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Title	Association Between Moderate Physical Activity Level and Subsequent Frailty Incidence Among Community-Dwelling Older Adults : A Population-Based Cohort Study
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Citation	Journal of Aging and Physical Activity, 31(5), 815-822 https://doi.org/10.1123/japa.2022-0052
Issue Date	2023-10
Doc URL	http://hdl.handle.net/2115/90174
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Type	article (author version)
File Information	PA_frailty_JAPA_Hokudai backup.pdf

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Association between moderate physical activity level and subsequent frailty incidence among community-dwelling older adults: a population-based cohort study

Abstract

Our study aimed to demonstrate the association between PA and frailty incidence among Japanese community-dwelling older adults with a narrow age range of 70–74 years. This study included 485 participants from the Japan Gerontological Evaluation Study. Frailty was assessed at baseline and 3 years later by using the Kaigo-Yobo Checklist. PA was assessed using the short-term International Physical Activity Questionnaire at baseline. Logistic regression was performed to calculate the odds ratio (OR) with 95% confidence intervals (CIs) after adjusting for potential confounders. The associations of frailty scores with both PA volume and daily walking time presented a U-shaped curve, albeit only the latter statistically significant. After adjusting for potential confounders, walking for 0.5–1 h/d displayed a greater association with decreased frailty risk than higher levels of daily walking time. Further study is needed to cumulate the evidence that moderate PA levels may delay frailty incidence and improve the aging process.

Keywords: Daily walking time, mobility, frail, aging

Background

Frailty, as a complex geriatric syndrome, is a consequence of impairment and loss of physiological reserve in multiple systems, including the nervous system, endocrine system, immune system, respiratory system, cardiovascular system, and skeletal muscle (Angulo, El Assar et al. 2020). Frailty is considered a state of transition from successful aging to low quality of life and increased vulnerability to falling (Kojima 2015), fractures (Kojima 2016a), disability (Kojima 2017), institutionalization (Kojima 2018a), hospitalization (Kojima 2016b), and even mortality (Kojima 2018b) among community-dwelling older adults. Reportedly, frailty affected globally 4.9%–27.3% of adults aged ≥65 years living in the community (Choi, Ahn et al. 2015). A progressive global increase in the aging population is expected to aggravate the prevalence of frailty, which inevitably increases the burden of health care costs for individuals and countries.

Physical inactivity, along with age, is one of the dominant risk factors for frailty incidence and a modifiable factor for the prevention of frailty (Yu, Wu et al. 2017, Kehler and Theou 2019, Niederstrasser, Rogers et al. 2019). Physical activity (PA) is well known for promoting functional capacity in older adults. Practicing regular PA preserves the normal functioning of several body systems including musculoskeletal, cardiorespiratory, endocrine, and nervous systems; the dysfunctioning of which increases the risk of frailty development (Angulo, El Assar et al. 2020). Although several previous studies have investigated the longitudinal association between frailty and leisure-time PA (Savela, Koistinen et al. 2013, Niederstrasser, Rogers et al. 2019, Kolehmainen, Havulinna et al. 2020); the measurement of PA frequency (Abe, Nofuji et al. 2020, Borda, Perez-Zepeda et al. 2020, Zhang, Tan et al. 2020), PA intensity (Peterson, Giuliani et al. 2009, Perez-Tasigchana, Sandoval-Insausti et al. 2020), PA volume (Peterson, Giuliani et al. 2009), PA type (Peterson, Giuliani et al. 2009), PA length

(Yuki, Otsuka et al. 2019, Gil-Salcedo, Dugravot et al. 2020), and the daily number of walking steps (Yuki, Otsuka et al. 2019), varied in the scales, tools, or modules, making it challenging to compare the results. Longitudinal studies related to each PA module remain scarce, and literature accumulation is needed. Meanwhile, most PA modules were measured previously by Yes or No, inactive or active (Kehler and Theou 2019), and the gradient effect of PA on frailty is difficult to detect. Meanwhile, most previous studies covered an extensive age range, where age was one of the essential risk factors for cumulative chronic diseases and physical function declines, including frailty development. Therefore, our study focused on the community-dwelling older adults with a narrow age range of 70–74 years and investigated the association between PA and sequential frailty incidence using a univeral PA questionnaires with rich dimensions.

Methods

Study population

The Japan Gerontological Evaluation Study (JAGES) 2013 is one of the waves of JAGES, an ongoing population-based panel study aimed at investigating the association between social and behavioral factors and health-related outcomes in the old population (Kondo 2016). JAGES 2013 was conducted from October to December 2013 recruiting 195,290 community-dwelling residents aged ≥65 years who were ineligible for the long-term care certification from 30 municipalities in 14 of 47 Japanese prefectures. In the Hokkaido prefecture, JAGES at Taisetsu community Hokkaido in 2014 (JAGES ATTACH 2014) was developed based on JAGES 2013. JAGES ATTACH 2014 further limited the number of participants compared with the JAGES 2013 by eliminating those living in Taisetsu community Hokkaido (Higashikawa, Higashikagura, and Biei town) aged 70–74 years who were ineligible for the long-term care certification at the beginning of the study, thereby finally enrolling 1,127 participants. Overall, 824 participants responded to the questionnaire by mail (response rate: 73.1%), and a home visit survey was conducted to measure weight, height, and other indicators after agreeing to participate in the study. After successively excluding the participants who did not reply to the lifestyle questionnaire (4 persons), who had missing data on frailty assessment (30 persons), who had missing data on vigorous PA, moderate PA and walking (10 persons), who had outliers on daily vigorous PA, moderate PA and walking time according to the data analysis guideline of the short-term International Physical Activity Questionnaire (IPAQ) (26 persons), and who had self-report depression (6 persons) and cognitive impairment (1 person), and Parkinson's disease (4 persons), 743 participants remained. Then further excluding baseline frail participants (127 persons) made 616 participants remaining (Figure1). The follow-up survey was conducted in August 2017. Follow-up data on frailty were obtained by mailing the Kaigo-Yobo Checklist, and data related to total mortality or the number of participants who moved out of their community were obtained from the local basic resident registry. Responding to the questionnaire was considered informed consent. This study was approved by the Ethics Review Committee of Hokkaido University Graduate School of Medicine (NO. 14-024).

Physical activity assessment

PA was evaluated at baseline using the Japanese version of short-term IPAQ, a useful validated tool for evaluating PA in older Japanese adults (Tomioka, Iwamoto et al. 2011). Participants were asked about the number of days they engaged in vigorous PA, moderate PA, or walking during the past 7 days; the options included "none" and frequencies of the given PA. If the answer was not "none," they were then asked to report the time spent on the given PA. Vigorous PA (heavy lifting, digging, and jogging) requires extensive physical effort, making the participants breathe heavier than normal. Moderate PA requires moderate physical effort and makes the participants breathe somewhat heavier than normal (carrying light loads, gardening, or table tennis, but not walking). Daily walking should last at least 10 minutes at a time, such as walking at work or home, walking to move from one place to another, and any other walking that one does solely for recreation, sport, exercise, or leisure. The PA volume for each PA intensity (Metabolic Equivalent of Task [METs]-minutes/week) is as follows: vigorous PA volume = 8.0 × vigorous-intensity activity minutes × vigorous-intensity days; moderate PA volume = 4.0 × moderate-intensity activity minutes × moderate days; walking volume = 3.3 × walking minutes × walking days. The total PA volume was defined as the sum of the volumes of vigorous PA, moderate PA, and walking and was further categorized into low, moderate, and high levels according to the guidelines for data processing analysis of the IPAQ. Daily walking time was defined as the weekly average of walking time (walking minutes × walking days) and then classified into 4 categories: daily walking ≤0.5 h, daily walking 0.5–1 h, daily walking 1–2 h, and daily walking >2 h.

Frailty assessment

Frailty at baseline and follow-up was assessed using the Kaigo-Yobo Checklist, a brief questionnaire for screening frailty in older Japanese adults. The Kaigo-Yobo Checklist has good concurrent validity which was tested by examining the relationship between its scores and Fried's criteria (Shinkai S, Watanabe N et al. 2013). It consists of 15 items and includes 3 subscales as follows: home boundness, falling, and lower nutrition. Each item scored 1 for those with a risk of frailty (e.g., low ability, difficulty, and having no friends); otherwise, a score of 0 was given. The total scores ranged from 0–15, and those who had scores of ≥4 were classified to have frailty. Considering the missing data on 15 items, frailty was further defined as follows: (i) participants whose total scores were ≥4 were defined as frail regardless of missing data; (ii) participants whose total scores were 3 without missing data were defined as non-frail; (iii) participants whose total scores were 2 with ≤1 missing data point on any of the items were defined as non-frail; (iv) participants whose total scores were 1 with ≤2 missing data points on any of the items were defined as non-frail; (v) participants whose total scores were 0 with ≤3 missing data points on any of the items were defined as non-frail, and (vi) participants who did not meet any of the previously described criteria were deemed "missing" and excluded from the analysis. The detailed items of the Kaigo-Yobo Checklist and scoring method were listed in the supplement materials (Table S1).

Covariate assessment

The covariates were self-reported through the questionnaires or measured during the home visiting survey. These included demographic factors (age and sex), lifestyle factors (smoking status, drinking status, work status, and living arrangement), and health status (body mass index [BMI], depressive symptoms, and comorbidity index). Smoking status included "never," "former," or "current smoker." Drinking status included "never," "occasional," and "heavy drinker." Occasional drinking was defined as the daily consumption of Japanese sake, beer, Japanese spirits, whisky, and wine (<23 g/d); for heavy drinkers, the daily consumption amounted to ≥23 g/d. The information related to alcohol consumption was obtained from the Brief-Type Self-Administered Diet History Questionnaire, through which alcohol consumption could be estimated by the amount of each alcoholic drink consumed at a time, with its frequency being recorded (Kobayashi, Murakami et al. 2011). Working status included "currently employed," "retired," or "never employed." Living status included "living alone" or "living with others." BMI ($kg \cdot m^{-2}$) was calculated using height and weight measured during the home visiting survey and categorized into 3 groups: <18.5, 18.5–25, and ≥25. If data on BMI were missing, the data input was self-reported BMI calculated from self-reported height and weight in the questionnaires. The short-term Geriatric Depression Scale was used for screening depressive symptoms, and participants with scores of ≥6 were considered to have depressive tendencies. The comorbidity index was defined as the number of historical incidences of hypertension, stroke, heart disease, diabetes mellitus, hyperlipidemia, musculoskeletal disorders, injuries (e.g., fall or fracture), cancer, and depression.

Statistical analysis

Baseline descriptive statistics of the participants were shown as number (percentage) for categorical variables and as the mean (standard deviation) or median (range) for continuous variables according to PA volume and daily walking time; the Chi-squared test and Kruskal–Wallis test were used to test between-group differences. Due to the skewed data for PA volume, daily walking time and frailty scores at follow-up period, generalized linear model with restricted cubic splines was conducted to figure out the non-linear association of frailty scores at follow-up period with PA volume, and daily walking time. Multiple logistic regression was applied to estimate odds ratios (ORs) and 95% confidence intervals (CIs) for subsequent frailty based on PA volume or daily walking time. There were two multi-adjusted models: Model 1 adjusted for age and sex and Model 2 adjusted for age, sex, BMI, smoking status, drinking status, working status, living arrangement, depressive symptoms, and comorbidity index. The presence of a linear trend was tested by placing the continuous variable of PA volume or daily walking time into the unadjusted or adjusted model. A quadratic trend was tested by placing a second-order polynomial of PA volume or daily walking time into the corresponding models. Sensitivity analysis was conducted by excluding participants with a history of cancer (15 participants), stroke (8 participants), or heart diseases (37 participants) because these participants were susceptible to frailty and these diseases might impact their PA practices.

Statistical analysis was conducted using the SAS statistical software package version 9.4 for Microsoft Windows (SAS Institute Inc., Cary, NC, USA). Two-tailed tests were used for statistical analysis, and P-values <0.05 were considered statistically significant.

Results

During the 3-year follow-up, 9 participants died and 6 moved out of the communities. Accordingly, 601 participants were eligible for the follow-up survey; of which, 487 participants responded (response rate: 80.2%). After excluding those with missing data on frailty at the follow-up survey (2 participants), 485 participants remained; data from 475 participants were used for the analysis of PA volume because 10 participants could not be identified as having a moderate PA volume due to missing data on vigorous PA. Furthermore, data from 456 participants were used for the analysis of daily walking time because 29 participants did not report daily walking time (Fig 1). Meanwhile, the baseline distribution of age, gender, working status, smoking status, drinking status, commobidity index in the participants who did not respond to the follow-up survey was not different from those who did respond except for the characteristics ofBMI (P<.0001), living arrangement (P=0.001), depressive sympotom (P=0.001).

After the 3-year follow-up, 46 new frailty cases were recorded. Table 1 shows the baseline characteristics of the participants according to PA volume and daily walking time. Participants who remained employed were more likely to practice a high volume of PA. Male participants were likely to walk for a longer time each day. Furthermore, retirees were more likely to walk more than those who had never been employed or remained employed.

Figure 2 presents the non-linear trend for the association of frailty scores at follow-up period with PA volume (A), and daily walking time (B). Both the association between PA volume, daily walking time at baseline and frailty scores at follow-up period was approaching a U shape though only the association for daily walking time was significant (p=0.030). Table 2 presents the ORs and 95% CI for frailty incidence according to PA volume and daily walking time. Compared with participants who practiced low PA volume, those who practiced moderate PA volume tended to decrease the risk of frailty after adjusting for the covariates (age, sex, BMI, smoking status, drinking status, working status, living arrangement, depressive symptoms, and comorbidity index). Although high PA volume also tended to decrease the risk of frailty incidence, the OR of subsequent frailty was approximately 1.00 after complete adjustment. The trend for ORs of subsequent frailty by PA volume resembled a U-shaped curve, although neither the linear trend nor quadratic trend was statistically significant. A daily walking time of 0.5–1 h/d was significantly associated with a decreased risk of frailty than that in walking for ≤0.5 h/d (OR, 0.35; 95% CI, 0.12–0.98). Moreover, longer daily walking durations, such as 1–2 h/d or >2 h/d, decreased the risk of frailty by 39% and 18%, respectively. Adjusting the regression models exclusively for age and sex or all covariates did not impact the final results. Similar to that seen concerning PA volume, the trend for the ORs of subsequent frailty by daily walking time also resembled a U-shape curve.

Sensitivity analyses for the associations of frailty incidence with PA volume and daily walking time by excluding participants with a history of cancer, stroke, or heart disease did not change the association substantially (Table 3).

Discussion

This study was conducted to investigate the association between PA and subsequent incident frailty in community-dwelling older adults. The association of frailty scores at follow-up period with both PA volume and daily walking time both presented U-shaped curves though only the association for daily walking time was statistically significant. And a lower frailty incidence risk was observed for walking 0.5–1 h/d but not PA volume.

To the best of our knowledge, this is the first study to investigate the association between daily walking time and incident frailty in older adults living in the community. The WHO guidelines on PA and sedentary behaviors (Bull, Al-Ansari et al. 2020) recommend multicomponent PA for older adults to maintain their physical fitness. Studies from the UK (Niederstrasser, Rogers et al. 2019) and Finland (Kolehmainen, Havulinna et al. 2020) reported that both moderate (e.g., washing the car or gardening) and vigorous (e.g., tennis or swimming) leisure-time PAs reduced the risk of frailty in older adults by 41%–69%. Moreover, a study of the Finnish population reported that vigorous leisure-time PA in midlife could lower frailty risk in the older stages of life by up to 77% (Savela, Koistinen et al. 2013). Decreased frailty risk was also observed in Chinese (Yu, Wu et al. 2017), Japanese (Abe, Nofuji et al. 2020), and Mexican (Borda, Perez-Zepeda et al. 2020) older adults who practiced PA at higher frequencies. In the US, no associations were observed between PA intensity and subsequent frailty among older adults who exercised instead of getting involved in sedentary activities (Peterson, Giuliani et al. 2009); however, moderate or vigorous PA reduced frailty risk by >40% in Spanish older adults (Perez-Tasigchana, Sandoval-Insausti et al. 2020). Our study found that daily walking, a regular moderate-intensity PA (3.3 estimated METs), decreased the risk of frailty in Japanese older adults by more than 60%. Consistent with our study, a regular frequency of moderate PA was associated with a low risk of frailty incidence in European older adults (Zhang, Tan et al. 2020). Walking—a simple, safe, easily accessible, and effective PA modality for older adults—promotes physical performance and fitness (Wong, Wong et al. 2003), prevents cardiovascular disease (Boone-Heinonen, Evenson et al. 2009), and decreases mortality risk (Zhao, Ukawa et al. 2015). Not only does our finding support that PA could prevent or delay the onset of frailty in community-dwelling older adults but it also yields new evidence that integrate walking into older adults' daily routines and keeping them physically active could delay frailty and adverse health outcomes.

Our study observed no significant association between PA volume and frailty prevention. Consistent with our findings, a study from the US did not find this association either (Peterson, Giuliani et al. 2009). However, we observed a U-shaped curve for the association of frailty scores with PA volume as well as daily walking time, although only the associations for daily walking time were significant. In our study, walking for 0.5–1 h/d, but not longer, could decrease subsequent frailty risk in Japanese adults aged 70–74 years. And the non-linear associations of frailty scores at follow-up with PA volume and daily walking time suggested that a non-beneficial effect of high-level PA was related to frailty development. Contrary to our findings, some previous studies reported a linear relationship between PA intensity and frailty incidence in the younger-old adult who were more likely to sustain higher physical capacity (Savela, Koistinen et al. 2013, Graciani, Garcia-Esquinas et al. 2016, Wade, Marshall et al. 2017, Niederstrasser, Rogers et al. 2019, Gil-Salcedo, Dugravot et al. 2020). A study from Japan reported the prospective association between frailty and walking >5,000 steps/d, approximately 50 minutes of activity, but it suggested that walking for >1 h/d was not related to the prevention of frailty (Yuki, Otsuka et al. 2019). The human body develops dysfunctions with aging, including physical and cognitive impairment, and likely experiences a series of chronic conditions, which, to some extent, justify the recommendation for performing high level (intensity or volume) of PA. The Physical Activity Guidelines for Americans highlight the importance of regular PA for older adults with or without chronic conditions and indicate tailored levels of PA based on their physical capacity (Piercy, Troiano et al. 2018). Consequently, our study conceived higher levels of PA might not provide additional benefits for frailty prevention in the older-old adults who was likely to suffering from functional declines. The further study is needed to demonstrate it. It is suggested that older adults should consider customizing their PA levels according to their physical capacity or the physician's suggestions to avoid unnecessary injury caused by excessive PA. Maintaining a physically active lifestyle through moderate daily walking is more likely to decrease low-grade inflammation, increase muscle mass and strength required to maintain movement, accelerate metabolic processes to adapt to glucose and fatty acid metabolism, regulate cardiopulmonary fitness to efficiently carry oxygen and nutrients throughout the body, and enable neurological function to coordinate multiple systems, consequently enhancing the physical capacity (McPhee, French et al. 2016).

This study has some limitations. First, the relatively small sample size may have possibly weakened the statistical power of the association of interest, but we obtained a consistent trend of the association for both PA volume and daily walking time. Second, PA was assessed using a self-reported questionnaire rather than an objective assessment tool such as an accelerometer. However, this study obtained results consistent with those of a study that measured PA using accelerometers (Yuki, Otsuka et al. 2019). Third, PA was assessed only at the baseline, and PA levels were likely to change with age; but our participants were in a narrow age range of 70-74 years. Fourth, the follow-up period in this study was relatively short (about 3 years). Nonetheless, a previous study demonstrated that PA had an equivalent impact on frailty risk over both short- and long-term follow-up periods (Perez-Tasigchana, Sandoval-Insausti et al. 2020). Fifth, our analysis considered the continuous physical activity time less than 10 minutes as zero according to the guidelines for data processing analysis of the IPAQ, which to some extent neglected the real physical acitivty status for some participants. Finally, it might be difficult to statistically generalize the results to all older populations domestically or globally, because our study population came from only three towns in Hokkaido, Japan. But the median daily walking time (51min/d, equal to about 5000step/d) of our participants approximated the value (5730 steps/d) reported for the older adults aged 65-74 years by Japan National Health and Nutrition Survey 2019 (2019); and the incidence rate 9.5% of the frailty in three years also closed to the global frailty incidence 13.5% (Ofori-Asenso, Chin et al. 2019). The main strength of our study is that the age of our study population was limited to 70–74 years, which could reduce the effect of age on the association of interest.

Conclusions

The longitudinal association between daily walking time and frailty tended to be an approximate U-shaped curve and walking for 0.5–1 h/d might decrease the risk of frailty among community-dwelling older residents more significantly than longer walking times. Further studies are needed to investigate the impact of longer daily walking times (higher PA levels) on the risk of frailty among older adults.

List of abbreviations

ATTACH: JAGES at the Taisetsu community Hokkaido
BMI: Body mass index
CI: Confidence interval
GDS: Geriatric Depression Scale
GDS-15: Short-term Geriatric Depression Scale
IPAQ: International Physical Activity Questionnaire
JAGES: Japan Gerontological Evaluation Study
MET: Metabolic Equivalent of Task
OR: Odds ratio
PA: Physical activity
WHO: World Health Organisation

DECLARATIONS

Data Availability Statement

The datasets generated and/or analyzed during the current study are not publicly available because of privacy concerns but are available from the corresponding author on reasonable request.

Conflict of Interest Statement

The authors declare that they have no competing interests.

Funding Sources

This study was supported by Grant-in-Aid for Scientific Research (20319338, 22390400, 23243070, 23590786, 23790710, 24140701, 24390469, 24530698, 24653150, 24683018, 25253052, 25870881, 26882010, 17H04129) from the Japan Society for the Promotion of Science; Health Labour Sciences Research Grant, Comprehensive Research on Aging and Health (H26-Choju-Ippan-006, H25-Choju-Ippan-003, H25-Kenki-Wakate-015, H25-Irryo-Shitei-003 (Fukkou), H24-Junkanki (Syosyu)-Ippan-007) from the Japanese Ministry of Health, Labour and Welfare; a grant from the Department of Health and Human Services, National Institutes of Health, National Institute on Aging (research grant number 1R01AG042463-01A1); and a grant from the National Center for Geriatrics and Gerontology (no. 24-17, no. 24-23, no. J09KF00804). This study was also supported by the Pfizer Health Research Foundation, Nestle Nutrition Council, Japan Dairy Association, and Meiji Yasuda Life Foundation of Health and Welfare.

Author Contributions

All authors conceived and designed the study. WJZ analyzed the data and drafted the manuscript; SU and EO collaborated and prepared the final dataset of the survey; SU, TK, and AT conducted the follow-up survey; SU, SS and KK obtained the funding to support this study; SU, SS, EO, TK, KK, and AT reviewed and edited the manuscript.

Acknowledgements

We greatly appreciate all the participants of the surveys, and staff members of each study area. We are also grateful for the suggestions we received for this study from the staff members of our department and the members of the JAGES.

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FIGURE LEGEND

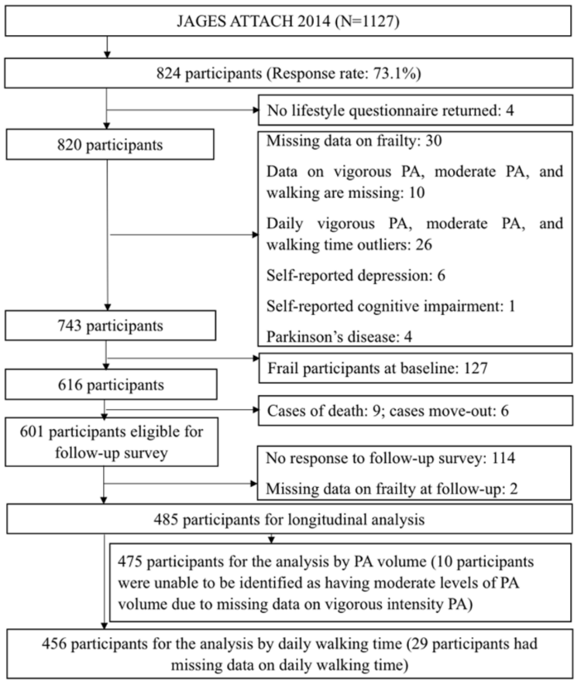

Fig 1 Flowchart of the study population

PA, Physical activity; JAGES ATTACH, The Japan Gerontological Evaluation Study at Taisetsu community Hokkaido

Table 1. Baseline characteristics of the participants according to physical activity volume and daily walking time

	Physical activity volume (N = 475)				Daily walking time (N = 456)				
	Low (n=134)	Moderate (n=152)	High (n=189)	*P*	≤0.5 h/d (n=147)	0.5–1 h/d (n=115)	1–2 h/d (n=92)	>2 h/d (n=102)	*P*
Age, years, mean (SD) [a]	71.7 (1.3)	71.8 (1.4)	71.9 (1.4)	0.720	71.7 (1.3)	71.7 (1.3)	72.1 (1.5)	71.9 (1.5)	0.224
Male sex	56 (41.8)	67 (44.1)	95 (50.2)	0.241	50 (34.0)	58 (50.4)	51 (55.4)	54 (52.9)	0.002*
BMI, kg/m^2, N (%)									
<18.5	4 (3.0)	6 (3.9)	6 (3.2)		5 (3.4)	4 (3.5)	4 (4.3)	2 (2.0)	
18.5–24.9	45 (33.6)	71 (46.7)	71 (37.6)	0.080	58 (39.5)	41 (35.7)	42 (45.7)	40 (39.2)	0.903
≥25	76 (56.7)	71 (46.7)	108 (58.1)		78 (53.1)	67 (58.3)	44 (47.8)	57 (55.9)	
Smoking status, N (%)									
Current	8 (6.0)	15 (9.9)	11 (5.8)		7 (4.8)	9 (7.8)	8 (8.7)	9 (8.8)	
Past	44 (42.8)	50 (32.9)	66 (34.9)	0.878	47 (32.0)	49 (42.6)	30 (32.6)	33 (32.4)	0.431
Never	74 (55.2)	79 (52.0)	102 (54.0)		85 (57.8)	55 (47.8)	48 (52.2)	56 (54.9)	
Drinking status, N (%)									
Never	66 (49.3)	71(46.7)	95 (50.3)		79 (53.7)	53 (46.1)	39 (42.4)	53 (52.0)	
Occasional drink	13 (9.7)	16 (10.5)	19 (10.1)	0.553	21 (14.1)	9 (7.8)	15 (16.3)	6 (5.9)	0.125
Heavy drink	39 (29.1)	50 (32.5)	64 (33.9)		36 (24.5)	45 (39.1)	32 (34.8)	36 (35.3)	
Working status, N (%)									
Current	33 (24.6)	33 (21.7)	68 (36.0)		36 (24.6)	26 (22.6)	21 (22.8)	45 (44.1)	
Retired	73 (54.5)	91 (59.9)	101 (53.4)	0.025*	82 (55.8)	67 (58.3)	66 (66.3)	51 (50.0)	0.008*
Never	12 (9.0)	15 (9.9)	13 (6.9)		15 (10.2)	15 (13.0)	4 (4.3)	5 (4.9)	
Living alone, N (%)	17 (12.7)	18 (11.8)	22 (11.6)	0.797	20 (13.6)	9 (7.8)	13 (14.1)	12 (11.8)	0.558
Depressive symptom, GDS score ≥6, N (%)	25 (18.7)	27 (17.8)	40 (21.2)	0.828	24 (16.3)	31 (27.0)	16 (17.4)	19 (18.6)	0.450
Comorbidity index, median (range) [a]	1 (0–3)	1 (0–4)	1 (0–5)	0.566	1 (0–5)	1 (0–3)	1 (0–5)	1 (0–4)	0.631

Note. BMI = body mass index; GDS = short-term Geriatric Depression Scale.

[a]Kruskal–Wallis test was used for age and comorbidity index, and Chi-squared test was used for others. * Statistical significance.

(a) (b)

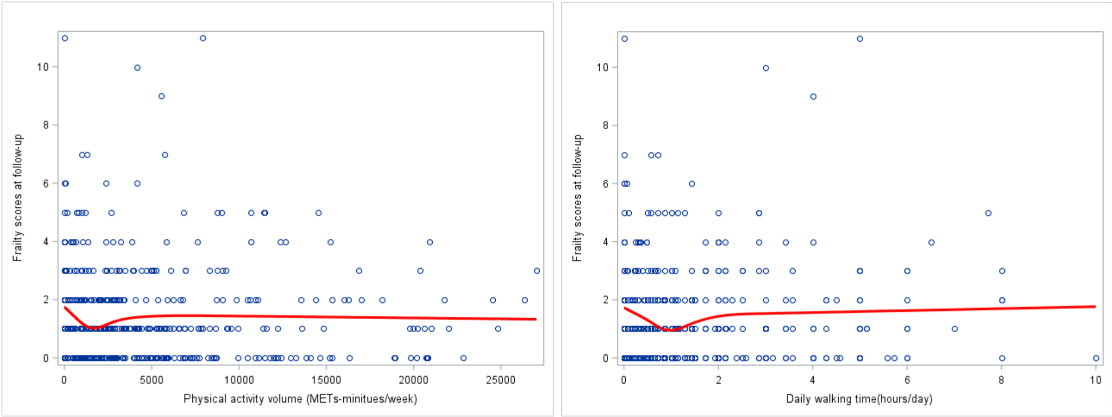

Fig 2 The non-linear association between physical activity volume (a), daily walking time (b) and frailty scores at follow-up period using restricted Cubic Spline

Table 2. Association between physical activity and frailty after three years of follow-up

	Sample size	Frailty case	OR (95% CI) [#†]	OR (95% CI) [#‡]
Physical activity volume (METs-minutes/week) [§]				
Low	134	16	1.00	1.00
Moderate	152	11	0.57 (0.25–1.28)	0.61 (0.26–1.45)
High	189	18	0.77 (0.38–1.58)	0.85 (0.38–1.88)
P for linear trend			0.757	0.666
P for quadratic trend			0.352	0.494
Daily walking time (h/d)				
≤0.5	147	19	1.00	1.00
0.5–1	115	6	0.39 (0.15–1.01)	0.35 (0.12–0.98) [*]
1–2	92	8	0.63 (0.26–1.53)	0.61 (0.23–1.63)
>2	102	11	0.81 (0.36–1.81)	0.82 (0.34–1.97)
P for linear trend			0.925	0.795
P for quadratic trend			0.624	0.567

Note. MET, Metabolic Equivalent of Task; CI, Confidence interval; OR, Odds ratio.
[#]Continuous physical activity volume and daily walking time were analyzed using the logistic regression model to calculate *p* values for the linear trend or *p* values for the quadratic trend.
[*] P<0.05.
[†]Adjustment for age and sex;
[‡]Adjustment for age, sex, body mass index, smoking status, drinking status, working status, living arrangement, depressive symptoms, and comorbidity index.

Table 3. Sensitivity analysis for the associations between physical activity and frailty after three years of follow-up by excluding participants with disease history of cancer, stroke and heart diseases

	Sample Size	Frailty case	OR (95% CI) *†	OR (95% CI) *‡
Physical activity volume (METs-minutes/week) §				
Low	121	13	1.00	1.00
Moderate	136	9	0.58 (0.24–1.42)	0.64 (0.25–1.65)
High	165	17	0.96 (0.44–2.07)	1.15 (0.48–2.74)
P for linear trend			0.441	0.394
P for quadratic trend			0.613	0.946
Daily walking time (h/d)				
≤0.5	134	17	1.00	1.00
0.5–1	105	6	0.44 (0.17–1.18)	0.42 (0.15–1.23)
1–2	77	4	0.37 (0.12–1.15)	0.40 (0.18–1.36)
>2	88	11	0.98 (0.43–2.24)	1.02 (0.40–2.60)
P for linear trend			0.684	0.512
P for quadratic trend			0.591	0.563

Note. MET, Metabolic Equivalent of Task
*Continuous physical activity volume and daily walking time were analyzed using the logistic regression model to calculate *p* values for the linear trend or *p* values for the quadratic trend. Sensitivity analysis was conducted by excluding the participants with heart disease, stroke, or cancer at baseline.
†Adjustment for age and sex;
‡Adjustment for age, sex, body mass index, smoking status, drinking status, working status, living arrangement, depressive symptoms, and comorbidity index.

Table S1 The Kaigo-Yobo Checklist items

Variables	**Coding**
1. Do you usually stay at home all day long?	Yes = 1, No = 0
2. How often do you usually go out?	More than once per 2-3 days = 0, Less than once a week = 1
3. Do you have any hobby?	Yes = 0, No = 1
4. Do you have neighbors who you can talk closely with?	Yes = 0, No = 1
5. Besides your neighbors, do you have close friends, families, or relatives who you visit?	Yes = 0, No = 1
6. Have you experienced a fall in the past year?	Yes = 1, No = 0
7. Can you walk for 1 km?	Yes = 0, No = 1
8. Can you see things clearly? (with glasses if necessary)	Without difficulty = 0, With difficulty or cannot = 1
9. Do you often slip or stumble at home?	Yes = 1, No = 0
10. Do you refrain from going out because of fear of falling?	Yes = 1, No = 0
11. Have you been hospitalized in the past year?	Yes = 1, No = 0
12. Do you have appetite these days?	Yes = 0, No = 1
13. Do you have any difficulty chewing? (even with a denture)	Yes = 1, No = 0
14. Have you lost 3 kg or more in the past 6 months?	Yes = 1, No = 0
15. Do you think you have lost muscle or fat in the past 6 months?	Yes = 1, No = 0