Table 2. Multivariate logistic regression model to determine the association with a high MMSE score

	All (n=174)		Male (n=84)		Female (n=90)	
	OR (95% CI)	p	OR (95% CI)	p	OR (95% CI)	p
Age, year	1.00 (0.92-1.09)	1.00	1.08 (0.95-1.12)	0.25	0.96 (0.85-1.09)	0.51
Height, cm	1.04 (0.97-1.12)	0.27	0.97 (0.88-1.08)	0.60	1.13 (1.00-1.28)	0.05
Weight, kg	1.05 (1.00-1.11)	0.03*	1.11 (1.03-1.19)	0.01*	1.01 (0.94-1.09)	0.82
Gender	–	0.04*	–	–	–	–
men	1 [Reference]	–	–	–	–	–
women	3.13 (1.05-9.34)	–	–	–	–	–
Mean CAVI	0.68 (0.48-0.96)	0.03*	0.57 (0.33-0.98)	0.04*	0.73 (0.44-1.23)	0.24

Mean CAVI = the mean value of the right and left CAVI scores; OR = Odds Ratio, 95% CI = 95% confidence interval.
*: $p<0.05$

tive function and the CAVI in Japanese community-dwelling elderly subjects. In this study, we found a negative correlation between the CAVI and the cognitive function, even after adjusting for age, height, weight and gender. Many studies have demonstrated a relationship between arterial stiffness and a decreased cognitive function[5, 12, 13]; however, there are no reports using the novel index of arterial stiffness, the CAVI, in community-dwelling elderly subjects.

Several mechanisms may potentially explain why arterial stiffness is associated with the cognitive function. First, the development of dementia is associated with organic brain lesions, such as ischemic lesions and white matter abnormalities[20]. Because stiff blood vessels lose their capacity to buffer pulse pressure, the pulsatile flow is increased, causing damage to the fragile small vessels in the brain[21]. This phenomenon has been demonstrated in animal studies, in which locally induced isolated alterations in pressure pulsatility have been shown to have major effects on the cerebral microvascular structure and function[22]. Pase *et al.*[23] reported that the augmented pressure caused by arterial stiffness independently predicts the cognitive function. In addition, some studies have shown evidence that asymptomatic cerebral microvascular lesions caused by augmented pressure are associated with an increased risk of AD[24, 25]. Our major finding indicating a correlation between the CAVI and the cognitive function is consistent with the results of these previous reports. However, this relationship was found only in elderly men in a gender-specific analysis; therefore, cognition may be more strongly affected by arterial stiffness in men than in women. Larger studies should address the effects of the CAVI on the cognitive function in elderly women.

The peculiarity of the CAVI is that it indicates BP-independent arterial stiffness, unlike the baPWV. Therefore, it is conceivable that the CAVI is a useful parameter in patients who are subject to variation in BP at various times due to masked hypertension or the use of antihypertensive medications. Masked hypertension is defined as a normal BP in the clinic or office (<140/90 mmHg) with an elevated BP out of the clinic (ambulatory daytime BP or home BP> 135/85 mmHg)[26]. This phenomenon can occur in up to 8-38% of the general population and is observed at all ages[27]. In addition, antihypertensive medication use has recently increased. Men have seen the greatest increase in antihypertensive medication use (47.5%, 1988-1994 versus 57.9%, 1999-2002) among hypertensive adults[28]. Moreover, Takaki *et al.* demonstrated the superiority of the CAVI to the baPWV in measurement sensitivity[29]. They found that the CAVI was better correlated with the parameters of left ventricular diastolic indices, low-density lipoprotein cholesterol and angina pectoris than the baPWV.

When evaluating arterial stiffness in community-dwelling elderly subjects, the most important properties of an instrument for assessment are ease of measurement and validation. The clinical advantage of our study is the indication of a significant relationship between arterial stiffness and the cognitive function in community-dwelling elderly subjects based on the use of a better arterial stiffness index, the CAVI. In order to early detect cognitive decline, clinicians should conduct screening exams for community-dwelling elderly patients. This is why we adopted the 26/27 cutoff point for our patients, all of whom lived independently and were highly educated. This index has the potential to be used to detect cognitive decline earlier in community-dwelling elderly subjects due to its validity and noninvasive nature.

This study is associated with several limitations. First, because this study is a cross-sectional study, the cause-effect relationship between the CAVI and the cognitive function is unknown. Second, we were unable to perform neuroimaging procedures. The participants may have had asymptomatic brain lesions that we could not fully investigate. In addition, we did not distinguish between the types of dementia. Different types of dementia may affect the results. Further investigations, such as prospective studies, are required to confirm the findings of the present study.

Conclusion

This is the first study to determine the relationship between the cognitive function and the CAVI in community-dwelling elderly subjects. We found a significant relationship between a higher CAVI and mild cognitive decline. This finding indicates the usefulness of the CAVI in the early detection of dementia.

Conflicts of Interest

None.

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Original Article

Arterial Stiffness Determined According to the Cardio-Ankle Vascular Index (CAVI) is Associated with Mild Cognitive Decline in Community-Dwelling Elderly Subjects

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Aims: The purpose of this study was to determine the cross-sectional relationship between the cognitive function and cardio-ankle vascular index (CAVI) in Japanese community-dwelling elderly subjects.

Methods: A total of 179 Japanese community-dwelling elderly subjects were recruited for this study. The age, height, weight, gender and past medical history (cardiovascular disease, hypertension, diabetes mellitus, hyperlipidemia) of each participant was recorded. In addition, the degree of arterial stiffness was determined according to the CAVI, while the cognitive function was assessed using the Mini-Mental State Examination (MMSE). After dividing the cohort into two groups according to the MMSE score (≤ 26, >26), we used a multiple regression analysis to assign the level of the cognitive function as a dependent variable.

Results: The data were statistically analyzed for the 174 participants (84 men and 90 women) who completed the data collection process without omissions. A multivariate logistic regression analysis showed that a higher weight (Odds Ratio [OR]: 1.05, 95% Confidence Interval [95% CI]: 1.00-1.11, $p=0.03$), male gender (OR: 3.13, 95% CI: 1.05-9.34, $p=0.04$) and lower CAVI (OR: 0.68, 95% CI: 0.48-0.96, $p=0.03$) were significantly correlated with a higher MMSE score. We also found significant correlations between the MMSE and weight (OR: 1.11, 95% CI: 1.03-1.19, $p=0.01$) and CAVI (OR: 0.57, 95% CI: 0.33-0.98, $p=0.04$) in elderly men only using a gender-specific analysis.

Conclusions: We found that the elderly subjects with a high CAVI exhibited a worse cognitive function even after adjusting for age, height, weight and gender. This finding therefore indicates the usefulness of the CAVI in the early detection of dementia.

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Key words: Cognitive function, Arterial stiffness, Community-dwelling elderly

Introduction

Dementia can drastically influence daily life and is currently one of the most common diseases in the elderly. The World Health Organization estimated that 35 million people worldwide suffered from dementia in 2012, and people with dementia have been shown to be frail due to their poor mobility and body composition. Approximately 48% of people with Alzheimer's disease (AD), the most common form of dementia, are estimated to live in Asia, and this percentage will grow to 59% by 2050[1]. The transitional stage between normal aging and AD is called mild cognitive impairment (MCI), and more than half of MCI cases progress to dementia within five years[2, 3]. Therefore, preventing cognitive decline is crucial.

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Identifying risk factors that can predict cognitive decline will help to prevent such decline. Although many studies have attempted to address this issue, evidence supporting the role of modifiable risk factors remains limited[4-6]. Meanwhile, vascular risk factors have received attention in recent years[7, 8]. High blood pressure[9], dyslipidemia[9], obesity[10] and diabetes mellitus[10] have been proposed to be risk factors for cognitive decline. Among these factors, arterial stiffness, specifically, is a comparatively easy-to-modify risk factor. It has been reported that systemic atherosclerosis plays a role in the cognitive function and is directly linked to the pathology of Alzheimer's disease[11]. In one European study, it was found that functional changes in the arterial system may be involved in the onset of dementia[12].

Arterial stiffness is one of the most easily measured vascular risk factors in community-dwelling elderly subjects due to its noninvasive nature. The brachial-ankle pulse wave velocity (baPWV) is widely used for this purpose. In a cross-sectional study of 370 middle-aged Korean participants, the baPWV was found to be significantly correlated with the cognitive function[13]. In addition, in a Japanese study, a high baPWV was shown to be a risk factor for a poor cognitive function in 352 community-dwelling elderly subjects[5]. However, there are several problems associated with the measurement of baPWV, as the value of the parameter depends on the blood pressure (BP) at the time of measurement[14]. Therefore, it is difficult to evaluate arterial stiffness in patients treated with antihypertensive medications or those with masked hypertension. In contrast, the cardio-ankle vascular index (CAVI) is a novel BP-independent parameter of arterial stiffness[15, 16]. This parameter is adjusted for the PWV according to the systolic and diastolic blood pressure and blood density and is therefore a theoretically BP-independent index. Clinicians can ensure the validity of arterial stiffness measurements using this parameter. However, no studies have so far evaluated the relationship between the cognitive function and arterial stiffness using the CAVI. In addition, few studies have evaluated this relationship in community-dwelling elderly patients.

The purpose of this study, therefore, was to determine the cross-sectional relationship between the cognitive function and the CAVI in Japanese community-dwelling elderly subjects.

Methods

Participants

Participants were recruited for this study through local press requesting healthy community-dwelling volunteers, resulting in a total of 179 Japanese participants 65 years of age or older and currently living in the community. Interviews were then performed to exclude participants based on the following exclusion criteria: severe cardiac, pulmonary or musculoskeletal disorders; comorbidities associated with a greater risk of falls, such as Parkinson's disease and stroke; and the use of psychotropic drugs. Written informed consent was obtained from each participant for the trial in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1995. The study protocol was approved by the ethical committee of the Kyoto University Graduate School of Medicine.

Measurements

Demographic Data

Age, height, weight, gender, past medical history (cardiovascular disease, hypertension, diabetes mellitus, hyperlipidemia), smoking status (number of cigarettes smoked per day and total number of years smoked) and educational background (elementary school, junior high school, high school, career college and university) were recorded as demographic data. All data were collected at the onset of data collection. We surveyed age and gender from the participant directly and measured the height and weight using standardized height and weight scales.

CAVI

The CAVI was determined using the VaSera-1500 (Fukuda Denshi Co., Ltd., Tokyo, Japan). The procedure has been detailed previously[15, 16]. Briefly, after the participants had rested for five minutes in a sitting position, they were placed in a supine position. Then, cuffs were wrapped around both brachia and ankles to detect the brachial and ankle pulse waves. Electrocardiograms and heart sounds were monitored. The PWV from the heart to the ankle was calculated by measuring the length from the aortic valve to the ankle and dividing by time, which was determined according to the heart sounds and the rise of the brachial and ankle pulse waves. Blood pressure was also measured at the brachial artery. Finally, scale conversion was performed using the following formula:

$$\mathrm{CAVI} = a\{(2\rho/\Delta P) \times \mathrm{In}(Ps/Pd)PWV^2\} + b \text{ (no unit)}$$

ρ: blood density, Ps: systolic blood pressure, Pd; diastolic blood pressure, ΔP: Ps-Pd, PWV: pulse wave velocity, a and b: constants.

The validity, reproducibility and blood pressure-independent nature of this experiment have been well

Table 1. Differences in each variable between the MMSE high/low score groups

	All (n=174)			Men (n=84)			Women (n=90)		
	Low MMSE (≤26) n=56	High MMSE (>26) n=118	p	Low MMSE (≤26) n=30	High MMSE (>26) n=54	p	Low MMSE (≤26) n=26	High MMSE (>26) n=64	p
MMSE	24.6±1.3	28.7±1.1	<0.01**	24.8±1.0	28.8±1.1	<0.01**	24.5±1.5	28.6±1.1	<0.01**
Age, year	74.2±4.6	73.4±4.3	0.26	73.8±5.2	73.8±4.2	0.94	74.5±3.7	73.0±4.4	0.12
Height, cm	155.5±8.7	156.1±8.1	0.65	162.2±5.3	162.8±6.0	0.64	147.8±4.6	150.5±4.7	0.02*
Weight, kg	54.0±8.8	57.3±9.7	0.03*	57.6±9.3	63.6±8.7	0.01*	49.9±6.1	52.0±7.1	0.19
Gender, male	30 (53.6%)	54 (45.8%)	0.21	–	–	–	–	–	–
Mean CAVI	9.61±1.30	9.13±1.16	0.02*	9.97±1.52	9.38±0.87	0.03*	9.19±0.85	9.03±0.93	0.47
Cardiovascular disease	8 (14.3%)	8 (6.8%)	0.16	6 (20.0%)	4 (7.4%)	0.16	2 (7.7%)	4 (6.3%)	1.00
Hypertension	21 (37.5%)	50 (42.4%)	0.62	13 (43.3%)	23 (42.6%)	1.00	8 (30.8%)	27 (42.2%)	0.35
Diabetes mellitus	6 (10.7%)	14 (11.9%)	1.00	2 (6.7%)	8 (14.9%)	0.47	4 (15.4%)	6 (9.4%)	0.47
Hyperlipidemia	8 (14.3%)	18 (15.3%)	1.00	4 (13.3%)	5 (9.6%)	0.72	4 (15.4%)	13 (20.3%)	0.77
Brinkman index	0 (0-762.5)	0 (0-356.3)	0.70	0 (0-787.5)	0 (0-637.5)	0.50	0 (0-612.5)	0 (0-2.25)	0.23
Educational background			n.s.			n.s.			n.s.
Elementary school	2 (3.6%)	1 (0.8%)		2 (6.7%)	1 (1.9%)		0 (0.0%)	0 (0.0%)	
Junior high school	26 (46.4%)	28 (23.7%)		16 (53.3%)	15 (27.8%)		10 (38.5%)	13 (20.3%)	
High school	26 (46.4%)	69 (58.5%)		11 (36.7%)	30 (55.6%)		15 (57.7%)	39 (60.9%)	
Career college	0 (0.0%)	7 (5.9%)		0 (0.0%)	1 (1.9%)		0 (0.0%)	6 (9.4%)	
University	2 (3.6%)	13 (11.0%)		1 (3.3%)	7 (13.0%)		1 (3.8%)	6 (9.4%)	

Mean CAVI = the mean value of the right and left CAVI scores; Mean ± SD values are shown for age, height, weight and mean CAVI; n (%) is shown for gender, cardiovascular disease, hypertension, diabetes mellitus, hyperlipidemia and educational background; Median (25% quartile-75% quartile) is shown for the Brinkman index; n.s.: not significant.
*: $p<0.05$, **: $p<0.01$

documented by several studies[15, 16]. The measurements were obtained once, and the mean value of the right and left CAVI scores for each patient was used for the analysis[17].

Cognitive Function Measurement

The cognitive function was assessed using the Mini-Mental State Examination (MMSE)[18]. The MMSE is a short screening test that consists of five areas of possible cognitive impairment: orientation; registration; attention and calculation; and language. The scores ranged from 0 to 30, with a higher score indicating a better cognitive performance. We tested the participants individually based on the generalized method and used 26/27 as the cutoff score, according to Spering CC *et al.*[19].

Statistical Analysis

The participants were divided into two groups based on the MMSE score: ≤26 or >26. This cutoff of 26/27 has been shown to be a better balanced score of estimates of diagnostic accuracy for educated individuals[19]. Because our participants were community-dwelling and highly educated and all lived independently, we adopted this 26/27 cutoff.

We statistically analyzed the differences between the two groups using the unpaired *t*-test for age, height, weight and the mean CAVI on both sides, the χ^2 test for gender, past medical history and educational background and the Mann Whitney *U*-test for the Brinkman index (number of cigarettes smoked per day × total number of years smoked). A multivariate logistic regression model was performed to investigate whether the CAVI was independently associated with the MMSE score. We assigned a high MMSE score as the dependent variable adjusted for age, height, weight and gender. A value of $p<0.05$ was considered to be statistically significant for all analyses.

Results

In total, there were 179 elderly participants (85 men and 94 women) in this study. Of the 179 patients, 84 men and 90 women completed the data collection without omissions, for a total of 174 data points.

We assigned 56 elderly subjects (30 men and 26 women) into the low MMSE group and 118 elderly subjects (54 men and 64 women) into the high MMSE group. **Table 1** shows the differences in each variable between the two groups. While there were no significant differences in age, height, gender or past medical history, a higher weight was associated with a higher MMSE score ($p=0.03$). In addition, the low MMSE group had significantly higher CAVI values than the high MMSE group (**Fig. 1**, the low group: 9.61 ± 1.30, the high group: 9.13 ± 1.16, $p=0.02$).

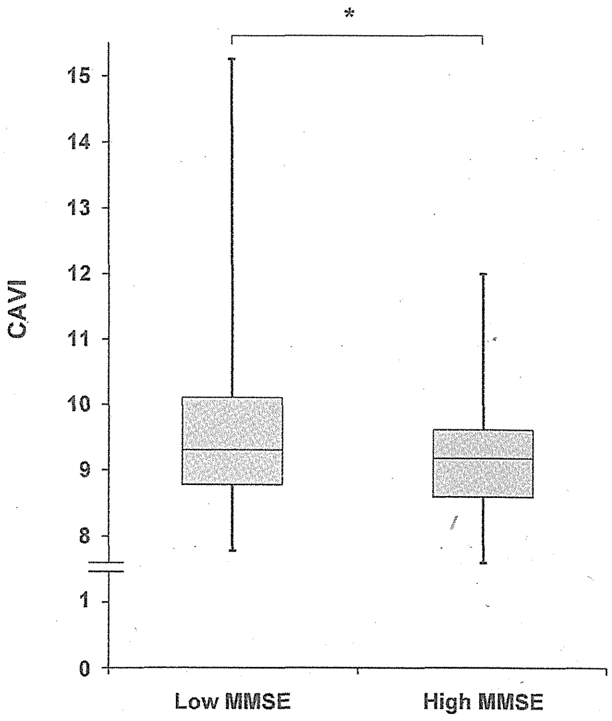

Fig. 1. Differences in the mean CAVI values between the high and low MMSE groups.

We statistically analyzed the differences between the two groups using the unpaired *t*-test for the mean CAVI on both sides.
*: $p=0.02$

The multivariate logistic regression analysis showed that a higher weight (odds ratio [OR]: 1.05, 95% confidence interval [95% CI]: 1.00-1.11, $p=0.03$), female gender (OR: 3.13, 95% CI: 1.05-9.34, $p=0.04$) and lower CAVI (OR: 0.68, 95% CI: 0.48-0.96, $p=0.03$) were significantly correlated with a higher MMSE score (**Table 2**), indicating that elderly subjects with a higher CAVI have a lower cognitive function, even after adjustment for age, height, weight and gender. In the multivariate logistic regression analysis of each gender, we found a significant correlation between the MMSE score and weight (OR: 1.11, 95% CI: 1.03-1.19, $p=0.01$) and CAVI (OR: 0.57, 95% CI: 0.33-0.98, $p=0.04$) in the elderly men only (**Table 2**).

Discussion

We analyzed the relationship between the cogni-

Table 2. Multivariate logistic regression model to determine the association with a high MMSE score

	All (*n*=174)		Male (*n*=84)		Female (*n*=90)	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Age, year	1.00 (0.92-1.09)	1.00	1.08 (0.95-1.12)	0.25	0.96 (0.85-1.09)	0.51
Height, cm	1.04 (0.97-1.12)	0.27	0.97 (0.88-1.08)	0.60	1.13 (1.00-1.28)	0.05
Weight, kg	1.05 (1.00-1.11)	0.03*	1.11 (1.03-1.19)	0.01*	1.01 (0.94-1.09)	0.82
Gender	–	0.04*	–	–	–	–
men	1 [Reference]	–	–	–	–	–
women	3.13 (1.05-9.34)	–	–	–	–	–
Mean CAVI	0.68 (0.48-0.96)	0.03*	0.57 (0.33-0.98)	0.04*	0.73 (0.44-1.23)	0.24

Mean CAVI = the mean value of the right and left CAVI scores; OR = Odds Ratio, 95% CI = 95% confidence interval.
*: $p<0.05$

tive function and the CAVI in Japanese community-dwelling elderly subjects. In this study, we found a negative correlation between the CAVI and the cognitive function, even after adjusting for age, height, weight and gender. Many studies have demonstrated a relationship between arterial stiffness and a decreased cognitive function[5, 12, 13]; however, there are no reports using the novel index of arterial stiffness, the CAVI, in community-dwelling elderly subjects.

Several mechanisms may potentially explain why arterial stiffness is associated with the cognitive function. First, the development of dementia is associated with organic brain lesions, such as ischemic lesions and white matter abnormalities[20]. Because stiff blood vessels lose their capacity to buffer pulse pressure, the pulsatile flow is increased, causing damage to the fragile small vessels in the brain[21]. This phenomenon has been demonstrated in animal studies, in which locally induced isolated alterations in pressure pulsatility have been shown to have major effects on the cerebral microvascular structure and function[22]. Pase *et al.*[23] reported that the augmented pressure caused by arterial stiffness independently predicts the cognitive function. In addition, some studies have shown evidence that asymptomatic cerebral microvascular lesions caused by augmented pressure are associated with an increased risk of AD[24, 25]. Our major finding indicating a correlation between the CAVI and the cognitive function is consistent with the results of these previous reports. However, this relationship was found only in elderly men in a gender-specific analysis; therefore, cognition may be more strongly affected by arterial stiffness in men than in women. Larger studies should address the effects of the CAVI on the cognitive function in elderly women.

The peculiarity of the CAVI is that it indicates BP-independent arterial stiffness, unlike the baPWV. Therefore, it is conceivable that the CAVI is a useful parameter in patients who are subject to variation in BP at various times due to masked hypertension or the use of antihypertensive medications. Masked hypertension is defined as a normal BP in the clinic or office (<140/90 mmHg) with an elevated BP out of the clinic (ambulatory daytime BP or home BP> 135/85 mmHg)[26]. This phenomenon can occur in up to 8-38% of the general population and is observed at all ages[27]. In addition, antihypertensive medication use has recently increased. Men have seen the greatest increase in antihypertensive medication use (47.5%, 1988-1994 versus 57.9%, 1999-2002) among hypertensive adults[28]. Moreover, Takaki *et al.* demonstrated the superiority of the CAVI to the baPWV in measurement sensitivity[29]. They found that the CAVI was better correlated with the parameters of left ventricular diastolic indices, low-density lipoprotein cholesterol and angina pectoris than the baPWV.

When evaluating arterial stiffness in community-dwelling elderly subjects, the most important properties of an instrument for assessment are ease of measurement and validation. The clinical advantage of our study is the indication of a significant relationship between arterial stiffness and the cognitive function in community-dwelling elderly subjects based on the use of a better arterial stiffness index, the CAVI. In order to early detect cognitive decline, clinicians should conduct screening exams for community-dwelling elderly patients. This is why we adopted the 26/27 cutoff point for our patients, all of whom lived independently and were highly educated. This index has the potential to be used to detect cognitive decline earlier in community-dwelling elderly subjects due to its validity and noninvasive nature.

This study is associated with several limitations. First, because this study is a cross-sectional study, the cause-effect relationship between the CAVI and the cognitive function is unknown. Second, we were unable to perform neuroimaging procedures. The participants may have had asymptomatic brain lesions that we could not fully investigate. In addition, we did not distinguish between the types of dementia. Different types of dementia may affect the results. Further investigations, such as prospective studies, are required to confirm the findings of the present study.

Conclusion

This is the first study to determine the relationship between the cognitive function and the CAVI in community-dwelling elderly subjects. We found a significant relationship between a higher CAVI and mild cognitive decline. This finding indicates the usefulness of the CAVI in the early detection of dementia.

Conflicts of Interest

None.

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Effects of dual-tasking on control of trunk movement during gait: Respective effect of manual- and cognitive-task

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ABSTRACT

Trunk control during gait provides a stable platform for vision and head control. However, in dual-task gait, cognitive tasks result in increased trunk movements, reduced gait speed, and increased gait variability. Manual tasks have been associated with reduced gait speed, but their effects on trunk movement have not been fully investigated. Furthermore, the fear of falling (FoF) during dual-task gait remains relatively unstudied. We aimed to assess trunk movements during cognitive-task gait (CG) and manual-task gait (MG), and examine the effects of CG and MG on individuals with and without FoF. The participants were 117 healthy older adults. We used two triaxial accelerometers: one to record trunk movements at the L3 spinous process and one at the heel to measure initial contact. Participants counted backward by one (CG) or carried a ball on a tray (MG), and we calculated stride time variability and standardized root-mean-square trunk accelerations in the mediolateral (ML) and anteroposterior (AP) directions. CG significantly increased lower trunk oscillations in the ML ($t = 4.9$, $p < 0.001$) and AP directions ($t = 6.1$, $p < 0.001$). Conversely, MG significantly decreased trunk oscillations in the ML ($t = -5.9$, $p < 0.001$) and AP directions ($t = -8.3$, $p < 0.001$). The difference in trunk oscillations during CG in the ML direction was significantly larger in subjects with FoF than without FoF ($t = 2.6$, $p < 0.01$). We conclude that for the tasks we studied, CG and MG have different effects on trunk movement. Finally, FoF was associated with changes in trunk movement in the ML direction during CG but not MG.

1. Introduction

In normal gait, stable trunk movements contribute to successful locomotion. During walking, the control of trunk movement is prioritized and plays an important role in providing a stable platform for vision and head control [1]. Several reports suggest that the control of trunk movements requires attentional resources, and challenging attention-splitting conditions, e.g., dual-task walking, strongly affects trunk movement [2]. Dual-task-related gait changes help assess age-related changes in gait and trunk control that may lead to falls.

Two different types of task, a cognitive task and a manual task, have been used as an additional attention-demanding task in research on dual-task gait [3]. A cognitive task is chosen more often in dual task studies because it directly affects cognitive brain function and its performance can be easily quantified [2,3]. Many reports have demonstrated that a cognitive task affects gait patterns and trunk movements, e.g., reduced gait speed, increased gait variability and increased fluctuation of trunk movements in the horizontal plane [2,4,5]. A manual task is used less often than a cognitive task in dual task studies, because no standard manual task exists and its performance cannot be easily quantified. Some reports have demonstrated that a manual task, similarly to a cognitive task, affects gait patterns, e.g., reduced gait speed, but the effects of a manual task on trunk movement have not yet been fully studied [2,6].

Although both tasks induce similar gait pattern changes, the allocation of attention differs between cognitive-task and manual-task gaits. In the case of cognitive-task gaits, the attentional resources are split and allocated arbitrarily to each task; the

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additional cognitive task draws attentional resources away from gait, and gait movements fluctuate and oscillate [6]. However, when a simple goal-directed manual-task gait is performed, e.g. carrying a tray while walking, the dual-task-related reductions in gait speed are less apparent when compared with cognitive-task gait [7,8]. Resources for the control of walking and the performance of a manual task are both within the motor control system [2]. Together, these findings suggest that the attention allocated to walking movements in manual-task gait closely resembles that in normal gait (no task gait). Therefore, dual-task-related changes in trunk movements may differ between cognitive-task gait and manual-task gait, even if similar dual-task-related gait changes are observed.

Furthermore, dual-task gait may be affected by mental status, including a fear of falling (FoF) [9]. FoF is common among older adults with fall history and refers to the lack of self-confidence in performing normal activities without falling [10]. FoF induces gait pattern changes, including reduced gait speed and increased step width, and may influence the control of trunk movements during walking [11]. Gage et al. proposed that anxiety associated with FoF reduces the attentional resources available for gait control [9]. The effect of FoF on gait may therefore be more apparent in the dual-task gait condition. To our knowledge, only one study has investigated the effect of FoF on trunk movement during cognitive-task gait, and found no effect of FoF on trunk sway [12]. However, the effect of FoF on trunk movement in manual-task gait remains unclear.

Therefore, the first objective of this study was to assess the effects of a cognitive task and a manual task on trunk movements during gait. A second objective was to examine the effect of FoF on trunk movement in both dual-task walking conditions: cognitive-task and manual-task gaits.

2. Methods

2.1. Subjects

One hundred and seventeen healthy, community-dwelling older adults (51 male and 66 female, age 73.7 ± 4.0 years) were included in this study. Subjects were recruited through a local community center. Inclusion criteria were the ability to independently perform activities of daily living and absence of self-reported neurological or musculoskeletal conditions affecting mobility or balance. Exclusion criteria were acute illness or cognitive impairment as determined by the Rapid Dementia Screening Test [13] (RDST < 7). Current medications, history of falls during the previous year, and fear of falling (FoF: yes/no question, "Are you afraid of falling?") were recorded [14], and basic mobility was assessed with a Timed Up & Go test (TUG) and Five Chair Stand test (5CS) [15,16]. The Research Ethics Committee of Kobe Gakuin University approved the study (Approval No. HEB100806-1), and informed consent was obtained from all subjects prior to participation. Table 1 lists the demographic data of all subjects.

2.2. Apparatus

Two triaxial accelerometers were used—one for measuring trunk movements and the other for detecting initial contact of the foot with the ground during walking. For trunk acceleration measurements, one triaxial accelerometer (MVP-RF8-BC; size: 45 mm wide, 45 mm deep, 18 mm high; range: ± 4 G; weight: 60 g) (Microstone Co., Nagano, Japan) was attached over the third lumbar vertebra spinous process (L3) using a Velcro$^{\text{TM}}$ belt. L3 was selected to represent the lower trunk at the approximate center of mass during walking [17]. Trunk linear accelerations were measured in the anteroposterior (AP) and mediolateral (ML) directions while subjects walked along a walkway. The other triaxial accelerometer (MVP-RF8-BC) was attached to the heel on the subject's dominant side using surgical tape to detect the time of initial contact during walking. Before each measurement, we calibrated the accelerometers statically against gravity. All accelerations were sampled at 200 Hz and all acceleration signals were synchronized. After analog-to-digital conversion, signals were immediately transferred to a laptop computer.

2.3. Measurements

Subjects were instructed to walk on a smooth 20-m walkway at self-selected comfortable, very slow, slow, and fast speeds with no other task (reference no dual task). Subjects were then asked to perform the following tasks in random order, while walking at a self-selected comfortable speed: count backward by 1 from 100 (cognitive-task gait) and carry a ball (100 g, 7 cm diameter) on a round tray (50 g, 17 cm diameter, 1.5 cm high raised edge) with the dominant hand only (manual-task gait). Carrying a ball on the tray was chosen as the additional task, rather than the typical manual task of carrying a glass of water; the task complexity of carrying a ball remained constant during walking, while that of carrying a glass of water would change if water were spilled. Prior to testing, we explained how to perform both dual-task gaits until subjects understood precisely. No instructions were given regarding which task to prioritize during dual-task gait. One trial was performed for each of the six walking conditions (self-selected comfortable, very slow, slow, and fast speeds with no other task, and cognitive-task gait and manual-task gait). The time taken to walk over the central 10 m of the walkway (5–15 m) was measured using a digital stopwatch. Gait speed was calculated by dividing 10 m by the time taken. The sum total of numbers enumerated in the central 10 m of the walkway was measured for the cognitive-task gait. In the manual-task gait, all subjects were required to complete the walk without dropping the ball from the tray.

Table 1
Demographic data of subjects ($n = 117$).

Characteristics	Total subjects ($n = 117$)	Subjects without FoF ($n = 85$)	Subjects with FoF ($n = 32$)
Age (y)	73.7 ± 4.0	73.4 ± 4.0	74.5 ± 4.0
Sex, men/women (n)	51/66	42/43	9/23*
Height (cm)	154.9 ± 8.8	156.1 ± 9.0	151.8 ± 7.7*
Weight (kg)	56.1 ± 10.6	57.8 ± 10.8	51.9 ± 9.0**
Number of medications per day (n)	2.3 ± 2.0	2.3 ± 2.0	2.4 ± 2.0
Subjects who fell in previous year, n (%)	25 (21)	15 (18)	10 (31)
TUG (s)	6.6 ± 1.3	6.4 ± 1.1	7.1 ± 1.6
5CS (s)	8.8 ± 2.2	8.5 ± 2.0	9.3 ± 2.7
RDST	9.5 ± 2.5	9.6 ± 2.6	9.1 ± 2.4

Mean ± standard deviation, TUG, Timed Up & Go test; 5CS, 5 Chair Stand test; RDST, rapid dementia screening test; FoF, fear of falling.

* $p < 0.05$.

** $p < 0.01$.

2.4. Signal processing

Signal processing was performed using Matlab Release 2009a (MathWorks, Natick, MA). All acceleration data were low-pass filtered using a dual pass zero-lag Butterworth filter with a cut-off frequency of 20 Hz. Analyses were performed on data from all strides over the central 10 m of the walkway for each trial. Stride time variability (STV) was used as the index of gait variability and calculated using the following equation [18]:

$$\mathrm{STV}(\%) = \frac{\text{standard deviation of stride time}}{\text{mean stride time}} \times 100 \qquad (1)$$

We calculated the root-mean-square (RMS) acceleration, which provides information about the average magnitude of acceleration at L3 in the AP and ML directions. Using the RMS of acceleration at L3, we calculated the standardized RMS based on the methodology introduced by van Iersel [19]. The standardized RMS exhibits oscillation at L3 independent of the effect of gait speed and is comparable between different conditions, i.e., single-task gait vs. dual-task gait [20]. The first step to calculating the standardized RMS was the log-transformation of the RMS in the AP and ML directions to obtain a normal distribution and to decrease the influence of outliers. We then constructed a formula based on regression analysis using each RMS and gait speed in the four self-selected gait speed conditions (linear mixed models with the subjects as the random effect and gait speed as the fixed independent effect and the logarithm of the RMS as dependent variable) that described how these data varied with speed in each direction during walking without an additional task (Upper panel in Fig. 1). The logarithmic RMS increased linearly with increasing gait speed. The resulting regression coefficient for gait speed was a_1; a_0 was the constant regression term (ML direction: $a_0 = +1.0466$, $a_1 = +1.0223$, AP direction: $a_0 = -0.8502$, $a_1 = +1.1158$). For each subject, the standardized logarithmic RMS was calculated as follows:

$$\text{Standardized logarithmic RMS} = \text{logarithm of RMS} - a_0 - (a_1 \times \text{gait speed})$$

Because the standardized logarithmic RMS is difficult to interpret, we also calculated the standardized RMS:

$$\text{Standardized RMS} = 100\exp(\text{standardized logarithmic RMS}) \qquad (3)$$

A standardized RMS = 100 means that the oscillation is equal to the median standardized RMS of all subjects (Lower panel in Fig. 1). We used Eq. (3) to calculate the standardized RMS in the cognitive-task gait and manual-task gait conditions for each subject. If an additional task increased the RMS, the median percentage during dual-task gait would be >100%.

2.5. Statistical analyses

One-way repeated measure analysis of variance (ANOVA) was used to evaluate the effects of task conditions. If a significant effect of walking condition was identified, a series of pair-wise comparisons was performed using Bonferroni-adjusted *t*-tests to determine differences between the reference no dual task during the self-selected comfortable walking speed (single-task gait) and cognitive-task gait, and between single-task gait and manual-task gait. To investigate the association between trunk oscillation and age, basic physical performance and gait variability, correlations between standardized RMS in the ML and AP directions, and age, TUG, 5CS and STV were evaluated using Pearson's *r* correlation coefficient. To evaluate the effect of FoF, unpaired *t*-tests adjusted for potential confounders (age, sex and fall history) were performed between subjects with and without FoF for the gait variables of gait speed, STV, and standardized RMS in the ML and AP directions. Analyses were performed for the following conditions: single-task gait, cognitive-task gait, manual-task gait, cognitive-task gait–single-task gait (difference in values between cognitive-task gait and single-task gait) and manual-task gait–single-task gait (difference in values between manual-task gait and single-task gait). A p value of <0.05 was considered statistically

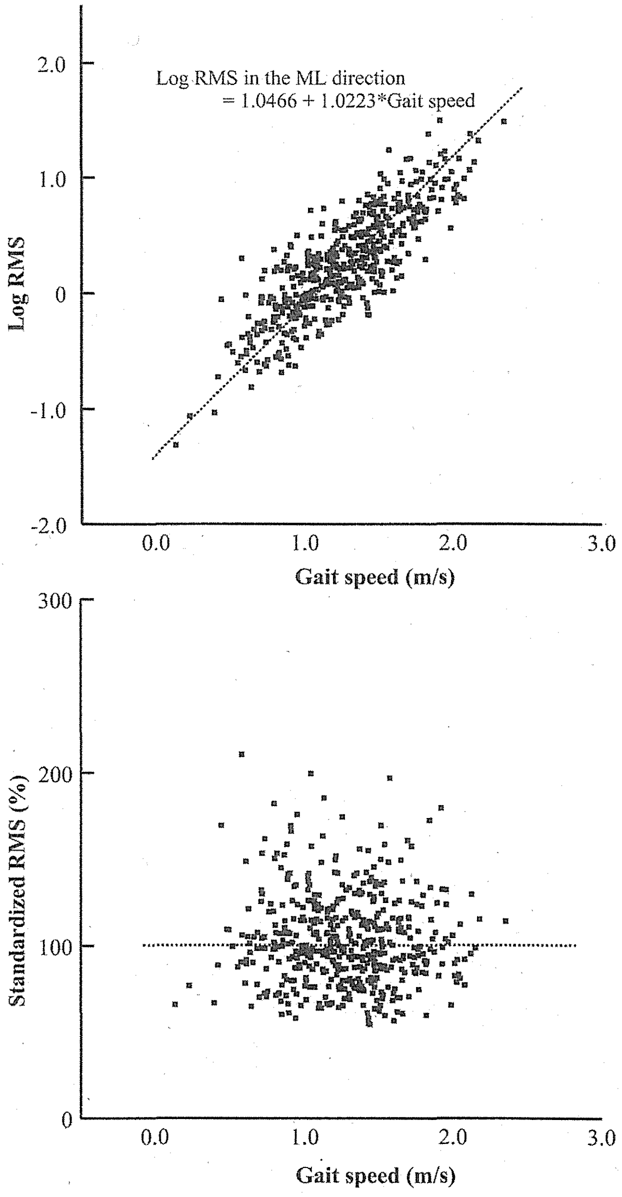

Fig. 1. Upper panel: RMS of lower trunk accelerations in the ML direction. The logarithmic RMS increased linearly with increasing gait speed. The regression line was obtained using a linear mixed model regression. The regression coefficients were $a_0 = +1.0466$ and $a_1 = +1.0223$ for the ML direction (AP direction: $a_0 = -0.8502$, $a_1 = +1.1158$). The distribution of points around the line is approximately normal and the variance is equal over the gait speeds. RMS, root-mean-square; ML, mediolateral; AP, anteroposterior. Lower panel: standardized RMS of lower trunk accelerations in the ML direction. Taking the exponential of the logarithmic RMS and multiplying by 100, we converted the logarithmic value to a percentage. The median value of the RMS at each gait speed was set to 100%. The standardized RMS remained constant over the entire range of gait speed; thus, the influence of gait speed was removed.

significant for one-way repeated measures ANOVA, Pearson's r correlation coefficient, and unpaired t-test. A p value < 0.025 was considered statistically significant for Bonferroni adjusted t-tests because two pair comparisons were conducted (single-task gait and cognitive-task gait, single-task gait and manual-task gait: $p = 0.05/2$). All statistical analyses were performed using JMP 10 software (SAS Institute Japan, Tokyo, Japan).

3. Results

The sum total of numbers enumerated in the central 10 m of the walkway for the cognitive-task gait was 10.6 ± 3.2. In the manual-task gait, all subjects were able to complete the walk without dropping the ball from the tray.

The effects of the different task conditions and the results of the ANOVA are presented in Table 2. Task conditions significantly affected gait speed and STV (gait speed: $F = 44.8$, $p < 0.001$; STV: $F = 18.8$, $p < 0.001$). Subjects walked more slowly and with greater STV in the cognitive-task gait (gait speed: $t = -10.3$, $p < 0.001$; STV: $t = 5.4$, $p < 0.001$) and manual-task gait (gait speed: $t = -7.4$, $p < 0.001$; STV: $t = 4.4$, $p < 0.001$). Task conditions significantly affected RMS in the ML direction ($F = 40.7$, $p < 0.001$) and the AP direction ($F = 82.7$, $p < 0.001$). Both tasks significantly decreased lower trunk oscillations in the ML direction (cognitive-task gait: $t = -4.1$, $p < 0.001$; manual-task gait: $t = -8.6$, $p < 0.001$) and the AP direction (cognitive-task gait: $t = -4.9$, $p < 0.001$; manual-task gait: $t = -12.2$, $p < 0.001$). After standardization of RMS for gait speed, task conditions significantly affected standardized RMS in the ML direction ($F = 47.0$, $p < 0.001$) and the AP direction ($F = 97.9$, $p < 0.001$). However, task effects were not the same between cognitive-task and manual-task gaits. The cognitive task significantly increased lower trunk oscillations in the ML ($t = 4.9$, $p < 0.001$) and AP directions ($t = 6.1$, $p < 0.001$), while the manual task significantly decreased lower trunk oscillations in the ML ($t = -5.9$, $p < 0.001$) and AP directions ($t = -8.3$, $p < 0.001$).

The Pearson's r correlation coefficients are shown in Table 3. The standardized RMS in the ML direction was significantly associated with STV in the cognitive-task gait ($r = 0.382$, $p < 0.01$), and with TUG in the manual-task gait ($r = 0.186$, $p < 0.05$). The standardized RMS in the AP direction was significantly associated with STV in the single-task gait ($r = -0.198$, $p < 0.05$), cognitive-task gait ($r = 0.575$, $p < 0.01$), and manual-task gait ($r = -0.195$, $p < 0.05$).

The results of unpaired t-tests are shown in Table 4. Subjects with FoF walked slower during cognitive-task gait than subjects without FoF ($t = 2.3$, $p < 0.05$) and walked with greater STV during single-task gait than subjects without FoF ($t = 2.5$, $p < 0.05$). Additionally, the difference in trunk oscillations between the cognitive-task and single-task gait in the ML direction was significantly larger in subjects with FoF than in subjects without FoF ($t = 2.6$, $p < 0.01$).

4. Discussion

After standardizing RMS for gait speed, the manual-task significantly decreased standardized RMS in the ML and AP directions, while the cognitive task increased standardized RMS in both directions. Additionally, subjects with FoF exhibited larger changes in trunk movement in the ML direction during the cognitive-task gait, but not during the manual-task gait. This study is the first to demonstrate that a manual task affects lower trunk oscillations in the horizontal plane differently than a more attention-demanding cognitive task, and that the effect of FoF on trunk oscillations varies between cognitive- and manual-task gaits.

The manual-task gait, carrying a ball on a tray, requires subjects to hold the upper arm firmly beside the trunk and to maintain a

Table 2
Effect of task conditions on gait variables. The task conditions of single-task gait and dual-task gait (cognitive-task gait and manual-task gait) were assessed.

Gait variables	Single-task gait	Dual-task gait		F value	p value
		Cognitive-task gait	Manual-task gait		
Gait speed (m/s)	1.40 ± 0.19	1.24 ± 0.25*	1.28 ± 0.24*	44.8	<0.001
STV (%)	2.2 ± 1.1	3.9 ± 3.2*	2.9 ± 1.6*	18.8	<0.001
RMS in the ML direction (m/s^2)	1.53 ± 0.46	1.42 ± 0.42*	1.25 ± 0.44*	40.7	<0.001
RMS in the AP direction (m/s^2)	2.14 ± 0.50	2.00 ± 0.53*	1.69 ± 0.51*	82.7	<0.001
Standardized RMS in the ML direction (%)	102.6 ± 24.5	112.0 ± 26.9*	93.3 ± 21.6*	47.0	<0.001
Standardized RMS in the AP direction (%)	103.5 ± 14.2	114.9 ± 22.7*	91.7 ± 15.3*	97.9	<0.001

Mean ± standard deviation, STV, stride time variability; RMS, root-mean-square; ML, mediolateral; AP, anteroposterior.
Single-task gait: reference no dual task during self-selected comfortable speed of walking.
Cognitive-task gait: walking while counting backward by 1 from 100.
Manual-task gait: walking while carrying a ball on a round tray with raised edge.
* $p < 0.01$, result of comparision to single-task gait.

Table 3
Associations between standardized RMS in the ML and AP directions, and age, TUG, 5CS and STV.

	Task conditions	Age	TUG	5CS	STV
Standartized RMS in the ML direction	Single-task gait	−0.076	0.130	0.024	0.089
	Cognitive-task gait	−0.154	0.124	0.092	0.382**
	Manual-task gait	0.035	0.186*	0.063	−0.086
Standartized RMS in the AP direction	Single-task gait	0.020	−0.003	0.043	−0.198*
	Cognitive-task gait	−0.094	−0.056	0.067	0.575**
	Manual-task gait	0.092	0.029	0.024	−0.195*

RMS, root-mean-square; ML, mediolateral; AP, anteroposterior; TUG, Timed Up & Go test; 5CS, 5 Chair Stand test; STV, stride time variability.
Single-task gait: reference no dual task during self-selected comfortable speed of walking.
Cognitive-task gait: walking while counting backward by 1 from 100.
Manual-task gait: walking while carrying a ball on a round tray with raised edge.
* $p < 0.05$.
** $p < 0.01$.

Table 4
Differences of gait variables between subjects with and without FoF.

Gait variables	Subjects without FoF (n = 85)	Subjects with FoF (n = 32)
Gait speed (m/s)		
Single-task gait	1.42 ± 0.20	1.35 ± 0.17
Cognitive-task gait	1.27 ± 0.25	1.16 ± 0.24*
Manual-task gait	1.30 ± 0.23	1.26 ± 0.25
Cognitive-task gait–single-task gait	−0.14 ± 0.15	−0.20 ± 0.20
Manual-task gait–single-task gait	−0.12 ± 0.17	−0.13 ± 0.19
Stride time variability (%)		
Single-task gait	2.01 ± 1.09	2.56 ± 1.12*
Cognitive-task gait	3.70 ± 2.57	4.33 ± 4.51
Manual-task gait	2.79 ± 1.51	3.15 ± 1.73
Cognitive-task gait–single-task gait	1.69 ± 2.79	1.77 ± 4.76
Manual-task gait–single-task gait	0.78 ± 1.61	0.59 ± 2.21
Standardized RMS in the ML direction (%)		
Single-task gait	102.7 ± 24.4	102.3 ± 25.2
Cognitive-task gait	109.4 ± 25.6	119.0 ± 29.3
manual-task gait	92.2 ± 19.8	96.3 ± 26.0
Cognitive-task gait–single-task gait	6.7 ± 19.3	16.6 ± 23.0*
Manual-task gait–single-task gait	−10.4 ± 16.0	−6.0 ± 18.7
Standardized RMS in the AP direction (%)		
Single-task gait	103.3 ± 14.2	104.0 ± 14.5
Cognitive-task gait	112.7 ± 20.2	120.7 ± 27.9
Manual-task gait	91.1 ± 14.9	93.4 ± 16.4
Cognitive-task gait–single-task gait	9.4 ± 16.6	16.8 ± 26.7
Manual-task gait–single-task gait	−12.21 ± 10.6	−10.6 ± 13.4

Mean ± standard deviation, RMS, root-mean-square; ML, mediolateral; AP, anteroposterior; FoF, fear of falling.
Single-task gait: reference no dual task during self-selected comfortable speed of walking.
Cognitive-task gait: walking while counting backward by 1 from 100.
Manual-task gait: walking while carrying a ball on a round tray with raised edge.
Cognitive-task gait-single-task gait: difference in value between cognitive-task gait and single-task gait.
Manual-task gait-single-task gait: difference in value between manual-task gait and single-task gait.
* $p < 0.05$.

steady gaze on the ball to avoid dropping it. In the manual-task gait, therefore, subjects are required to enhance their trunk stability to maintain a stable platform for the arm and for vision [21,22]. As a result, trunk oscillations become smaller than those during the single-task gait condition. These observations and our results suggest that conscious attention was allocated to trunk control in the manual-task gait, resulting in smaller trunk oscillations. In contrast, the cognitive task increased trunk oscillations in the horizontal plane, consistent with another study that found that an additional arithmetic task increased upper trunk angular velocity in the horizontal plane [20]. Many reports suggest that insufficient attention allocation affects gait control through fluctuated gait patterns and increased trunk movements [2]. Thus, the increased trunk oscillations may be attributed to an insufficient attention allocation induced by a cognitive task.

Interestingly, trunk oscillation was negatively associated with gait fluctuations in the manual-task gait, and was positively associated with it in the cognitive task gait. These results suggest that the effect of dual task related gait changes on trunk movements differ depending on the nature of the additional task. In the manual-task gait, subjects needed to frequently change their gait patterns to avoid dropping the ball from the tray, i.e., "cautious gait" [23]. In contrast, during the cognitive-task gait, subjects' gait patterns fluctuated because they most likely could not allocate attention to their gait appropriately [2]. These findings suggest that dual task related gait changes induced by the manual task may have diminishing effects on trunk movement, while those induced by the cognitive task have increasing effects on trunk movement.

Another important finding of our study was that FoF was associated with changes in trunk movement in the ML direction during cognitive-task gait, but not during the manual-task gait. Changes in gait movements related to dual tasking (identified as a dual-task cost) can be attributed to competition for limited attentional resources [24]. Therefore, dual-task costs are an index of individual's ability to perform dual tasks. Some reports suggest that FoF can reduce the attentional resources available for trunk control during walking [9]. Additionally, lateral trunk movements are strongly affected by dual-task walking [22,25]. Furthermore, our findings are consistent with and extend upon the prior literature on falling in older adults [26]. Our findings may help explain why older adults with FoF are prone to falls from a postural control perspective. For older adults with FoF, attention-splitting conditions may induce irregular trunk control while walking that predisposes them to falls.

However, another study found no effect of FoF on trunk sway in dual-task gait [12]. One possible explanation could be that the cognitive task used in that study (counting backward by 7) was relatively more difficult than in our study (counting backward by 1). People may give priority to postural control during dual-task gait in the case where the additional task is more complicated and difficult [27]. In such cases, the cognitive load is not constant during walking, and the dual-tasking interference may not be observable. In the manual-task gait, however, no significant changes were observed. In the present study, subjects were required to carry a ball on a tray without dropping it from the tray. Postural stability may have been prioritized and conscious attention allocated more heavily to postural stability. As a result, the effect of FoF on trunk movement may be less significant in manual-task gait.

One limitation of the current study was that spatial gait data, e.g., step length and width, were not measured. Spatial gait data are reportedly affected by the specific attention-demanding task and are associated with trunk movements [28–30]. However, because we did not measure these gait variables, the association between these gait variables and trunk control remains unclear. Another limitation is that we did not assess the effects of any other type of manual task on gait. Our results show only the effects of one type of manual task on gait, and further study is needed to assess trunk control during different types of manual tasks. The other limitation is that FoF was not assessed by a standard FoF assessment method, such as the activities-specific balance confidence (ABC) scale [10]. FoF is often not easily admitted and may be trivialized by an individual. The ABC scale quantifies FoF and classifies subjects according to the level of FoF [10]. Future studies should examine the difference between varying levels of FoF and their influence on dual-task gait.

Acknowledgment

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Conflict of interest statement

The authors have no conflicts of interest to disclose.

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Effect of a Kinect-Based Exercise Game on Improving Executive Cognitive Performance in Community-Dwelling Elderly: Case Control Study

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Abstract

Background

Decrease of dual-task (DT) ability is known to be one of the risk factors for falls. We developed a new game concept, Dual-Task Tai Chi (DTTC), using Microsoft's motion-capture device Kinect, and demonstrated that the DTTC test can quantitatively evaluate various functions that are known risk factors for falling in elderly adults. Moreover, DT training has been attracting attention as a way to improve balance and DT ability. However, only a few studies have reported that it improves cognitive performance.

Objective

The purpose of this study was to demonstrate whether or not a 12-week program of DTTC training would effectively improve cognitive functions.

Methods

This study examined cognitive functions in community-dwelling older adults before and after 12 weeks of DTTC training (training group [TG]) or standardized training (control group [CG]). Primary end points were based on the difference in cognitive functions between the TG and the CG. Cognitive functions were evaluated using the trail-making test (part A and part B) and verbal fluency test.

Results

A total of 41 elderly individuals (TG: n=26, CG: n=15) participated in this study and their cognitive functions were assessed before and after DTTC training. Significant differences were observed between the two groups with significant group × time interactions for the executive cognitive function measure, the delta-trail-making test (part B–part A; $F_{1,36}$=4.94, P=.03; TG: pre mean 48.8 [SD 43.9], post mean 42.2 [SD 29.0]; CG: pre mean 49.5 [SD 51.8], post mean 64.9 [SD 54.7]).

Conclusions

The results suggest that DTTC training is effective for improving executive cognitive functions.

Trial Registration

Japan Medical Association Clinical Trial Registration Number: JMA-IIA00092; https://dbcentre3.jmacct.med.or.jp/jmactr/App/JMACTRS06/JMACTRS06.aspx?seqno=2682 (Archived by WebCite at http://www.webcitation.org/6NRtOkZFh).

Keywords: fall prevention, cognitive function, dual-task, training, elderly

Introduction

Cognitive impairment among elderly individuals is a serious issue in many countries. Many investigators have developed different cognitive function training methods as countermeasures to prevent cognitive impairment and have reported their effects [1]. Other investigators also have reported the effects of physical exercise training on cognitive functions among elderly individuals [2,3]. Additionally, Hillman et al and Silsupado have indicated that executive cognitive functions, which are related to the control of goal-oriented actions and adaptive behaviors, are strongly impaired by aging and respond positively to exercise training [4,5].

Recently, dual-task (DT) ability, or the performance of simultaneous motor and cognitive tasks, has been receiving considerable attention [6]. DT training is now recognized as a fall prevention tool that enhances physical functions among elderly people [7].

With a focus on DT, we developed a new concept called the Dual-Task Tai Chi (DTTC) test [8]. This system was developed using Kinect (Microsoft, Redmond, WA, USA), a motion-capture device, and demonstrated that the DTTC test quantitatively evaluates compound functions, including DT, balance, and cognitive abilities in elderly people [9]. In unpublished data, we found that DTTC training was useful not only to assess but also to improve balance and mobility among elderly people [10].

Several investigators have reported the effects of DT training on balance, mobility, walking, and DT ability [11,12]. However, only a few have reported that DT training improves cognitive performance. We reported that Trail-Walking Exercise, which is similar to Trail-Making Test (TMT) under DT condition, improved executive cognitive functions [13]. According to this, we expected that DTTC training would improve cognitive functions as well, especially executive functions. Therefore, the purpose of this study was to reveal that training with the DTTC device affects cognitive performance in elderly individuals.

Methods

Participants

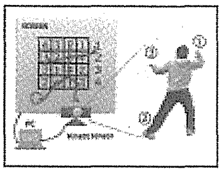
Community-dwelling elderly subjects (n=48) participated in this study. The subjects were recruited through an advertisement in the local press. The following selection criteria were used: age ≥65 years, community dwelling, independent ambulation, willingness to participate in the measurement of physical fitness, and minimal hearing and vision impairment. Exclusion criteria were as follows: inability to complete the tasks because of reduced cognitive functions, evaluated by Rapid Dementia Screening Test [14] scored 8 or greater; severe cardiac, pulmonary, or musculoskeletal disorders; pathologies associated with increased risk of falls, such as Parkinson's disease or stroke; osteoporosis; and psychotropic drug use. We obtained written informed consent from each participant. This study was approved (protocol approval E-880) by the Ethical Review Board of Kyoto University Graduate School of Medicine, Kyoto, Japan.

Device

The DTTC test [8-10] requires users to solve a number placement problem (Sudoku) by controlling a stick figure with the movement of their entire body. The user's full-body motion is captured using Kinect and is translated into movements for the stick figure on a screen. The cognitive task is to fill in 3 boxes chosen at random from a 4 × 4 grid with digits ranging from 1 to 4. The user selects a digit using his or her right hand and left foot and points to a box with his or her left hand. In addition, the user must move his or her right hand to the left hand to fill the indicated box with the selected digit. As such, full-body motion, similar to Tai Chi Chuan movements, is required. We recorded the time taken to fill in all 3 boxes, as our evaluation index.

To begin with, the user stands 3 m in front of the Kinect sensor with his or her right foot in front of the sensor (Figure 1). The following instructions were provided:

Figure 1



View of the Dual-Task Tai Chi (DTTC) test.

1. Reach a digit you need to use with your right hand to fill a blank you want to answer.
2. Step 50 cm laterally, with your left leg, to grip the digit in your right hand.
3. Select the blank you want to answer with your left hand, and move your right hand to your left one.

Intervention

All subjects participated in group training sessions lasting 75-80 minutes once a week for 12 weeks. The participants were divided into two training groups according to their participation in the exercise class: (1) the control group (CG), 75-minute standardized training, and (2) the training group (TG), 5-minute DTTC training, in addition to the standardized training [10].

The exercise classes were individualized for each group and were supervised by physical therapists. Each exercise class used a standardized format that included 15 minutes of moderate-intensity aerobic exercise, 15 minutes of progressive strength training, 10 minutes of flexibility and balance exercises, and 10 minutes of cool-down activities, followed by exercises known to improve muscle strength and balance [15,16]. In addition, the class included a 25-minute rhythmic stepping exercise involving cognitive ability, which is an exercise intended to improve DT ability [11], before cool-down.

The participants in the TG were additionally asked to solve DTTC problems and mirror-reversed DTTC problems, alternately, as many times possible in 5 minutes.

Outcome Measures

All participants underwent evaluation upon entry into the study (pre-intervention) and at the end of the study (post-intervention), using the results of 2 cognitive performance tests.

Cognitive functions were evaluated using the trail-making test (TMT) [17] and verbal fluency test (VFT) [18-20]. The TMT is a well-established psychomotor test originally developed as part of the Army Individual Test Battery. The TMT has been widely used in clinical evaluations to assess deficits in executive cognitive functions. The test consists of 2 parts: part A is a visual-scanning task and part B is a measure of cognitive flexibility. For this analysis, we used a different score defined as delta-TMT, calculated as the difference between the times for each part (part B-part A). The delta-TMT score is used to control for the effect of motor speed on TMT performance and is considered a more accurate measure of executive functions than performance on part B alone [20,21].

The VFT has a letter fluency component and a category fluency component. Participants were asked to think of as many animal names as possible in 1 minute (category fluency). Verbal fluency is an evaluation of expressive language ability and executive functions. The score was the number of successful words (except for some proper nouns).

Statistical Analysis

We compared baseline characteristics between the participants in each group to examine the comparability between the 2 groups using Student's *t* test or the chi-square test. Repeated-measures, mixed-linear, two-way ANCOVA (analysis of covariance) was used to analyze the effect of exercise on outcome measurements while adjusting for each cognitive performance, at pre-intervention, as a covariate.

Data were entered and analyzed using the Statistical Package for the Social Sciences (Windows version 20.0, SPSS Inc., Chicago, IL, USA). For all analyses, *P*<.05 was considered statistically significant.

Results

Study Population

A total of 41 of the 48 selected subjects (85.4%) completed the study protocols and returned for their exit interviews and final testing (TG: n=26, CG: n=15). The participants' baseline data did not differ significantly between the two groups. Thus, the groups were comparable and well matched with regard to their baseline characteristics.

Adherence to the Study Protocols

During the 12-week intervention phase, 10 exercise sessions were scheduled and all took place. Excluding the 4 participants who dropped out, the TG subjects had an overall attendance rate of 82% and the CG subjects had an overall attendance rate of 81% over the 12 weeks. No health problems, including cardiovascular or musculoskeletal complications, occurred during training sessions or testing. Moreover, almost all participants seemed to have enjoyed the DTTC training. They shared many positive opinions after each session and seemed to look forward to playing DTTC once a week.

Evaluation Outcomes

Pre- and post-intervention group statistics and group × time interactions are shown in Table 1. There was a significant difference between the groups regarding the changes (intervention to baseline) in delta-TMT. There were no significant differences among the other measures.

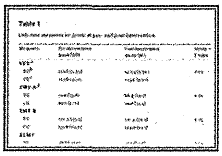


Table 1
Outcome measures by group at pre- and post-intervention.

Discussion

Principal Findings

The delta-TMT score was significantly improved after DTTC training. The results suggested that DTTC training was effective in improving executive cognitive functions. In our unpublished data, DTTC training was useful for improving balance ability and mobility among elderly people [10]. Thus, DTTC training has the capability of improving both physical and cognitive functions. Executive cognitive functions are closely related to DT performance and are good predictors of falling [20]. Thus, an improvement in executive functions, by DTTC training, has a positive impact on DT ability and the prevention of falling.

Conversely, the TMT-A and -B scores were not significantly improved. In the TMT-A, both groups improved similarly. On the other hand, in the TMT-B, only the TG had a tendency to improve the score, while CG showed little change. That is why the score of delta-TMT in CG increased and in TG decreased. The TMT-A and -B are used to assess visual scanning, cognitive flexibility, and executive functions [17]. The delta-TMT score is considered a more accurate measurement of executive functions [21,22]. That is, the results reflect specific improvement in executive cognitive functions.