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Association between cardiorespiratory fitness, physical activity, and cognitive function in Japanese community-dwelling elderly adults

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Abstract We investigated factors correlated with cognitive decline in elderly adults by measuring aerobic fitness, physical activity, and cognitive function. Participants were community-dwelling adults aged 65 years or older (N = 455; 130 men and 325 women). Aerobic fitness was assessed in an incremental exercise test using a cycle ergometer; physical activity was determined with step counts using a uniaxial accelerometer. Cognitive function was examined using Urakami's screening test for Alzheimer's disease (AD). We analyzed the results for 287 participants (71 men and 216 women) with no missing data. The maximum possible score for cognitive function was 15; impairment was defined as scores of ≤ 12 . The χ^2 and *t*-test were used to compare data between participants with impairment and controls. Male and female participants were analyzed separately. After adjusting for age, BMI, and diabetes, we performed analysis of covariance. Of the total, 29 participants (10.1%) were categorized as impaired on screening. For aerobic fitness and physical activity, there were no significant differences between men with impairment and controls. However, aerobic fitness was significantly lower ($p < 0.002$) and physical activity was not significantly different for women with impairment than for controls by *t*-test. After adjustment, significant differences were also found for aerobic fitness ($p < 0.001$) between the groups in women. The impairment group had a significantly higher ratio of women with diabetes than the control group ($p < 0.05$). Our results suggest that decline in aerobic fitness is obviously associated with decline in cognitive function among women.

Keywords : aerobic fitness, step counts, cognitive function, community-dwelling elderly adults

Introduction

Globally, Japan is the leading country with respect to longevity of its population¹⁾ and has one of the fastest aging societies worldwide. It is expected that the aged population will increase indefinitely in the future²⁾. With an aging population, there is concern about an increasing number of people with dementia. Dementia is the leading causative disease requiring caregiving³⁾, and prevention of cognitive decline and dementia is an important issue of public health in extending the healthy life span. Physical inactivity is the primary risk factor for dementia, followed by depression, smoking, hypertension, obesity, education level, and diabetes⁴⁾. Except for smoking and education level, these risk factors can be prevented by exercise.

Physical activity and physical fitness are widely used to evaluate exercise practice.

Cognitive function and physical fitness decline with age. It has been reported that cognition is negatively correlated with age and positively correlated with maximal oxygen consumption ($\dot{V}O_{2\max}$) in elderly people^{5,6)}. There is an association between cardiorespiratory fitness and cognition; people who maintain higher levels of cardiorespiratory fitness have been found to have better cognitive function than those with lower cardiorespiratory fitness in middle to older age⁷⁾. Studies have also shown that greater cardiorespiratory fitness may help protect against cognitive deterioration, even at more advanced ages⁶⁾. It has been reported that elderly people with high cardiorespiratory fitness have episodic memory that is inferior to that of young adults, but superior to that of elderly adults with low cardiorespiratory fitness; and people with high

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cardiorespiratory fitness can maintain executive functions equivalent to those of young adults⁸). A study investigating 877 middle-aged and elderly adults found that higher $\dot{V}O_2\text{max}$ is associated with better global cognitive function and better performance in the cognitive domains of memory, executive function, and motor skills, and this association is not mediated by the presence of white matter lesions, lacunes, and brain atrophy⁹). Longitudinal studies have reported that cognitive function decreases remarkably with age in people with poorer cardiorespiratory fitness^{10,11}). Aerobic fitness also has a positive correlation with hippocampal volumes associated with memory¹²). Older adults with good executive function have higher aerobic fitness and better preservation of vessel elasticity; it has been suggested that preservation of vessel elasticity may be one of the key mechanisms by which physical exercise helps to slow cognitive aging¹³).

Although the evaluation methods of physical fitness and cognitive function in previous studies have varied, these studies all suggest that low physical fitness levels in elderly adults are related to a decline in cognitive function, and low physical fitness levels in the middle aged and advanced aged accelerate the decline of cognitive function with aging.

To date, a number of studies using questionnaires have reported significant associations between cognitive function and physical activity¹⁴). However, subjective evaluation of physical activity using a questionnaire survey has limited accuracy, especially if the respondent is elderly and has problems with recollection and cognition¹⁵). In a study that objectively evaluated the physical activity of elderly participants with step counts using accelerometers, physical activity was significantly associated with memory ability, but was not related to executive function; and sedentary behavior had a negative correlation with memory ability¹⁶). In Japan, there are several studies reporting the relationship between physical activity, evaluated by activity time, and brain volume and cognitive function in older adults with mild cognitive impairment or cognitive complaints¹⁷⁻¹⁹). However, there are few studies on physical activity and cognitive function that have used objective indicators for the evaluation of general populations of community-dwelling elderly Japanese adults. In two previous studies, no association was found between cognitive function and physical activity evaluated with step counts, measured with an accelerometer, for 1 year among 184 community-dwelling elderly adults²⁰) and for 3 months among 72 healthy elderly Japanese people²¹). These studies did not investigate the relationship between cardiorespiratory fitness and cognitive function in Japanese participants. Currently, there are few studies that have measured cardiorespiratory fitness on a community basis among elderly Japanese people. This seems to be owing to technical problems in the measurement of cardiorespiratory fitness in elderly adults.

Evaluation of cardiorespiratory fitness using $\dot{V}O_2\text{max}$

with analysis of expired gas during an exercise stress test is restricted to locations such as a laboratory, and it is very strenuous for elderly participants to conduct an exercise load test wearing a mask. Therefore, it can be inferred that individuals who participate in such studies are likely to be biased towards those with considerably good health. For such reasons, the aerobic fitness of elderly people has rarely been measured on a community basis. Heart sounds during an exercise stress test have been reported to approximate the anaerobic threshold (AT) and lactate threshold (LT)²²). Evaluation of aerobic capacity using heart sounds is noninvasive, inexpensive, and has no special environmental restrictions; this type of evaluation is therefore considered to be appropriate and useful as a measurement method for elderly people in a community-based investigation. In this study, we evaluated aerobic capacity using heart sounds together with heart rate (HR) during exercise tests conducted among elderly people living in the community²²).

Relationships between cardiorespiratory fitness, physical activity, and cognitive function have been demonstrated in many studies^{5-14,16,20,21}). However, there are few studies measuring both aerobic capacity and physical activity using objective indicators at the same time and in the same participants, on a community basis, as well as investigating the relationships of cognitive function with cardiorespiratory fitness and physical activity. Physical activity and cardiorespiratory fitness have been reported to be independent factors in epidemiological studies investigating relationships between physical activity and physical fitness and cardiovascular disease (CVD), stroke, all-cause mortality²³), and coronary heart disease (CHD) and CVD²⁴). Several studies have reported that cardiorespiratory fitness is a stronger predictor of mortality than physical activity²⁵⁻²⁸). However, this has not yet been clarified in dementia.

In the present study, we sought to objectively evaluate aerobic capacity and physical activity and to examine their relationship with cognitive impairment in community-dwelling elderly adults, by evaluating men and women separately. We aimed at investigating the association between current cognitive function and current physical activity and/or accumulated aerobic capacity, measured at the same time and in the same group of community-dwelling elderly adults. As a result, important information could be obtained on whether the current level of physical activity, or physical activity that maintains and improves cardiorespiratory fitness, is important for maintaining good cognitive function among elderly people living in the community.

Methods

Participants. Participants were recruited by postal mail from among 10,294 community-dwelling adults aged 65 years or more. We excluded individuals with certified

nursing care levels or assistance levels in Long-term Care Insurance, based on the Basic Resident Register of Yanai City, Japan. A total of 455 elderly adults (130 men and 325 women) were included in the present study. Of the 455 participants, 168 were excluded from the analyses because of missing data on physical activity (step counts), aerobic fitness, glycosylated hemoglobin (HbA1c), or self-reported diseases (Fig. 1). The measurement period was from June to August 2014. This study was conducted according to appropriate ethical guidelines. The purpose, procedures of this research, and handling of the obtained data were explained to all participants in written and oral form, and each gave their written informed consent before participating in the study. The Ethics Committee of Fukuoka University approved the study protocol (Fukuoka, Japan: approval number 14-05-01).

Aerobic capacity. Aerobic capacity was determined by an incremental exercise test using a cycle ergometer. Individuals with heart disease or a stroke history were ineligible for study inclusion. Participants underwent an electrocardiogram (ECG) and blood pressure measurement before the exercise test. Based on these results, some participants were categorized as “must not participate” by the attending primary physician or specialist; we excluded those with a judgment of “must not participate” or “can participate with caution” according to results of the ECG, as well as those whose blood pressure exceeded systolic pressure 180 mmHg or diastolic pressure 110 mmHg. The remaining individuals participated in the exercise stress test.

After a 1-minute rest in the sitting position, a 1-minute warm-up was performed by participants at 10 watts; after that, the exercise load was gradually increased by 10 watts every minute. Participants’ heart sounds, ECG, and

rating of perceived exertion (RPE)²⁹⁾ were continuously and noninvasively monitored during rest and during the exercise test. Heart sounds were measured using a heart sound microphone that was affixed at the position of the manubrium sterni, which is less influenced by movement and strenuous breathing. The criteria for discontinuing the exercise stress test was intense fatigue in the participant that exceeded the perceived exertion level, including ECG abnormalities.

The double product breakpoint (DPBP) of HR and amplitude of the first heart sound (AHS1) is approximately coincident with the AT²²⁾. Based on the American College of Sports Medicine’s (ACSM) Guidelines for Exercise Testing and Prescription, aerobic capacity was assessed using metabolic equivalents (METs) corresponding to the calculated workload of the DP (METs@DPBP-AHS1)³⁰⁾.

Physical activity. Physical activity was determined with step counts using a uniaxial accelerometer (Life-corder Plus; SUZUKEN Company Ltd., Nagoya, Japan). Participants were given a uniaxial accelerometer after measurements of physical fitness were completed, and they received an explanation of how to wear and use the accelerometer. The device was attached to an elastic belt and worn at the waist. Participants were instructed to wear the accelerometer during waking hours for about 2 weeks, exclusive of time spent bathing or in water. Those participants with at least 3 days of valid data, with over 8 hours each day, were included in the analysis. Details of the technical and estimation equation for the uniaxial accelerometer have been described elsewhere³¹⁾. Briefly, physical activity time by intensity level was obtained, using the uniaxial accelerometer: light physical activity such as easy-paced walking (< 3.0 METs), moderate physical activity such as brisk walking (3.0 – 6.0 METs), and vig-

Fig. 1 Participant flow through the study

orous physical activity such as jogging (≥ 6.0 METs).

Cognitive function. Cognitive function was evaluated using a simple screening test that was developed with reference to the Hasegawa Dementia Scale³²⁾, consisting of four test tasks involving an immediate memory test, temporal orientation test, three-dimensional visual-spatial perception test, and delayed recall test³³⁾. The total score was 15 points. Receiver operating characteristic (ROC) analysis yielded maximum sensitivity and specificity values of 96% and 97% for the total score, respectively, with a cutoff point of 12³⁴⁾. This screening test has been reported to be appropriate for detecting early-stage AD or mild cognitive impairment³⁵⁾. Therefore, we determined that this was suitable for use in the present community-based survey.

Morphometry. Body weight was measured to the nearest 0.1 kg using an electronic scale. Height was measured to the nearest 0.1 cm. Body mass index (BMI) was calculated as weight (kg) / height (m)².

Other measurements. Participants performed self-sampling of blood and simple hemanalysis of HbA1c (cobas b 101; Roche Diagnostics K.K. Tokyo, Japan). Demographic data and self-reported information of past medical history, current diseases, and so on were obtained using a questionnaire.

Exclusion from the data analysis. We excluded 125 participants from the analysis who had incomplete or missing data for step counts, 54 who were unable to perform the exercise test, 2 who had missing data of HbA1c, and 4 participants who had missing data on the questionnaire. Some of the excluded individuals overlapped.

Statistical analysis. Characteristics were compared by gender using an unpaired *t*-test or chi-square test. The maximum possible score for cognitive function was 15. Cognitive impairment was defined as a score of 12 or less; controls were defined as those with a score of 13 or more, based on a previous study³⁴⁾. An unpaired *t*-test or chi-square test was used to compare data between the two groups: participants with impairment and controls. Furthermore, after adjusting for age, BMI and diabetes, we performed analysis of covariance (ANCOVA). Male and female participants were analyzed separately. A value of $p < 0.05$ was considered indicative of statistical significance. All statistical analyses were performed using IBM SPSS for Windows, version 23 (IBM Japan, Ltd., Tokyo, Japan).

Results

The characteristics of participants included in the analysis and those who were excluded are shown in Table 1.

The mean age of men was slightly older than that of women (men 71.8 ± 6.1 years, women 70.2 ± 5.0 years), but this was not significant. Step counts and frequency of diabetes were significantly higher for men than for women. There were a total of 29 (10.1%) participants with cognitive impairment, 10 men (14.1%), and 19 women (8.8%), with no significant difference between men and women.

When comparing the participants who were analyzed with those who were excluded from the analysis, among men, there was no difference in cognitive function test scores and frequency of cognitive impairment between the two groups. In women, there was no difference between the groups for frequency of cognitive impairment; however, age was significantly higher among excluded participants than those included in the analysis. When we performed ANCOVA after adjusting for age, there was no difference in cognitive function test scores between the two groups of women.

We performed a comparison between the cognitive impairment group and control group by gender (Tables 2 and 3). There was no significant difference in HbA1c between the cognitive impairment and control groups in both men and women. However, the frequency of diabetes was significantly higher among women in the cognitive impairment group than those in the control group ($p < 0.05$). There was no significant difference between the two groups with respect to hypertension and dyslipidemia in both men and women.

Aerobic capacity and physical activity. The aerobic capacity (METs@DPBP-AHS1) in the group with cognitive impairment was significantly lower than that in the control group for women ($p < 0.002$), but not for men. There was a significant difference between women in the cognitive impairment and control groups, even after adjusting for age, BMI, and diabetes ($p < 0.001$). In a comparison of step counts, there was no significant difference between the groups for both men and women. Physical activity time by intensity level (light, moderate, and vigorous intensity) was also compared between the cognitive impairment group and control group, by gender; no significant differences were found ($p > 0.05$). In addition, we performed ANCOVA, with aerobic capacity as the dependent variable and using covariates of physical activity, age, BMI, and diabetes; no significant difference was observed in men, but significantly low values were observed in women with cognitive impairment ($p < 0.001$). Moreover, the results of ANCOVA with physical activity as the dependent variable and the covariates aerobic capacity, age, BMI, and diabetes showed no significant differences for both men and women (data not shown).

Discussion

This study is the first to perform highly accurate

Table 1. Characteristics of participants, included and excluded from the study analysis.

	Participants included in analysis			Participants excluded from analysis					
	Total (n= 287)	Men (n = 71)	Women (n= 216)	n ^g	Total(n=168)	n ^g	Men (n = 58)	n ^g	Women(n=110)
Age (years)	70.6 ± 5.3	71.8 ± 6.1	70.2 ± 5.0		72.0 ± 5.8 †		72.6 ± 6.3		71.8 ± 5.6 §
Height (cm)	154.2 ± 7.5	163.2 ± 5.8	151.2 ± 5.3 *		155.2 ± 7.8		162.9 ± 5.9		151.1 ± 5.0
Weight (kg)	53.7 ± 9.0	61.4 ± 8.8	51.2 ± 7.6 *		53.9 ± 10.1		60.4 ± 8.5		50.3 ± 9.1
BMI (kg/m ²) ^a	22.5 ± 2.9	23.0 ± 2.5	22.4 ± 3.0		22.3 ± 3.3		22.7 ± 2.7		22.0 ± 3.6
METs@DPBP-AHS1 ^b	5.0 ± 0.9	5.1 ± 1.0	4.9 ± 0.9		5.0 ± 0.9		5.2 ± 1.0		4.8 ± 0.9
Step counts	7448 ± 2949	8266 ± 3237	7180 ± 2805 *		6307 ± 3982		6170 ± 3975		6343 ± 4043
Cognitive test score ^c	13.9 ± 1.5	13.9 ± 1.7	13.8 ± 1.4		13.5 ± 2.1		13.8 ± 1.8		13.3 ± 2.3
Cognitive impairment, n (%) ^d	29 (10.1)	10 (14.1)	19 (8.8)		27 (16.1)		12 (20.3)		15 (13.8)
HbA1c (%) ^e	6.1 ± 0.7	6.2 ± 0.9	6.1 ± 0.7		6.0 ± 0.6 †		6.0 ± 0.6		6.0 ± 0.6
Diabetes, n (%) ^f	23 (8.0)	11 (15.5)	12 (5.6*)		10 (6.1)		4 (6.9)		6 (5.7)
Hypertension, n (%) ^f	38 (13.2)	12 (16.9)	26 (12.0)		15 (9.1)		8 (13.8)		7 (6.6)
Dyslipidemia, n (%) ^f	16 (5.6)	2 (2.8)	14 (6.5)		13 (7.9)		2 (3.4)		11 (10.4)
Exercise habits, n (%)	213 (74.2)	52 (73.2)	161 (74.5)		107 (65.6)		39 (68.4)		68 (64.2)

Unpaired *t*-test or analysis of covariance (ANCOVA): data adjusted for age, sex, BMI, χ^2 test. Values are shown as mean ± standard deviation or number (percentage).

*: $p < 0.05$ men vs. women for analyzed participants. †: $p < 0.05$ Total included vs. total excluded participants. §: $p < 0.05$ Included vs. excluded female participants.

a: Body mass index; b: metabolic equivalents at the double product break point: heart rate and amplitude of the first heart sound; c: Urakami's screening test score; d: Defined as Urakami's screening test score ≤ 12 points; e: glycosylated hemoglobin; f: self-reported disease; g: number of valid data for each item for excluded participants, blanks do not include missing data.

Table 2. Comparison between cognitive impairment group and control group in men.

	Cognitive impairment ^a n =10	Control n = 61	p
Age (years)	75.9 ± 9.2	71.1 ± 5.3	0.139
Height (cm)	161.3 ± 3.6	163.6 ± 6.0	0.260
Weight (kg)	57.5 ± 8.3	62.0 ± 8.8	0.137
BMI(kg/m ²) ^b	22.1 ± 2.9	23.1 ± 2.4	0.232
METs@DPBP-AHS1 ^c	5.3 ± 1.0	5.1 ± 1.0	0.520
	5.4 ± 0.3 †	5.1 ± 0.1 †	0.353 *
Step counts	7624 ± 2455	8371 ± 3353	0.503
	8551 ± 1008 †	8219 ± 392 †	0.763 *
Cognitive test score ^d	10.5 ± 1.8	14.5 ± 0.7	0.000
HbA1c (%)	6.2 ± 0.7	6.2 ± 0.9	0.968
Diabetes, n (%) ^e	3 (30)	8 (13.1)	0.171
Hypertension, n (%) ^e	2 (20)	10 (16.4)	0.778
Dyslipidemia, n (%) ^e	0 (0)	2 (3.3)	0.561

Values are shown as mean ± standard deviation or number (percentage), †: estimate ± standard error.

p values vs. Control.: Unpaired *t*-test or χ^2 test; *: ANCOVA adjusted for age, BMI and Diabetes.

a: Defined as Urakami's screening test score ≤12 points; b: Body mass index; c: Metabolic equivalents at the double product break point: heart rate and amplitude of the first heart sound; d:Urakami's screening test score ; e: Self-reported diseases

Table 3. Comparison between cognitive impairment group and control group in women.

	Cognitive impairment n =19	Control n = 197	p
Age (years)	74.2 ± 6.3	69.8 ± 4.7	0.000
Height (cm)	149.9 ± 6.5	151.3 ± 5.2	0.270
Weight (kg)	50.6 ± 8.2	51.2 ± 7.6	0.739
BMI (kg/m ²) ^b	22.4 ± 2.8	22.4 ± 3.0	0.908
METs@DPBP-AHS1 ^c	4.2 ± 0.9	5.0 ± 0.9	0.002
	4.3 ± 0.2 †	5.0 ± 0.1 †	0.001 *
Step counts	7236 ± 3899	7174 ± 2689	0.546
	7548 ± 668 †	7144 ± 200 †	0.566 *
Cognitive test score ^d	10.4 ± 1.7	14.2 ± 0.8	0.000
HbA1c (%)	6.0 ± 0.7	6.1 ± 0.7	0.728
Diabetes, n (%) ^e	3 (15.8)	9 (4.6)	0.041
Hypertension, n (%) ^e	2 (10.5)	24 (12.2)	0.832
Dyslipidemia, n (%) ^e	2 (10.5)	12 (6.1)	0.453

Values are shown as mean ± standard deviation or number (percentage), †: estimate ± standard error.

p values vs. Control.: Unpaired *t*-test or χ^2 test; *: ANCOVA adjusted for age, BMI and Diabetes.

a: Defined as Urakami's screening test score ≤12points; b: Body mass index; c: Metabolic equivalents at the double product break point: heart rate and amplitude of the first heart sound; d: Urakami's screening test score ; e: self-reported disease

measurement of aerobic capacity and to investigate the relationship between aerobic capacity and the presence of cognitive impairment among elderly adults on a community basis in Japan. We found an association with cognitive impairment and aerobic capacity in our elderly Japanese population. By comparing aerobic capacity, evaluated using an incremental exercise test, in participants with cognitive impairment and controls, it was revealed that the control group had significantly higher aerobic capacity than the group with cognitive impairment, in women. The results of this cross-sectional study suggest the protective effect of aerobic capacity on cognitive decline with aging. However, this effect was significant only in women.

A study on the effects of cardiorespiratory fitness and cerebral blood flow on cognitive outcomes in elderly women reported strong relationships between high $\dot{V}O_{2\max}$ and good cerebrovascular function, which is beneficial for systemic circulation blood vessels, suggesting that the brain may also be affected by cardiorespiratory fitness levels⁵. Whereas there is not a large decrease in cerebral blood flow among premenopausal women or older men, the postmenopausal decrease in cerebral blood flow is accelerated in women³⁶. Therefore, women who maintain high aerobic capacity after menopause may be protected from decreasing cerebral blood flow, and their cognitive function may be preserved. Another study that examined the relation between $\dot{V}O_{2\text{peak}}$ and cerebrospinal fluid amyloid- β ($A\beta$), immediate memory, verbal learning, and memory in older and middle-aged adults reported that high $\dot{V}O_{2\text{peak}}$ was associated with better cognitive function than low $\dot{V}O_{2\text{peak}}$, even with a high $A\beta$ burden. These findings suggest that high $\dot{V}O_{2\text{peak}}$ attenuates the influence of $A\beta$ on cognition⁷. In other words, maintaining high aerobic capacity has been suggested to prevent or delay the onset of AD. Ericsson et al. reported that a 1-year aerobic exercise intervention among middle-aged and elderly people significantly increased memory capacity and the hippocampal volume responsible for memory³⁷. This result is believed to be influenced by blood vessel neogenesis caused by aerobic exercise and an increase in the cerebral blood flow rate³⁸.

In the present study, we found an association of cognitive function with aerobic capacity in women, but not in men. Among those who participated in the baseline measurement, 33% of women and 45% of men were excluded from analysis due to missing data. The rate of exclusion from analysis in men was higher than that in women. The influence of sampling bias owing to the rate of exclusion for missing data was high; in addition, the number of male participants was small. Thus, we conducted an additional comparison by substituting the data of aerobic capacity from those participants who were excluded owing to missing data of step count. As a result, no significant difference was observed between the two groups in men; in women, it was significantly lower in the group with

cognitive impairment than in the control group ($p < 0.05$). Furthermore, we compared aerobic capacity by including the aerobic capacity data of participants who were excluded owing to missing data of step count; however, there were no significant differences between the two groups. It is unclear why an association between cognitive function and aerobic capacity was not observed in men. Further research on this finding is needed in the future.

The frequency of diabetes mellitus was significantly higher for women with cognitive impairment than for women in the control group ($p < 0.05$). Diabetes is known to be a risk factor for cognitive function decline and dementia, particularly in AD, with risk reported to be more than twice that of normal individuals³⁹. Baker et al. confirmed improvement in cardiorespiratory fitness and insulin sensitivity after a 6-month aerobic exercise intervention in elderly people with diabetes⁴⁰. In a cross-sectional study including participants with type 2 diabetes, those with impaired glucose tolerance, and normal middle-aged adults, an association was observed between low cognitive function, low insulin sensitivity, and low aerobic capacity⁴¹. These findings emphasize the importance not only of glycemic control but also of an appropriate lifestyle⁴¹. In our study, no significant difference was observed in HbA1c between the cognitive impairment group and control group; the reason for this may be that we did not exclude individuals under treatment for diabetes.

The results of the present study revealed no significant difference, in either men or women, between cognitive impairment and controls, with respect to physical activity evaluated by step counts. A cross-sectional study using objective indicators in the United States reported an association of cognitive function with physical activity evaluated by step counts¹⁶. In that study, participants had a fairly high mean BMI (25.6 ± 4.5) and younger mean age (64.5 ± 7.0 years) than participants in our study. According to results of the 2015 National Health and Nutrition Survey of the Ministry of Health, Labor and Welfare, the average step counts per day among Japanese people aged 65 years and older is 5919 for men and 4924 for women⁴². The mean step counts taken by participants in this study were 8266 ± 3237 for men and 7180 ± 2805 for women, which are considerably higher than the data of the Ministry of Health, Labor and Welfare. Among participants who were excluded from the analysis, 85% of men and 69% of women were excluded owing to missing data of step counts because of not wearing the accelerometer at all, wearing it incorrectly or wearing the device for an insufficient period of time. For these reasons, the influence of sampling bias cannot be ruled out.

Yoshiuchi and colleagues²⁰ investigated the relationship among depression, anxiety, and cognitive function, examined after measuring the step count and intensity of physical activity for 1 year. These authors found that depression was negatively correlated with step count and medium intensity activity time, but they did not find a re-

lationship with cognitive function²⁰⁾. In the present study, the wearing period of the accelerometer was as short as 2 weeks, but the same results were obtained. It has been reported that the relationship between physical activity and cardiorespiratory fitness is a stronger predictor of CHD, CVD²⁴⁾, and mortality²⁶⁻²⁸⁾, consistent with the results of the present study. This does not mean that measures of physical activity should be ignored. Even with equivalent physical activity, cardiorespiratory fitness may be different. Although cardiorespiratory fitness does not necessarily increase with an increased number of steps, fitness is improved with this activity; therefore, cardiorespiratory fitness may be a better indicator. Since this was a cross-sectional study, causality is unclear; we found a relationship of accumulated aerobic capacity with current cognitive function in women, which may be considered owing to the effect of physical activity. It is clear that physical activity is required to develop and maintain fitness levels that are consistent with good health²³⁾. To maintain and improve aerobic capacity among elderly adults, physical activity that maintains and improves aerobic ability prior to reaching an advanced age may be important.

There are several limitations in this study. There was a large number of study participants who were excluded from the analysis owing to missing data for physical activity or aerobic capacity. Participants in this study may have been biased towards a more physically healthy population as a whole. In addition, the population of men was small compared to that of women in this study, which may have made it impossible to find a relationship between cognitive impairment and aerobic capacity and physical activity in men. Although the measurement period was during the summer (June to August), when physical activity is at the second lowest level among the four seasons in a year⁴³⁾, the average number of steps among analyzed participants was about 7,500, which is higher than the mean step counts for the general population of elderly Japanese adults. The wearing period of the accelerometer was as short as 2 weeks; however, wearing of the device could have affected the behavior of participants. Another limitation of this research is that we did not obtain any information on social factors such as smoking, drinking, educational history, and income, among others.

The strength of this research was use of an exercise test among elderly people on a community basis, with continuous monitoring of heart sounds and heart rate, and estimation of individual aerobic capacity. Despite some limitations, we revealed a relationship between cognitive function and aerobic capacity in community-dwelling elderly women. To examine the relationship between cognitive decline, aerobic capacity, and physical activity in community-dwelling elderly adults, we evaluated aerobic capacity with an incremental exercise test using a cycle ergometer, physical activity using an accelerometer, and cognitive function using simple cognitive screening tests that can be completed in a short time. The results of this

study suggest that aerobic capacity and cognitive function are related. Although participants in this study were a relatively active group, the results nevertheless show that there was an association between aerobic capacity and cognitive function. Thus, aerobic capacity can be a marker for cognitive decline among elderly Japanese people living in the community. In the future, it is important to promote research on aerobic capacity, physical activity, and cognitive function in community-dwelling elderly Japanese people, to contribute to prevention of cognitive deterioration and dementia in Japan's rapidly aging society.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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