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Physical activity and/or sedentary behaviour and the development of functional disability in community-dwelling older adults in Tsuru, Japan: a prospective cohort study (the Tsuru Longitudinal Study)

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ABSTRACT

Objectives To clarify the association between moderate-to-vigorous physical activity (MVPA) and/or sedentary behaviour (SB) and the incidence of functional disability (FD) in older adults.

Design Prospective cohort study.

Setting Local municipality of Tsuru, Yamanashi, Japan. We conducted a baseline survey in January 2016. Follow-up was commenced on 1 February 2016 and completed on 31 October 2018.

Participants All individuals (6661 people) aged >65 years who were independently living in the community were eligible.

Methods and outcome measures MVPA (min/week) and SB (min/day) were measured using self-administered questionnaires in 5311 independently living older adults who participated in this study. The follow-up period was 33 months, and the incidence of FD was objectively determined by experts. The participants were divided into three groups based on MVPA distribution (non-MVPA, 0 min; short-MVPA, 1–299 min and long-MVPA, ≥300 min/week) and into two groups based on the median value of SB (short-SB,<190 min; and long-SB, ≥190 min/day). The participants were also classified into six categories based on different combinations of MVPA and SB. Cox proportional hazards model was used to calculate the HR and 95% CI for FD development with MVPA, SB and a combination of these behaviours.

Results Among the included participants, 2415 were male and 2896 were female. The mean ages (SD) of the male and female participants were 74.5 (6.8) and 74.9 (6.9) years, respectively. The total number of participants with chronic conditions was 3489 (65.7%). Using the non-MVPA group as the reference, the multivariable-adjusted HR (95% CI) was 0.68 (0.54 to 0.84) in the short-MVPA group and 0.53 (0.41 to 0.69) in the long-MVPA group. Regarding SB, the short-SB group had an HR of 0.86 (0.71 to 1.03) compared with the long-SB group. The combined behaviour showed the lowest HR in the long-MVPA and short-SB group 0.49 (0.34 to 0.72) and the long-MVPA and long-SB group 0.49 (0.34 to 0.68), respectively.

Conclusions Long-MVPA had a robust association with FD development, whereas short-SB had a modest association. Moreover, a combination of these behaviours had a stronger association than individual behaviours. If the identified associations are assumed to be causal in nature, these findings suggest that encouraging older adults to engage in MVPA and reduce SB in their daily lives could be effective to prevent or delay FD development.

Strengths and limitations of this study

- The data in this study were obtained from a large sample (n=5311) that is highly representative (79.8% response rate) of the entire population of independently living older adults in the local municipality.
- Functional disability incidence was determined objectively by experts and physicians based on multidisciplinary data.
- The applicability of the present results should be limited to municipalities with similar living conditions to those in the study area.
- The validity and reliability of the sedentary behaviour assessment tool used have not been evaluated.

INTRODUCTION

Functional disability (FD), as defined by the WHO,[1] is a crucial and urgent public health issue in several countries.[2] Hence, it is important to identify and evaluate FD-related risk factors for developing efficient preventive measures. A previous systematic review reported that the main risk factors of FD development in older adults involve age, living conditions, socioeconomic status, chronic diseases, body mass index (BMI), mental health and sedentary lifestyle and thus suggested that prevention of FD in older adults should act on these risk factors.[3]

Physical activity (PA) is known to have many health benefits, including a lower incidence of ischaemic heart disease,[4] diabetes,[5] several forms of cancers[6] and musculoskeletal diseases.[7] Moreover, PA has a profoundly positive effect on individuals' mental health.[8] Consequently, these health benefits can contribute to FD prevention. Indeed, a recent review reported that older adults who engage in more moderate-to-vigorous PA (MVPA) demonstrate a lower incidence of FD than those who are physically inactive.[9] Most studies included in that review,[9] however, determined the incidence of FD using self-administered questionnaires focusing on a single dimension of functional ability (such as the basic activity of daily living, instrumental activity of daily living or mobility). Therefore, an objective assessment of FD is necessary for examining and evaluating the total risk factors of FD. Furthermore, the association between sedentary behaviour (SB), an essential facilitator of negative health outcomes,[10] and FD has not been fully investigated. In particular, there is only one study on the joint association of PA and SB with mobility disability, revealing a strong association.[11] However, no study has evaluated the joint association of PA and SB with FD.

This population-based cohort study aimed to examine the association between the incidence of FD and MVPA or SB, including their joint association, using data that can objectively determine FD in a highly representative population of all independently living older adults in a local Japanese community.

METHODS

Study design and participants

The survey area included a local municipality with a population of 31 474 in Tsuru, Yamanashi, Japan. The baseline survey in this study was a complete survey of older adults living independently in this community who were registered in the local government (6661 eligible participants). All questionnaire responders provided informed consents and were included in the study only after their consent was obtained. We provided the following information to each participant on the face sheet of the questionnaire: 'After understanding the explanation regarding this survey, if you agree to participate in this study, please respond to the questionnaire and return it to the following address'. A baseline survey was conducted in January 2016 using a self-administered mailed questionnaire that included questions on demographic variables, PA and SB, lifestyle and health status. Follow-up observation was commenced on 1 February 2016 and completed on 31 October 2018 (follow-up period, 33 months).

Physical activity and sedentary behaviour

We used the Japanese version of the International PA Questionnaire to estimate MVPA (total time per week). A previous study reported the reliability and validity of this questionnaire.[12] The total SB time was calculated by summing the time spent doing five distinct activities—reading, conversations with other family members, PC use, watching TV and other activities that involve lying/sitting positions.

We divided the participants into three groups based on the distribution of MVPA (non-MVPA, 0 min; short-MVPA, 1–299 min and long-MVPA, ≥300 min/week) and into two groups based on the median value of SB (short-SB, <190 min and long-SB, ≥190 min/day). The participants were also classified into six categories based on different combinations of MVPA and SB: (1) non-MVPA×long-SB, (2) non-MVPA× short-SB, (3) short-MVPA×long-SB, (4) short-MVPA×short-SB, (5) long-MVPA×long-SB and (6) long-MVPA×short-SB.

Functional disability

Information on the incidence of FD during the follow-up period was obtained from the local government. The Certification Committee of Needed Long-Term Care performed an objective assessment of the incidence of FD based on the data acquired from home-visit interviews. This assessment was facilitated by certified investigators who implemented a standardised format to evaluate the functional availability in all dimensions and by family physicians in accordance with their written opinions regarding the applicant's physical and mental health status.[13 14] To optimise this process, the Certification Committee meeting was held every 10 days.

Participants with FD were defined as individuals who were certified for the first time by the Certification Committee as people requiring long-term care. The date when participants were certified as functionally disabled by the committee was set as the date when the outcome of FD developed. With regards to the participants who died during the follow-up period, the last day of follow-up was set as the day of hospitalisation, whereas for participants who moved out of the area, the last day of follow-up was defined as the date when the local government was officially notified about the participants' decisions. All participants other than those concerned with these events were confirmed to not have FD on the last day of follow-up.

Survey measurements

Demographic variables included age, sex, educational history and marital status. The choices for educational history were 'elementary school/junior high school', 'high school', 'technical college/junior college/vocational school', 'university/graduate school' and 'others'. The response options for marital status were 'has a spouse', 'separated by death or divorce' and 'others'. For health status, data on height, weight and chronic conditions (hypertension, hyperlipidaemia, diabetes, stroke, heart disease, arthritis and hip fracture) were collected. BMI was calculated from the self-reported height and weight. Chronic conditions refers to a history of any medical treatment received in the past for musculoskeletal, metabolic and circulatory disorders, which are the

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main factors associated with FD in Japanese older adults. The participants were asked to select the applicable disease(s) among the listed diseases for response.

Based on the responses, the participants were accordingly classified into two groups: those who responded 'none of them' as the 'no treatment' group and those who responded 'yes' in more than one disease as the 'with treatment' group. The nutritional status was assessed by the following question 'Did you lose more than 2–3 kg weight in 6 months?', and the participants were classified into two groups according to their answers: those who answered 'yes' as the 'malnourished' group and those who answered 'no' as the 'eutrophic' group. Additionally, data on smoking and drinking habits were collected. Regarding the smoking habit, the participants were asked if they smoked and were provided with the following response options: 'I smoke now', 'I have never smoked' and 'I used to smoke but quit'. Regarding the drinking habit, the participants were asked if they consumed alcohol and were provided with the following response options: 'I don't drink' (including 'I used to drink but quit'), 'Sometimes (less than 3 days a week)' and 'Almost every day'.

Statistical analyses

All missing data (25.9%, 1374/5311) were imputed (50 times) based on the full conditional specification using the demographic variables, health conditions, lifestyle, MVPA and SB.

The Cox proportional hazards model was used to evaluate the relationship between the incidence of FD and MVPA or SB and the combination of these behaviours. The analysis model was applied to 50 sets of imputed data, and the results were merged based on Rubin's method.[15] We calculated the HR and 95% CI for each MVPA, SB and combined group using three models: crude, age-adjusted and sex-adjusted and multivariable-adjusted models. In the multivariable model, the educational background, marital and nutritional statuses, smoking and drinking habits, chronic conditions, BMI and MVPA or SB were adjusted as confounders based on previous studies.[16] We performed sensitivity analyses using the complete case data (n=3937) and the excluded data of participants who developed FD within 6 months from the baseline (n=56). Additionally, the interactions among MVPA, SB and other main confounding factors were examined to evaluate the presence of any potential modification effect on the associations.

IBM SPSS 26.0 for Windows (IBM Corp) was used for statistical analyses, and the significance level was set at p<0.05 on both sides.

Patient and public involvement

There was no patient or public involvement in the study.

RESULTS

Out of 6661 eligible participants, 5311 older adults (response rate, 79.7%) responded to the questionnaire at the baseline and were followed up for 33 months. Among the included participants, 2415 were males and 2896 were females. The mean ages (SD) of the males and females were 74.5 (6.8) and 74.9 (6.9) years, respectively. The total number of participants with medical history was 3489 (65.7%). Of these, 517 participants developed FD, 146 died without FD and 30 moved out during the follow-up period. Figure 1 shows the participants' flow chart.

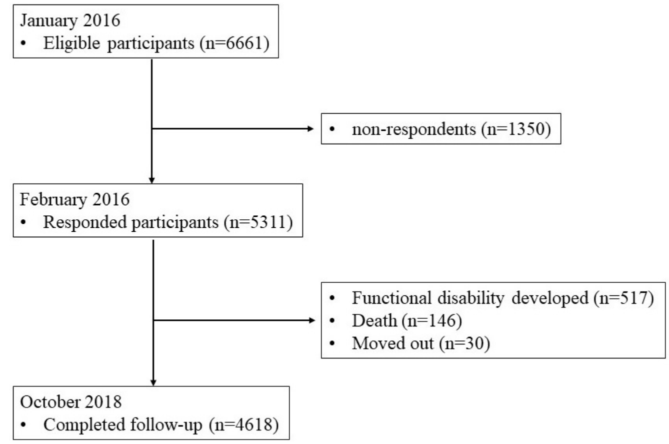

Figure 1 Participants' flow chart.

Table 1 presents the participant characteristics of each group with or without FD. Compared with the participants in the group without FD, those in the group with FD were older and had shorter MVPA time and longer SB time. Further, compared with the group without FD, the group with FD had fewer participants who had a drinking habit and more participants who received medical treatment, were malnourished, and had lower educational background.

Table 2 shows the participant characteristics in each group of MVPA or SB. With regard to the MVPA groups, the mean value (SD) was 144.0 (77.8) min/week in short-MVPA and 760.5 (450.5) min/week in long-MVPA. By contrast, the mean value (SD) of SB was 218.3 (155.6) min/day in non-MVPA, 212.9 (146.5) min/day in short-MVPA and 211.8 (144.3) min/day in long-MVPA. With respect to the SB groups, MVPA was 294.1 (449.4) min/week in long-SB and 309.7 (479.1) min/week in short-SB, whereas SB was 321.6 (115.5) min/day in long-SB and 101.4 (55.2) min/day in short-SB.

Table 3 shows the HRs and 95% CI for the incidence of FD in each group of MVPA and SB. Regarding MVPA, significantly lower HRs (0.34 to 0.68) were observed in short-MVPA and long-MVPA than in non-MVPA in every analytical model. These results revealed negative dose–response relationships between MVPA and the incidence of FD in every model (p for trend <0.001 in each model): a longer MVPA indicated a lower incidence of FD. With SB, short-SB showed significantly lower HRs in crude (0.80) and age-adjusted and sex-adjusted (0.82) models. The adjusted HR for SB in the multivariable analysis was not significant but showed a modest association (0.86, 0.71 to 1.03) with the incidence of FD.

Table 4 shows the HRs and 95% CI for the incidence of FD in each group of combined MVPA and SB. Using

Table 1 Participants' characteristics in each group with or without functional disability (analysis results with multiple imputations)

	Total N=5311	With N=517	Without N=4794
Age, years	74.7 (6.9)	81.4 (6.7)	74.0 (6.5)
Males, (%)	2415 (45.5)	218 (42.2)	2197 (45.8)
Body mass index, kg/m2	22.9 (3.6)	22.7 (4.6)	22.9 (3.5)
MVPA, min/week	301.7 (475.7)	147.0 (393.5)	318.4 (476.9)
Sedentary behaviour, min/day	214.3 (143.8)	235.5 (154.7)	212.0 (142.5)
Smoking habit, (%)			
Non-smoker	3001 (56.5)	296 (57.3)	2705 (56.4)
Former-smoker	1,740 (32.8)	176 (34.0)	1565 (32.6)
Smoker	570 (10.7)	46 (8.7)	524 (11.0)
Drinking habit, (%)			
Non-drinker	3312 (62.4)	371 (71.8)	2941 (61.3)
Occasional-drinker	835 (15.7)	56 (10.8)	780 (16.2)
Frequent-drinker	946 (17.8)	58 (11.2)	888 (18.5)
Former-drinker	218 (4.1)	32 (6.2)	186 (4.0)
Marital status, (%)			
Married	3723 (70.1)	282 (54.5)	3442 (71.8)
Widowed/divorced	1428 (26.9)	228 (44.1)	1200 (25.0)
Unmarried	127 (2.4)	6 (1.2)	121 (2.5)
Other	33 (0.6)	1 (0.2)	32 (0.7)
Nutrition status, (%)			
Poor	853 (16.1)	123 (23.8)	730 (15.2)
Good	4458 (83.9)	394 (76.2)	4064 (84.8)
Educational background, (%)			
Elementary/junior high school	2206 (41.5)	286 (55.3)	1920 (40.1)
High school	2207 (41.5)	146 (28.2)	2061 (43.0)
Tertiary college/junior college	408 (7.7)	30 (5.8)	378 (7.9)
University/graduate school	326 (6.1)	19 (3.7)	307 (6.4)
Other	165 (3.1)	36 (7.0)	129 (2.6)
Chronic conditions (%)			
Yes	3489 (65.7)	413 (79.9)	3076 (64.2)
No	1822 (34.3)	104 (20.1)	1718 (35.8)

Mean (SD), number of people (%).
MVPA, moderate-to-vigorous physical activity.

the combined group of non-MVPA and long-SB as the reference, each combined group exhibited significantly lower HRs in every analytical model and the combined groups with long-MVPA showed the lowest HR among the combined groups, regardless of the SB time. Sensitivity analysis results using the complete data showed almost identical results as the imputed data (online supplemental appendices 1–4). The analysis of the excluded data revealed findings similar to the results (online supplemental appendices 5 and 6). No significant interaction between MVPA and SB was observed (Wald χ^2=0.482; df=2; p<0.01).

DISCUSSION

The main findings of this study were that MVPA showed a strong inverse association with the development of FD in older adults, whereas SB showed a moderate association. Furthermore, the combination of MVPA and SB showed a stronger inverse association than individual behaviours. Among the combined groups, the long-MVPA groups showed the strongest association with the incidence of FD, regardless of SB level. These results suggest that promoting MVPA could be a stronger suppressive measure against the development of FD than decreasing SB and the combination of these

Table 2 Participants' characteristics in each group of moderate-to-vigorous physical activity and sedentary behaviour (analysis results with multiple imputations)

	Moderate-to-vigorous physical activity			Sedentary behaviour	
	Non-MVPA	Short-MVPA	Long-MVPA	Long-SB	Short-SB
	n=1764	n=1704	n=1843	n=2724	n=2587
Age, years	76.1 (7.7)	74.5 (7.0)	73.6 (6.7)	74.7 (7.0)	74.7 (6.8)
Males (%)	748 (42.4)	682 (40.0)	986 (53.5)	1293 (47.5)	1122 (43.3)
Body mass index, kg/m2	23.0 (4.2)	22.8 (3.7)	22.8 (3.2)	23.0 (3.6)	22.7 (3.6)
MVPA, min/week	–	144.0 (77.8)	760.5 (450.5)	294.1(449.4)	309.7 (479.1)
Sedentary behaviour, min/day	218.3 (155.6)	212.9 (146.5)	211.8 (144.3)	321.6 (115.5)	101.4 (55.2)
Smoking habit (%)					
Non-smoker	1005 (57.0)	1019 (59.8)	997 (54.1)	1436 (52.7)	1564 (60.5)
Former smoker	555 (31.4)	528 (31.0)	658 (35.7)	953 (35.0)	787 (30.4)
Smoker	204 (11.6)	158 (9.2)	209 (11.2)	334 (12.3)	236 (9.1)
Drinking habit (%)					
Non-drinker	1173 (66.5)	1115 (65.4)	1024 (55.6)	1680 (61.7)	1632 (63.1)
Occasional drinker	234 (13.3)	271 (15.9)	331 (18.0)	415 (15.2)	421 (16.3)
Frequent drinker	269 (15.2)	260 (15.3)	416 (22.6)	489 (18.0)	457 (17.7)
Former drinker	88 (5.0)	59 (3.4)	71 (3.8)	140 (5.1)	77 (2.9)
Marital status (%)					
Married	1201 (68.1)	1160 (68.1)	1362(73.9)	1726 (63.4)	1997 (77.2)
Widowed/divorced	509 (28.9)	495 (29.0)	424 (23.0)	896 (32.9)	532 (20.6)
Unmarried	40 (2.3)	39 (2.3)	48 (2.6)	88 (3.2)	40 (1.5)
Other	14 (0.7)	10 (0.6)	9 (0.5)	14 (0.5)	19 (0.7)
Nutrition status (%)					
Poor	330 (18.7)	259 (15.2)	264 (14.3)	463 (17.0)	390 (15.1)
Good	1434 (81.3)	1445 (84.8)	1579(85.7)	2261 (83.0)	2197 (84.9)
Education background (%)					
Elementary/junior high school	834 (47.3)	685 (40.2)	688 (37.3)	1067 (39.2)	1139 (44.0)
High school	661 (37.5)	712 (41.8)	833 (45.2)	1143 (42.0)	1064 (41.1)
Tertiary college/junior college	120 (6.8)	144 (8.4)	143 (7.8)	215 (7.9)	193 (7.5)
University/graduate school	81 (4.6)	112 (6.6)	132 (7.2)	206 (7.5)	120 (4.6)
Other	67 (3.8)	51 (3.0)	46 (2.5)	93 (3.4)	72 (2.8)
Chronic conditions (%)					
Yes	1214 (68.8)	1143 (67.1)	1131 (61.4)	1848 (67.8)	1641 (63.4)
No	550 (31.2)	561 (32.9)	711 (38.6)	875 (32.2)	947 (36.6)

Non-MVPA: 0 min/week, short-MVPA: 1–299 min or less per week, long-MVPA: 300 min or more per week, long-SB: 190 min or more per day, short-SB: less than 190 min/day. Mean±SD, number of people (%).
MVPA, moderate-to-vigorous physical activity; SB, sedentary behaviour.

behaviours could be the strongest measure to control the development of FD in older adults compared with individual behaviour.

Our results highlight that older adults with <300 min/week MVPA had a 32% lower risk of developing FD and that older adults with >300 min/week MVPA had a 47% lower risk of developing FD than inactive older adults. These results are consistent with findings from a previous meta-analysis that performed a subjective assessment of the activities of daily living disability.[16] The mean level of MVPA in short-MVPA group was 144.0 min/week, which was approximately the same level as that in the WHO guideline recommendations (≥150 min/week).[17] By contrast, the mean level of MVPA in long-MVPA group was 760.5 min/week, which appears to be extreme for older adults. Consequently, 150 min/week of MVPA should be recommended for older adults at first, which can be gradually increased thereafter. These results were confirmed via sensitivity analyses, which included both the complete case and excluded data.

Table 3 The HR and 95% CI for the incidence of functional disability in each group of moderate-to-vigorous physical activity and sedentary behaviour (analysis results with multiple imputations)

	Number of participants (n)	Number of participants with missing data (n)	Number of cases (n)	Cases per 1000 person-years (n)	Crude HR (95% CI)	Sex/age adjusted HR (95% CI)	Multivariable adjusted HR* (95% CI)
MVPA							
Non-MVPA (0 min)	1764	506	268	61.2	1 (Reference)	1 (Reference)	1 (Reference)
Short-MVPA (≤299 min/week)	1704	381	147	33.2	0.54 (0.43 to 0.67)	0.66 (0.53 to 0.83)	0.68 (0.54 to 0.84)
Long-MVPA (≥300 min/week)	1843	487	103	21.1	0.34 (0.26 to 0.44)	0.49 (0.38 to 0.64)	0.53 (0.41 to 0.69)
P for trend					< 0.001	< 0.001	< 0.001
Sedentary behaviour							
Long-SB (≥190 min/day)	2724	747	292	42	1 (Reference)	1 (Reference)	1 (Reference)
Short-SB (<190 min/day)	2587	627	225	33.4	0.8 (0.66 to 0.95)	0.82 (0.68 to 0.98)	0.86 (0.71 to 1.03)

*Adjusted for age, sex, educational background, marital status, smoking habit, drinking habit, chronic conditions, body mass index, nutrition status and other behaviour (MVPA or SB).
MVPA, moderate-to-vigorous physical activity; SB, sedentary behaviour.

Cohort studies have reported the significant relationship between sitting time and mortality in older adults.[18 19] However, to the best of our knowledge, only one cohort study has examined the association of SB with the incidence of mobility disability in older adults, and the authors reported that the total sitting time did not show a clear association with the development of mobility disability.[11] The present study showed that the multivariable-adjusted HR in short-SB was modestly associated (0.86, 0.71 to 1.03) with the incidence of FD but was not significantly lower than that in the reference group. This result is consistent with the findings of a previous cohort study.[11] However, in the current study, sensitivity analysis using the complete case data showed a significantly lower multivariable-adjusted HR of 0.74 (0.58 to 0.94) (online supplemental appendix 3). These results suggest that the total SB time may be a modest risk factor for the development of FD in older adults, independently of MVPA. However, because

Table 4 The HR and 95% CI for the incidence of functional disability in each group of combined moderate-to-vigorous physical activity and sedentary behaviour (analysis results with multiple imputations)

	Participants (n)	Participants with missing data (n)	Cases (n)	Cases per 1000 person-years (n)	Crude HR (95% CI)	Sex/age Adjusted HR (95% CI)	Multivariable Adjusted HR* (95% CI)
Non-MVPA×long-SB	911	263	153	68.8	1 (Reference)	1 (Reference)	1 (Reference)
Non-MVPA×short-SB	852	242	114	53	0.77 (0.59 to 1.00)	0.79 (0.60 to 1.02)	0.84 (0.64 to 1.10)
Short-MVPA×long-SB	882	220	86	37.9	0.55 (0.41 to 0.73)	0.67 (0.50 to 0.89)	0.69 (0.52 to 0.93)
Short-MVPA×short-SB	822	161	61	28.2	0.4 (0.29 to 0.56)	0.51 (0.37 to 0.71)	0.55 (0.40 to 0.76)
Long-MVPA×long-SB	930	263	53	21.5	0.31 (0.22 to 0.43)	0.45 (0.32 to 0.63)	0.49 (0.34 to 0.68)
Long-MVPA×short-SB	912	223	50	20.6	0.3 (0.20 to 0.43)	0.44 (0.30 to 0.64)	0.49 (0.34 to 0.72)

Non-MVPA: 0 min/week, short-MVPA: 1–299 min or less per week, long-MVPA: 300 min or more per week, long-SB: 190 min or more per day, short-SB: less than 190 min/day.
*Adjusted for age, sex, educational background, marital status, smoking habit, drinking habit, chronic conditions, body mass index and nutrition status.
MVPA, moderate-to-vigorous physical activity; SB, sedentary behaviour.

the complete case data might have been affected by selection bias, future studies are warranted to clarify the association between SB with FD based on data with no selection bias. A previous study reported that TV viewing has a dose–response relationship with the development of mobility disability in older adults,[11] and another study reported that sedentary activities (eg, playing board games, craft activities, reading and computer use) are associated with a lower risk of dementia.[20] These results suggest that the impact of SB on FD should be examined not only for total SBs but for each sedentary activity with its social and cognitive context.

Recently, DiPietro *et al*[11] examined the joint association of PA and SB with the incidence of FD in older adults. A dose–response association between the increasing levels of sitting time in combination with the decreasing levels of PA and mobility disability was observed. The authors reported that individuals with the longest sitting time (≥7 hours/day) and the lowest levels of PA (≤3 hours/week) showed more than a twofold increase in mobility disability compared with the least inactive (<3 hours/day) and the most active (>7 hours/week) reference groups. In the current study, we observed almost the same results as in the previous study on joint association: the combined group of long-MVPA×short-SB showed the lowest HR of 0.49 (0.34 to 0.72) for the incidence of FD among the combined groups. This HR was lower than that of any single behaviour group. Notably, a previous study reported the same HR of 0.49 for cardiovascular disease mortality in the combined group of consistently non-sedentary older individuals with a higher level of PA.[19] This may be because MVPA and SB act as common risk factors for both FD and cardiovascular disease. Our results also showed that two groups with long-MVPA exhibited the same HR, regardless of the length of SB; however, two groups with short-MVPA had different HRs depending on the length of SB: short-MVPA×short-SB, 0.55; short-MVPA×long-SB, 0.69. In this model, we did not observe a significant interaction between MVPA and SB, indicating that the association between SB or MVPA and FD is not modified by the level of MVPA or SB. DiPietro *et al*[11] reported similar findings with regards to the joint associations of PA and sitting time with all-cause mortality. These results, including ours, suggest that the combination of MVPA and SB has a stronger positive association with both FD and mortality than either single behaviour of MVPA or SB in older adults.

The preventive mechanism of PA against the development of FD may be attributed to the positive effects of PA on physical and mental functions. With regards to physical functions, PA in daily life prevents age-related muscle weakness, which leads to a decline in walking ability (walking speed)[20] and narrows the range of daily activity or decreases total energy expenditure.[21] These changes in muscle and daily activities proceed continuously in a negative spiral cycle, the 'cycle of frailty', that eventually facilitates a decline in mobility.[22] Another positive effect of PA involves metabolic syndrome prevention by increasing energy expenditure, improving insulin sensitivity, improving lipid profile and reducing blood pressure.[23] These positive effects can be attributed to lower stroke incidence, which is a major cause of FD in Japanese older adults.[24] Regarding mental functions, studies have reported that PA is associated with reduced decline in cognitive function[25] and reduced incidence of dementia.[26] These protective associations of PA might be attributed to the positive effects of PA on neurotrophic factors, such as inflammatory profile, brain-derived neurotrophic factor, insulin-like growth factor and adiponectin.[23] Consequently, these positive changes can promote neuronal growth and survival, thereby reducing the incidence and progression of neuronal disorders and dementia in older adults.[27]

The strengths of this study are as follows. First, the data in this study were obtained from a large sample (n=5311) that highly represents (79.8%) the entire population of independently living older adults in the local municipality. Second, FD incidence was determined objectively by experts and physicians based on the multidisciplinary data. Third, the relationship between the incidence of FD and MVPA or SB and their joint association was examined. Hence, the results of this study can be considered reliable and useful evidence for developing countermeasures to control the development of FD in older adults.

However, certain limitations of this study must be acknowledged when interpreting the results. First, the participants were recruited from a specific local municipality; thus, the applicability of the present results should be limited to municipalities with similar living conditions, as in the current study area. Second, although the rate of participants with valid responses was high, 20% of all eligible older adults did not respond. Therefore, the present results may be affected to some extent by response bias. Third, as this was an observational study, the results did not demonstrate any cause–effect relationship. Finally, although PA and SB were assessed using standardised assessment tools, survey respondents answered the questions based on his/her memory. Therefore, the present results may be affected to some extent by recall bias. In the future, objective and standardised assessment tools for these behaviours should be used.

CONCLUSIONS

In conclusion, a long-MVPA exhibits a strong inverse association with the development of FD in older adults, whereas a short-SB exhibits a moderate inverse association. Moreover, the combination of MVPA and SB shows a stronger inverse association with the incidence of FD than individual behaviours. If the associations identified in this study are assumed to be causal in nature, these findings suggest that the development and implementation of health policies that encourage people to engage in MVPA and reduce SB in their daily lives could constitute an important strategy for preventing or delaying the development of FD in older adults.

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