


## RESEARCH ARTICLE

# Patterns of daily ambulatory activity and the onset of metabolic syndrome in middle-aged and older Japanese women: the Toon Health Study

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## Abstract

**Background:** This cohort study aimed to identify the accumulation patterns of objectively measured ambulatory activity (AA) variables in the middle-aged and older Japanese women and examine the relationship of these derivative patterns with onset of metabolic syndrome (MetS).

**Methods:** A total of 794 women (mean age: 56.2 years) provided objectively assessed AA data using a uniaxial accelerometer. The number of steps, time accumulated in light-intensity AA (LIAA) and moderate-to-vigorous intensity AA (MVAA) and the ratio of MVAA to total AA (LIAA + MVAA) were calculated. Latent profile analysis was used to identify participant groups based on their distinct AA patterns. Logistic regression models were used to assess the association of groups with the onset of MetS after adjusting for age, sex, education, alcohol habit, smoking habit, energy intake, and the number of MetS components present at baseline.

**Results:** Four distinct groups were identified: Group A had low levels of the AA variable; group B accumulated a certain number or more steps primarily through MVAA; group C accumulated a certain number or more steps primarily through LIAA; and group D had high level of the AA variables. Over the course of the 5-year follow-up period, 61 participants (7.7%) developed MetS. The multivariate-adjusted odds ratio (95% confidence interval) for onset of MetS in groups B, C, and D relative to group A were 0.416 (0.166–1.218), 0.451 (0.223–0.914), and 0.933 (0.365–2.382), respectively. Group C had a significantly lower odds ratio of MetS onset than group A.

**Conclusion:** AA patterns accumulating a certain number or more steps, regardless of the intensity of AA, may help reduce the risk of MetS compared to inactive AA patterns.

**Keywords:** Latent profile analysis, Longitudinal study, Physical activity, Obesity

## Introduction

Metabolic syndrome (MetS) is defined as a cluster of conditions—including abdominal obesity, hypertension, dyslipidemia, and hyperglycemia—that increases the onset risk of various conditions, such as type 2 diabetes, cardiovascular disease, and cancer [1]. Previous studies have also suggested that MetS is more strongly associated with cardiovascular disease and death in women than in men [2]. Globally, the prevalence of MetS is increasing in both men and women [3], and in the Asia-Pacific region, >20% of adults are estimated to have MetS [4].

Physical activity (PA) is an important factor that can be modified to prevent MetS [5–7]. Most PA in daily life is

accounted for by ambulatory activity (AA) such as walking and running [8, 9]. AA is an easy PA to practice and is considered the easiest method to go through daily life actively [10]. Previous study reported a negative association between the daily amount of AA and the time spent at different AA intensities and the onset of MetS [11]. However, the daily amount of AA, typically measured in step counts, results from AA of different intensities, which means that these AA variables are mutually related [12]. Little is known about the real-world accumulation patterns of AA and which patterns are associated with MetS. This information is considerably useful in the field of public health, especially to examine strategies that involve promoting PA to prevent MetS.

Latent profile analysis identifies the mutual relationship between input variables to create naturally occurring profiles, or typical patterns, of combinations of different variables in a heterogeneous population [13, 14]. In other words, the latent profile analysis approach is useful for enhancing the understanding of how mutual relationships—in particularly those that occur concomitantly between more than two variables—occur within-persons, and how these relationships are related in outcome variables [15, 16]. In recent years, latent profile analysis has been gaining attention in the field of PA as a useful statistical method to convert complex behavior into patterns [17, 18].

Recently, we identified AA patterns in the daily life of middle-aged and older Japanese people using latent profile analysis, and examined the relationship with MetS in cross-sectional study [19]. The results suggested that AA pattern involving a certain number or greater of steps accumulated through not only moderate-to-vigorous intensity AA (MVAA), but also light-intensity AA (LIAA) may help reduce the risk of MetS compared to inactive AA pattern [19]. However, while cross-sectional study may be susceptible to reverse causality, it was difficult to infer causal relationships. Therefore, in this study, we used a cohort study design to investigate the association of identified daily AA patterns by latent profile analysis with MetS onset among middle-aged and older Japanese women.

## Methods

### Study population

This study was conducted as part of the Toon Health Study, a prospective cohort study that was planned to follow up the participants every 5 years in Toon City, Ehime Prefecture, Japan [11, 20]. The Toon Health Study commenced in 2009, with the aim to characterize risk factors for cardiovascular disease and its prevention in a community setting. In the Toon Health Study, we recruited participants from approximately 22,000 residents, aged 30–79 years, in Toon City using newspaper advertisements, posters, and invitations. In total, 1,306 women participated in the baseline survey conducted from 2009 to 2012. Of these, individuals with MetS ( $n = 85$ ) and pre-MetS ( $n = 88$ ), and those who had missing AA data (refusal to wear accelerometers,  $n = 63$ ; wearing accelerometers for less than the required time/days,  $n = 21$ ) were excluded. After excluding 255 individuals who did not undergo the 5-year examination, the remaining 794 were followed for 5 years. Therefore, the final analysis included 794 women, with a follow-up period of 5 years for all participants. The characteristics of the participants are presented in Table 1. The flow diagram of the participant selection process in this study is presented in Fig. 1. While our cohort included men, too few ( $n = 240$ ) met the eligibility criteria, and therefore, they were excluded from the analysis.

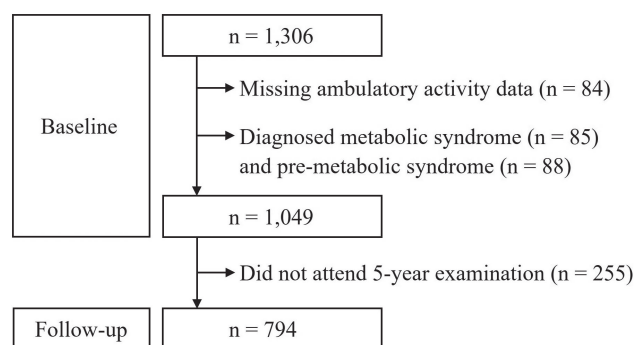
Written informed consent was given by all participants. The study protocol was approved by the Institutional Re-

**Table 1** Characteristics of the study population at baseline

	N = 794	
Age (years)	56.2	(11.7)
Education (education past high school)	377	47.5
Smokers (n, %)	22	2.8
Drinkers (n, %)	278	35.0
Energy intake (kcal/day)	1861	(382)
Body mass index (kg/m <sup>2</sup> )	21.9	(2.7)
Waist circumference (cm)	79.7	(7.6)
Systolic blood pressure (mmHg)	122.6	(20.4)
Diastolic blood pressure (mmHg)	72.9	(11.5)
Fasting glucose (mg/dL)	90.9	(12.1)
High-density lipoprotein cholesterol (mg/dL)	65.5	(13.7)
Triglycerides (mg/dL)	92.6	(46.9)
Abdominal obesity (n, %)	28	3.5
Hypertension (n, %)	311	39.2
Hyperglycemia (n, %)	43	5.4
Dyslipidemia (n, %)	181	22.8
Having number of MetS components for diagnostic criteria (n, %)		
0	376	47.4
1	289	36.4
2	113	14.2
3	16	2.0
Steps (step/day)	8630	(3106)
LIAA (min/day)	72.0	(24.0)
MVAA (min/day)	21.2	(14.2)
Total AA (min/day)	93.3	(32.4)
MVAA/Total AA (min/min)	0.22	(0.10)

Data presented as mean (standard deviation) or n (%)

MetS, metabolic syndrome; LIAA, light-intensity ambulatory activity; MVAA, moderate- to vigorous-intensity ambulatory activity; AA, ambulatory activity



**Fig. 1** Flow diagram of participant selection in this study

view Board, Ehime University Hospital (approval number: 170511).

### Ambulatory activity

Regarding AA, we evaluated the number of steps and period of activity according to intensity using a Lifecorder-Ex (LC, Suzuken Co., Ltd., Nagoya, Japan) with a uniaxial accelerometer [21]. This device detects acceleration signals ranging from 0.06 G to 1.94 G at 32 Hz. When the sensor detects three or more accelerations within 4 s, such activity is deemed as PA and classified into the LC's unique activity intensity level of 1–9. Furthermore, when

the level of acceleration is  $<0.06$  G, the movement intensity will be 0. Moreover, when acceleration of  $\geq 0.06$  G is detected, which does not correspond to activity intensities 1–9, it will be perceived as micromovement and obtain an activity intensity value of 0.5. Thus, every 4 s, each activity will be classified and recorded into one of 11 levels (0, 0.5, and 1–9) of activity intensity. The activity intensity on the LC was reported to be closely approximated to the metabolic equivalents (METs) when walking and running [21]. Furthermore, based on previous research [21], the LC's activity intensities of 1–3 and 4–9 were defined as LIAA and MVAA, respectively, where intensities of 1–3 correspond to less than 3 METs, and intensities of 4–9 correspond to 3 METs or more. The high level of measurement accuracy of the number of steps on the LC has been previously elucidated [22, 23].

The participants were instructed to wear the LC for 7 days continuously from waking up until bedtime, except when sleeping and during activities involving water (taking a bath and swimming). In the present study, an LC intensity of  $\geq 0.5$  for a total of  $\geq 8$  hours in 1 day, and for  $\geq 4$  days was defined as valid data [11, 19, 24] in which we calculated the mean number of steps, LIAA, MVAA, and total AA (LIAA + MVAA) per day for each individual.

### MetS components

Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Body weight was measured to the nearest 0.1 kg using a digital scale without shoes. Body mass index was calculated from body weight and height ( $\text{kg}/\text{m}^2$ ). Waist circumference (WC) was measured three times to the nearest 0.1 cm using a calibrated measuring tape at the midpoint of the lower costal margin; the mean value was used in the analyses.

Blood pressure (BP) was measured twice using an automatic sphygmomanometer (BP-103iII; OMRON Colin Co., Tokyo, Japan) when the participants were seated after a rest of at least 5 minutes. The mean values of the two measurements were used for analysis.

Overnight fasting blood samples were collected from the antecubital vein into vacuum tubes containing a serum separator gel—to determine glucose levels and blood chemistry. The serum tube was centrifuged immediately at 3,000 g for 15 minutes, and the separated serum was sent to the laboratory for analysis. Enzymatic methods were used to measure serum levels of total cholesterol and triglycerides (TG). Low-density lipoprotein cholesterol and high-density lipoprotein cholesterol (HDL-C) were measured using the direct homogeneous method. Lipid measurements were standardized using the CDC NHLBI Lipids Standardization Program provided by the Centers for Disease Control and Prevention (Atlanta, GA, USA). Serum glucose was measured using the hexokinase method (Sysmex, Kobe, Japan) with an automatic analyzer (7600-D; Hitachi Co., Tokyo, Japan).

In this study, the Japanese criteria for MetS were used to establish the diagnosis of MetS and pre-MetS [25]. MetS

was diagnosed when the participant had abdominal obesity (WC of  $\geq 90$  cm) in addition to  $\geq 2$  of the other components. Pre-MetS was diagnosed when the participant had abdominal obesity and one of the other components, including (1) dyslipidemia [TG  $\geq 1.7$  mmol/L and/or HDL-C level  $<1.0$  mmol/L or specific treatment for these lipid abnormalities]; (2) BP  $\geq 130/85$  mmHg or on drug treatment; and (3) fasting glucose  $\geq 6.1$  mmol/L or on drug treatment. Ministry of Health, Labor, and Welfare of Japan considers MetS and pre-MetS as important targets to reduce the risk of MetS-related diseases [26]. Therefore, in line with previous studies [11, 19, 27–29], we analyzed AA pattern for participants in MetS and pre-MetS in a single group (MetS/pre-MetS).

### Covariates

Using a self-administered questionnaire, we surveyed smoking habits, alcohol consumption, and energy intake at baseline, and we surveyed the highest educational qualifications at follow-up. Individuals who responded that they presently smoked tobacco were considered smokers, and those who consumed  $\geq 1$  g of alcohol per week were considered drinkers. The usual consumption of food and beverage items were assessed by a food frequency questionnaire for which reasonable validity was observed in a previous study [30], and energy intake was estimated using the Standard Tables of Food Composition in Japan (2010) [31].

### Statistical analysis

As previous study [19], four variables were used in the latent profile analysis, namely the number of steps, LIAA, MVAA, and the ratio of MVAA to total AA. To characterize the AA patterns, we calculated and used the ratio of MVAA to total AA, which is proportionate of MVAA to daily total AA, in addition to three variables of AA measured using the LC (number of steps, LIAA, and MVAA). These variables were converted into z score for use in the analysis [19, 32]. To identify the latent profile, we implemented a continuous latent model with 2–5 profile solutions. To derive the optimal number of profiles, the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), entropy, and group size of each profile was evaluated for each model from the two-profile model to a five-profile model. In addition, we performed a group interpretation [17] and selected the final model. Lower the AIC and BIC values, better the goodness-of-fit of the model. For entropy, a value of 0–1 was given, and values  $\geq 0.8$  were considered to indicate good profile classification. Group size was based on  $\geq 5\sim 10\%$  of participants belonging to each group of the total participant size [32, 33]. These fit statistics are commonly used in latent profile analysis [34]. For the latent profile analysis, we used Mplus (Version 8.5, Muthén & Muthén, Los Angeles, CA).

Categorical variables between AA patterns (groups) identified by latent profile analysis were compared using

a chi-square test, and to compare continuous variables, a one-way analysis of variance was performed using the Bonferroni method for multiple comparisons. To examine the relationship between AA pattern and MetS onset, we conducted a logistic regression analysis using MetS as a dependent variable and AA patterns (groups) as independent variables. On the basis of the group with the lowest activity level, we calculated the odds ratio and the 95% confidence interval (95% CI) of the other groups. As confounder variables, we incorporated age (continuous variable), education (high school graduate or lower/education past high school), smoking habit (smoker/nonsmoker), drinking habit (drinker/nondrinker), energy intake (continuous variable), and the number of MetS component present at baseline ( $\geq 1/0$ ) into the model. In the follow-up survey (5-year examination), those who corresponded to MetS or pre-MetS were defined as cases. The statistical analyses were performed using software SPSS version 28.0 (IBM Corp, Armonk, NY, USA), and  $p < 0.05$  was considered statistically significant (two-tailed test).

## Results

The fit statistic of the latent profile model is presented in Table 2. The AIC and BIC decreased as the profile number increased in the two-to-five-profile models. In all models, a value of  $\geq 0.8$  was obtained for entropy. Regarding group size, all models included groups with more participants than the minimum recommended cutoff value (5%). However, the five-profile model included two relatively small groups (9.0 and 5.7%). Based on these fit statistics and the interpretability of the later-mentioned groups, we used the four-profile model as the optimal model in the present study.

The AA characteristics of the four groups classified through latent profile analysis are presented in Table 3. The total AA was significantly high in descending order of groups A, B, C, and D; however, no significant differ-

ence observed in the number of steps between groups B and C. Group B had significantly higher MVAA than groups A and C, whereas group C had significantly higher LIAA than groups A and B.

The baseline characteristics of the four groups are presented in Table 4. The proportion of drinkers was highest in group C. The fasting glucose levels in group D tended to be higher than those in other groups, while the HDL-C levels in group A tended to be lower compared to the other groups.

Over the 5-years follow-up period, 61 participants (7.7%) developed MetS. The crude and multivariate adjustment odds ratios for MetS onset according to the four groups have been presented in Table 5. The multivariate-adjusted odds ratio (95% CI) of groups B, C, and D to groups A were 0.416 (0.142–1.218), 0.451 (0.223–0.914), and 0.933 (0.365–2.382), respectively, with a significantly lower value obtained for groups C. In a sensitivity analysis excluding individuals with each MetS component at baseline, groups B and C consistently showed a lower odds ratio for MetS onset than group A (Table 6). In a latent profile analysis, each individual was assigned to a class based on their highest posterior probability. To increase statistical power, we conducted an analysis by reassigning five individuals who had relatively high posterior probabilities ( $>0.30$ ) for Group B to this group. The multivariate-adjusted odds ratios (95% CI) of Groups B ( $n = 86$ ), C ( $n = 244$ ), and D ( $n = 58$ ) compared to Group A ( $n = 406$ ) were 0.378 (0.129–1.105), 0.460 (0.227–0.934), and 0.927 (0.363–2.368), respectively. As a result, we observed that the upper bound of the 95% CI for Group B decreased, approaching closer to 1.000.

## Discussion

This study adopted a latent model with four-profile solutions as the optimum model. Group A was a “low-level AA pattern,” group B was a “pattern in which a certain level of steps [35] was accumulated mainly by MVAA,” group C was a “pattern in which a certain level of steps [35] was accumulated by LIAA,” and group D was a “high-level AA pattern.” In our previous study that attempted to identify AA patterns in middle-aged and older Japanese through latent profile analysis, AA activities in daily life could be classified into four categories: “low-level AA patterns,” “AA patterns in which a certain level

**Table 2** Fit indices of 2–5-profile latent models

	2 Profiles	3 Profiles	4 Profiles	5 Profiles
AIC	7959	7497	7170	6801
BIC	8019	7581	7278	6931
Entropy	0.894	0.834	0.877	0.879
Group size	618/176	405/291/98	407/248/81/58	310/275/92/72/45

AIC, Akaike information criterion; BIC, Bayesian information criteria

**Table 3** Ambulatory activity variables among the identified distinct groups at baseline

	Group-A (n = 407)		Group-B (n = 81)		Group-C (n = 248)		Group-D (n = 58)		P
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	
Steps (step/day)	6278	1339 <sup>b,c,d</sup>	10499	1668 <sup>a,d</sup>	10250	1459 <sup>a,d</sup>	15597	1739 <sup>a,b,c</sup>	<0.001
LIAA (min/day)	56.7	12.7 <sup>b,c,d</sup>	63.9	13.6 <sup>a,c,d</sup>	90.6	16.5 <sup>a,b,d</sup>	111.5	23.8 <sup>a,b,c</sup>	<0.001
MVAA (min/day)	12.3	5.7 <sup>b,c,d</sup>	40.8	8.8 <sup>a,c,d</sup>	22.6	6.0 <sup>a,b,d</sup>	51.3	16.2 <sup>a,b,c</sup>	<0.001
Total AA (min/day)	69.0	14.7 <sup>b,c,d</sup>	104.7	17.0 <sup>a,c,d</sup>	113.1	17.4 <sup>a,b,d</sup>	162.8	19.1 <sup>a,b,c</sup>	<0.001
MVAA/Total AA (min/min)	0.18	0.07 <sup>b,c,d</sup>	0.39	0.07 <sup>a,c,d</sup>	0.20	0.05 <sup>a,b,d</sup>	0.32	0.10 <sup>a,b,c</sup>	<0.001

<sup>a</sup>p < 0.05 vs Group-A; <sup>b</sup>p < 0.05 vs Group-B; <sup>c</sup>p < 0.05 vs Group-C; <sup>d</sup>p < 0.05 vs Group-D

LIAA, light-intensity ambulatory activity; MVAA, moderate- to vigorous-intensity ambulatory activity; AA, ambulatory activity



**Table 4** Characteristics of participants in the identified distinct groups at baseline

	Group-A (n = 407)		Group-B (n = 81)		Group-C (n = 248)		Group-D (n = 58)		p
Age (years)	56.4	(12.4)	57.6	(11.4)	55.3	(11.2)	57.4	(10)	0.360
Education (education past high school)	195	47.9	40	49.4	114	46.0	28	48.3	0.942
Smokers (n, %)	13	3.2	1	1.2	5	2.0	3	5.2	0.432
Drinkers (n, %)	138	33.9	16	19.8	100	40.3	24	41.4	0.006
Energy intake (kcal/day)	1836	(383)	1853	(355)	1897	(392)	1901	(353)	0.198
Body mass index (kg/m <sup>2</sup> )	21.9	(2.6)	22.1	(2.2)	21.9	(2.8)	22.0	(3.1)	0.939
Waist circumference (cm)	80.2	(7.3)	79.4	(7.5)	79.2	(7.5)	79.3	(9.6)	0.382
Systolic blood pressure (mmHg)	121.9	(20.6)	126.0	(21.3)	122.1	(19.7)	125.0	(21.3)	0.292
Diastolic blood pressure (mmHg)	72.7	(11.6)	74.8	(11.0)	72.5	(11.1)	74.1	(12.4)	0.327
Fasting glucose (mg/dL)	90.8	(13.9)	91.7	(10.6)	89.9	(8.1)	94.6	(13.8)	0.059
High-density lipoprotein cholesterol (mg/dL)	64.0	(14)	67.1	(12.6)	66.5	(13.7)	69.3	(12.7)	0.009
Triglycerides (mg/dL)	96.2	(53.4)	91.9	(40.6)	88.3	(37.2)	87.0	(42.4)	0.148
Abdominal obesity (n, %)	10	2.5	3	3.7	10	4.0	5	8.6	0.112
Hypertension (n, %)	166	40.8	38	46.9	83	33.5	24	41.4	0.112
Hyperglycemia (n, %)	23	5.7	5	6.2	9	3.6	6	10.3	0.219
Dyslipidemia (n, %)	99	24.3	20	24.7	48	19.4	14	24.1	0.487
Having number of MetS components for diagnostic criteria (n, %)									
0	190	46.7	32	39.5	132	53.2	22	37.9	0.137
1	147	36.1	32	39.5	86	34.7	24	41.4	
2	59	14.5	17	21.0	26	10.5	11	19.0	
3	11	2.7	0	0.0	4	1.6	1	1.7	

Data presented as mean (standard deviation) or n (%). MetS, metabolic syndrome

**Table 5** OR and 95% CI for MetS onset in the identified distinct groups

	n	Case	Crude OR (95% CI)		Multivariable adjusted OR <sup>a</sup> (95% CI)	
Group-A	407	40	1.000	(reference)	1.000	(reference)
Group-B	81	4	0.477	(0.166–1.371)	0.416	(0.142–1.218)
Group-C	248	11	0.426	(0.214–0.846)	0.451	(0.223–0.914)
Group-D	58	6	1.059	(0.428–2.619)	0.933	(0.365–2.382)

<sup>a</sup>Adjusted for age (continuous variable), education (high school graduate or lower/education past high school), smoking habit (smoker/nonsmoker), drinking habit (drinker/nondrinker), energy intake (continuous variable), and the number of MetS components present at baseline ( $\geq 1/0$ ).

OR, odds ratio; CI, confidence interval; MetS, metabolic syndrome

of number of steps is accumulated mainly by MVAA,” “AA patterns in which a certain level of number of steps is accumulated by both MVAA and LIAA,” and “high-level AA patterns.” [19] The results of this study were generally consistent with the results of previous study [19]. The participants of this study are a subgroup of the previous study’s participants [19], excluding those with MetS and men. The similar results from different participants reinforce the possibility of such AA patterns in the real world. Based on previous research [19], group A was interpreted as an “insufficient” pattern, group B as an “active couch potato” pattern [36], group C as a “move more and sit less” pattern [37], and group D as a “Busy Bee” pattern [38] of PA. In the five-profile model, there were two groups with high AA levels, but the number of individuals belonging to these profiles was relatively small (9.0% and 5.7%) [34]. The low-level AA pattern, the AA pattern accumulating a certain level of steps mainly by MVAA, and the AA pattern accumulating a certain level

of steps mainly by LIAA were similarly present in the five-profile model.

In this study, the odds ratio for the onset of MetS was similarly low in groups B and C and observed to be significantly lower than the reference in group C. Many previous studies have examined the relationship between moderate-to-vigorous intensity PA and the onset of MetS, noting a significant negative dose-response relationship between the two [5, 6]. In recent years, the health benefits of light-intensity PA have also received attention [39]. Since light-intensity PA is a major determinant of daily PA-induced energy expenditure [40], it can be inferred that its level may be closely related to the onset of abdominal obesity, a central component of MetS. In addition, light-intensity PA has been reported to be negatively associated with cardiometabolic risk factors such as WC and TG, independently of moderate-to-vigorous intensity PA [39]. Furthermore, a negative association exists between light-intensity PA and daily sedentary time [19]. Previous studies have also reported that longer sedentary time may increase the risk of developing MetS [7]. Compared to group B, group C has a shorter MVAA time of about 20 minutes but a LIAA time of about 30 minutes longer and a total AA time of about 10 minutes longer. This additional effect of LIAA likely contributes to the lower odds ratio for MetS onset in group C, similar to that of group B.

The Japanese PA guidelines recommend intentional PA, such as exercise, as well as activities of daily living, such as non-exercise activity, as specific practices to increase daily PA [41]. The number of steps is an easy-to-understand indicator of the daily amount of PA and is a simple and feasible measure for monitoring and promoting PA as fitness trackers and mobile devices have increased in popu-

**Table 6** OR and 95% CI for MetS onset in baseline component-free participants

	Group-A		Group-B		Group-C		Group-D	
Participants excluding those with abdominal obesity at baseline	397/38		78/3		228/10		49/4	
n/case								
Crude OR (95% CI)	1.000	(reference)	0.378	(0.114–1.256)	0.414	(0.202–0.848)	0.771	(0.264–2.254)
Multivariable adjusted OR <sup>a</sup> (95% CI)	1.000	(reference)	0.329	(0.097–1.116)	0.456	(0.218–0.953)	0.712	(0.236–2.150)
Participants excluding those with hypertension at baseline	241/12		43/1		165/4		34/4	
n/case								
Crude OR (95% CI)	1.000	(reference)	0.454	(0.058–3.588)	0.474	(0.150–1.496)	2.544	(0.771–8.396)
Multivariable adjusted OR <sup>a</sup> (95% CI)	1.000	(reference)	0.382	(0.046–3.183)	0.467	(0.142–1.533)	1.906	(0.532–6.820)
Participants excluding those with hyperglycemia at baseline	384/34		76/4		239/10		52/6	
n/case								
Crude OR (95% CI)	1.000	(reference)	0.572	(0.197–1.662)	0.450	(0.218–0.928)	1.343	(0.535–3.372)
Multivariable adjusted OR <sup>a</sup> (95% CI)	1.000	(reference)	0.503	(0.169–1.495)	0.475	(0.226–0.999)	1.216	(0.465–3.182)
Participants excluding those with dyslipidemia at baseline	308/22		61/2		200/10		44/3	
n/case								
Crude OR (95% CI)	1.00	(reference)	0.441	(0.101–1.925)	0.684	(0.317–1.477)	0.951	(0.273–3.320)
Multivariable adjusted OR <sup>a</sup> (95% CI)	1.000	(reference)	0.350	(0.078–1.572)	0.688	(0.308–1.537)	0.741	(0.204–2.693)

<sup>a</sup>Adjusted for age (continuous variable), education (high school graduate or lower/education past high school), smoking habit (smoker/nonsmoker), drinking habit (drinker/nondrinker), energy intake (continuous variable), and the number of MetS components present at baseline ( $\geq 1/0$ ).

OR, odds ratio; CI, confidence interval; MetS, metabolic syndrome

larity [42]. For this reason, it has rapidly gained attention in the field of PA in recent years, and discussion is ongoing about showing the recommended amount of PA for health promotion using the measure of steps [42]. Therefore, evidence has accumulated on the number of steps and various health outcomes [43]. In general, LIAA is thought to occur and accumulate mainly in activities of daily living, such as housework and work, while MVAA is thought to occur and accumulate mainly in intentional PA, such as exercise [44, 45]. The notable points of this study are: 1) it showed that there are patterns in the real world in which a certain level of steps is accumulated mainly by MVAA or mainly by LIAA as recommended by the Japanese PA guidelines [41] and 2) it suggested that there is no major difference in preventing the onset of MetS between the different patterns of step accumulation. This information supports the assertion that any increase in daily step count should be considered for inclusion in public health guidelines [43], and may further emphasize the importance of daily step monitoring for public health. In this study, we believe that through person-centered analysis of findings obtained by variable-centered analysis to date [11], we were able to provide additional useful information to be implemented in public health activities to prevent MetS.

The main strength of this study is the objective measurement of daily AA using the accelerometer. Due to the difficulty in remembering such relatively low-intensity and intermittently occurring PAs, self-reported AA measurement may not be reliable and valid [46]. The objective methods guarantee more accuracy of AA assessment than self-reported methods. However, this study also has several limitations. First, the participants in this study were limited to middle-aged and older Japanese women. Walking speed declines with age [47], and Japanese women traditionally spend more time on housekeeping than men, leading to a higher proportion of low-intensity PA relative

to total activity time [44, 45]. Therefore, even if men and women have the same number of steps, their walking patterns may differ. As a result, the findings of this study may not be generalizable to other age groups, sexes, or populations in different countries. Future research should explore the applicability of these findings across various age groups, sexes, and cultural contexts. Second, the participants in this study were volunteers, which may have introduced selection bias. According to the National Health and Nutrition Survey in Japan, the average number of steps taken by the participants in this study was slightly higher than the national average for Japanese women [48]. This suggests that the participants were more likely to engage in a healthy lifestyle compared to the general population. Therefore, the findings of this study may not necessarily be applicable to the general population of middle-aged and older women. Future studies should consider examining a more representative sample to enhance the generalizability of the results. Third, in this study, AA was assessed only once at baseline. An 8-year follow-up study among Japanese individuals demonstrated that AA, as assessed by step count, maintained high stability over time, preserving its relative ranking within the population [49]. Thus, we believe that baseline AA measurements generally reflect AA levels during the follow-up period. However, since changes in AA during the follow-up period can lead to an underestimation of the true association between AA and the onset of MetS [50], the relationship observed in this study may have been underestimated. To assess more accurately the association between AA patterns and MetS onset, additional studies with designs that include multiple measurements of AA are warranted. Fourth, in this study, group B did not reach statistical significance, although it showed a low odds ratio for the MetS onset. No certain trend was observed for group D. We speculate that the lack of statistical power for group B is due to the small number

of MetS onset and group D due to the small group size. Future studies with larger sample sizes are needed to confirm these findings. Finally, the follow-up period in this study was relatively short at 5 years. A 5-year follow-up may miss late-onset cases, potentially reducing the statistical power. A longer follow-up would allow for a more detailed examination of the onset of MetS over time and help mitigate the risk of reverse causation. We plan to extend the follow-up period to assess the association more accurately between AA patterns and MetS risk.

## Conclusion

In the present study, we identified AA patterns in the daily life of middle-aged and older Japanese women, and examined the relationship with onset of MetS. The AA patterns of middle-aged and older Japanese women can be classified into four patterns. Our findings suggest that AA patterns involving the accumulation of a certain number of steps, regardless of the intensity of AA, may help reduce the risk of MetS compared to inactive AA patterns. These results support the idea that any step may contribute to better health and highlight the usefulness of providing PA recommendations based on step counts.

## Abbreviations

AA: Ambulatory activity; AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion; BP: Blood pressure; HDL-C: high-density lipoprotein cholesterol; LC: Lifecorder; LIAA: light-intensity ambulatory activity; METs: Metabolic equivalents; MetS: Metabolic syndrome; MVAA: Moderate-to-vigorous intensity ambulatory activity; PA: Physical activity; TG: Triglycerides; WC: Waist circumference; 95% CI: 95% confidence interval.

## Declarations

Written informed consent was given by all participants. The study protocol was approved by the Institutional Review Board, Ehime University Hospital (approval number: 170511).

## Consent for publication

All authors approved the manuscript.

## Availability of data and material

Available upon a reasonable request.

## Competing interests

None to declare.

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## Authors' contributions

IS, TT, and HO designed the study. KM, KT, RK, and YT collected the data. NY analyzed data and wrote the manuscript. KM and IS contributed to the discussion and reviewed/edited the manuscript. All authors have provided the final approval.

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