.5 ± 33.2	−26.7 ± 17.6	−34.0 ± 30.3	−22.9 ± 17.8
nMTC frequency**	1.0 ± 12.7	−2.7 ± 5.7	9.2 ± 13.5†	−1.5 ± 6.5†	8.4 ± 11.8††	−0.9 ± 5.1††

Mean ± SD.
ST: single-task; DT: dual-task.
3MWD: 3-minute walking distance; nMTC frequency: non-MTC gait cycle frequency.
nMTC frequency was caluculated using the formula: (cases of nMTC gait cycles / total cases of MTC and nMTC gait cycles) ×100%.
DTc: dual-task cost.
DTc was caluculated using the formula: DT−ST.
*two-way ANOVA: verbal vs. subtraction p<0.05.
verbal vs. recall p<0.05.
**two-way ANOVA: older vs. young p<0.001.
†DTc of nMTC of subtraction: older vs. young p<0.01.
†† DTc of nMTC of recall: older vs. young p<0.01.

Two-way ANOVA was used to examine the differences in variables among tasks and between groups. While differences were observed in the 3MWD and DTc of the 3MWD among the tasks, the nMTC frequency and DTc of the nMTC were significantly different between groups. The DTc of nMTC tended to differ among tasks, although the difference was not statistically significant (p=0.055). In the comparison of walking distance parameters among the four tasks, 3MWD was shorter and DTc of 3MWD was greater in the subtraction task (3MWD, p<0.001; DTc of 3MWD, p<0.05) and recall task (3MWD, p<0.001; DTc of 3MWD, p<0.05) than that in the ST. In the comparison of nMTC parameters between the two groups, nMTC frequency (p<0.05) and DTc of nMTC (p<0.001) were higher in the older group than in the young group.

Regarding DTc in each task between the two groups, all three DTc of 3MWD in the three tasks were not significantly different, while DTc of nMTC frequency in the subtraction (p<0.01) and recall (p<0.01) tasks were higher in the older group than in the young group.

The percentage of correct answers of subtraction and recall tasks in older group were lower than that in young group different between two groups (subtraction task, older 92.3 ± 7.3% vs. young 97.3 ± 4.4%, p<0.05; recall task, older 95.1 ± 5.4% vs. young 99.2 ± 1.5%, p<0.01).

DISCUSSION

The 3MWD in the subtraction and recall tasks was significantly different from that in the ST task, although the verbal task was not different. Since no significant difference was found in verbal tasks with low cognitive load, this result could be due to CMI by adding a cognitive load above a certain level. However, the 3MWDs did not differ between groups in all tasks. Older participants in this study who had no sarcopenia or physical frailty had normal cognitive and frontal brain function (judging from the results of MMSE and FAB) and were physically and mentally robust. Since the DTc of 3MWD was also not different between groups, we expected that the degree of CMI induced by an additional cognitive task in the older group was equivalent to that in the young group.

The result of the two-way ANOVA revealed that nMTC frequency was higher in the older group than that in the young group. This result supports Santhiranayagam's study[4], which utilized motorized treadmills and assigned holding a glass-of-water task as a secondary task. Older individuals who have declined executive functions with aging (not impairment) would prioritize postural stability to face cognitive tasks under DT conditions because it is difficult to process concurrent multitasks in parallel. Santhiranayagam considered the nMTC gait cycle to be an adaptive toe trajectory control strategy[4]. We assumed that the nMTC under DT (subtraction or recall tasks) would be a compensatory safety strategy to control the toe trajectory, and thus avoid tripping-related falls. Hence, the increase in the nMTC frequency under DT would be induced by an increase in the CMI. The most notable finding in our study is that the DTc of nMTC in the subtraction and recall tasks was higher in the older group than that in the young group, although DTc of 3MWD did not differ between the two groups. These results indicate that older adults might alter gait pattern unconsciously to avid the tripping-related falls while they could maintain the walking distance under subtraction or recall tasks. Therefore, the subtle qualitative change of gait appearance such as the nMTC frequency might be more useful to evaluate the degree of CMI rather than quantitative parameters such as walking distance for physically and mentally healthy older individuals, although it is well established that gait speed reduction under DT is useful to predict the degree of CMI for frailty[23] or older individuals[24].

However, nMTC frequency was not different among the four tasks as a result of two-way ANOVA, while the DTc of nMTC tended to be different among tasks (p=0.055). These results could be due to the nMTC frequency of the ST in the young group. The average value of nMTC frequency of ST was the highest among the four tasks in the young group, although there were no statistically significant differences. Our nMTC frequency of ST in the young group (9.5%) was higher than that reported by Santhiranayagam (2.8%). This could be due to the difference in measurement environment (treadmill vs. ground-level walking), foot condition (wearing shoes vs. barefoot), judgment of criterion for nMTC, and number of acquired gait cycles; however, we could not elucidate this further. We must also consider the difference in postural strategy between groups against cognitive tasks (subtraction and recall). Further research is needed to investigate the differences in gait kinematics and brain activity under the ST and DT conditions.

This study had several limitations. First, we expected that the increase in nMTC frequency under subtraction and recall tasks compared to ST would reflect the increase in CMI for older people. However, we could not examine the prefrontal brain activity, which supervised executive functions in this study. Therefore, in the future, the relationship between the change in nMTC frequency and the degree of prefrontal brain activity under the ST and DT conditions may be investigated. Second, the measurements in our study were obtained in a laboratory where participants did not require the allocation or division of attention resources as walking outdoors would entail. The participants also walked barefoot on an even floor. Hence, we could not confirm whether these results could predict tripping-related falls in daily life. Longitudinal studies with larger samples should be conducted to investigate the relationship between nMTC frequency under DT measured in the laboratory and tripping-related falls in daily life.

Our results showed that the nMTC frequency increased in the older group compared with that in the young group, and the DTc of nMTC increased in the subtraction and recall tasks compared to that in the verbal task. These results suggest that the nMTC frequency under DT would reflect the increase in CMI in the healthy older adults.

Conflict of interest

There is no COI to disclose.

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REFERENCES

1) Mills PM, Barrett RS: Swing phase mechanics of healthy young and elderly men. Hum Mov Sci, 2001, 20: 427–446. [Medline] [CrossRef]
2) Nagano H, Begg RK, Sparrow WA, et al.: Ageing and limb dominance effects on foot-ground clearance during treadmill and overground walking. Clin Biomech (Bristol, Avon), 2011, 26: 962–968. [Medline] [CrossRef]
3) Barrett RS, Mills PM, Begg RK: A systematic review of the effect of ageing and falls history on minimum foot clearance characteristics during level walking. Gait Posture, 2010, 32: 429–435. [Medline] [CrossRef]
4) Santhiranayagam BK, Sparrow WA, Lai DT, et al.: Non-MTC gait cycles: an adaptive toe trajectory control strategy in older adults. Gait Posture, 2017, 53: 73–79. [Medline] [CrossRef]
5) Mills PM, Barrett RS, Morrison S: Toe clearance variability during walking in young and elderly men. Gait Posture, 2008, 28: 101–107. [Medline] [CrossRef]
6) Winter DA: Foot trajectory in human gait: a precise and multifactorial motor control task. Phys Ther, 1992, 72: 45–53, discussion 54–56. [Medline] [CrossRef]
7) Schulz BW: Minimum toe clearance adaptations to floor surface irregularity and gait speed. J Biomech, 2011, 44: 1277–1284. [Medline] [CrossRef]
8) Pavol MJ, Owings TM, Foley KT, et al.: Gait characteristics as risk factors for falling from trips induced in older adults. J Gerontol A Biol Sci Med Sci, 1999, 54: M583–M590. [Medline] [CrossRef]
9) Santhiranayagam BK, Lai DT, Sparrow WA, et al.: Minimum toe clearance events in divided attention treadmill walking in older and young adults: a cross-sectional study. J Neuroeng Rehabil, 2015, 12: 58. [Medline] [CrossRef]
10) Maki BE: Gait changes in older adults: predictors of falls or indicators of fear. J Am Geriatr Soc, 1997, 45: 313–320. [Medline] [CrossRef]
11) Hausdorff JM, Rios DA, Edelberg HK: Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil, 2001, 82: 1050–1056. [Medline] [CrossRef]
12) Springer S, Giladi N, Peretz C, et al.: Dual-tasking effects on gait variability: the role of aging, falls, and executive function. Mov Disord, 2006, 21: 950–957. [Medline] [CrossRef]
13) Holtzer R, Kraut R, Izzetoglu M, et al.: The effect of fear of falling on prefrontal cortex activation and efficiency during walking in older adults. Geroscience, 2019, 41: 89–100. [Medline] [CrossRef]
14) Ruffieux J, Keller M, Lauber B, et al.: Changes in standing and walking performance under dual-task conditions across the lifespan. Sports Med, 2015, 45: 1739–1758. [Medline] [CrossRef]
15) Yogev-Seligmann G, Hausdorff JM, Giladi N: The role of executive function and attention in gait. Mov Disord, 2008, 23: 329–342, quiz 472. [Medline] [CrossRef]
16) Amboni M, Barone P, Hausdorff JM: Cognitive contributions to gait and falls: evidence and implications. Mov Disord, 2013, 28: 1520–1533. [Medline] [CrossRef]
17) Salzman T, Aboualmagd A, Badawi H, et al.: Prefrontal cortex involvement during dual-task stair climbing in healthy older adults: an fNIRS study. Brain Sci, 2021, 11: 71. [Medline] [CrossRef]
18) Watt JR, Franz JR, Jackson K, et al.: A three-dimensional kinematic and kinetic comparison of overground and treadmill walking in healthy elderly subjects. Clin Biomech (Bristol, Avon), 2010, 25: 444–449. [Medline] [CrossRef]
19) Chen LK, Woo J, Assantachai P, et al.: Asian Working Group for Sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. J Am Med Dir Assoc, 2020, 21: 300–307.e2. [Medline] [CrossRef]
20) Satake S, Arai H: The revised Japanese version of the Cardiovascular Health Study criteria (revised J-CHS criteria). Geriatr Gerontol Int, 2020, 20: 992–993. [Medline] [CrossRef]
21) Sasaki K, Ooi T, Yokota A, et al.: Effects of cognitive tasks on center-of-foot pressure displacements and brain activity during single leg stance: comparison in community-dwelling healthy older and young people. J Phys Ther Sci, 2022, 34: 177–182. [Medline] [CrossRef]
22) Beurskens R, Bock O: Age-related deficits of dual-task walking: a review. Neural Plast, 2012, 2012: 131608. [Medline] [CrossRef]
23) Guedes RC, Dias RC, Pereira LS, et al.: Influence of dual task and frailty on gait parameters of older community-dwelling individuals. Braz J Phys Ther, 2014, 18: 445–452. [Medline] [CrossRef]
24) Al-Yahya E, Dawes H, Smith L, et al.: Cognitive motor interference while walking: a systematic review and meta-analysis. Neurosci Biobehav Rev, 2011, 35: 715–728. [Medline] [CrossRef]