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# Impacts of substituting sedentary behavior with physical activity on older adults' depression



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| | |

# Title Page

Title of the article:

Impacts of substituting sedentary behavior with physical activity on older adults' depression

Akitomo Yasunaga[1], Ai Shibata[2], Kaori Ishii[3], Mohammad Javad Koohsari.[3, 4, 5], and Koichiro Oka.[3]

[1] Faculty of Liberal Arts and Sciences, Bunka Gakuen University, Shibuya-ku, Tokyo, Japan

[2] Faculty Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan

[3] Faculty of Sport Sciences, Waseda University, Tokorozawa, Japan

[4] Behavioural Epidemiology Laboratory, Baker Heart and Diabetes Institute, Melbourne, Australia

[5] Mary MacKillop Institute for Health Research, Australian Catholic University, Melbourne, Australia

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Address for correspondence: Akitomo Yasunaga, Faculty of Liberal Arts and Sciences, Bunka Gakuen University, 3-22-1 Yoyogi, Shibuya-ku, Tokyo, Japan

Telephone and Fax number: +81-3-3299-2361 E-mail: yasunaga@bunka.ac.jp

## ABSTRACT

**Objectives** Reducing sedentary behavior (SB) and increasing physical activity (PA) have been shown to be associated with decrease depression. However, there are yet few studies examining the potential benefits on older adults' depression, when SB is replaced with PA. This study aimed to examine the associations of objectively-assessed SB, light-intensity PA (LPA), and moderate-to-vigorous PA (MVPA) with depression among a sample of Japanese older adults, and to explore impacts of substituting SB with PA on older adults' depression.

**Design** Cross-sectional analysis.

**Setting** General community.

**Participants** A total of 276 older adults aged 65–85 years living in Japan.

**Main outcome measures** Three behaviors including the average daily time spent in SB (≤1.5 METs); LPA (>1.5 to <3.0 METs); and MVPA (≥3.0 METs) per day were calculated by accelerometers. Depression was assessed using the Japanese version of the 15-item Geriatric Depression scale (GDS-15).

**Results** Less SB ($\beta$ = 0.129, 95%CI 0.015 to 0.243) and more LPA ($\beta$ = -0.138, 95%CI -0.265 to -0.011) were found to be significantly and negatively associated with the GDS-15 score in the single-activity model. The isotemporal substitution model found that replacing 30 minutes/day of SB with LPA was significantly and negatively associated with the GDS-15 score ($\beta$ = −0.131, 95%CI -0.260 to -0.002).

**Conclusions** These findings indicated that substituting even small amounts of SB with LPA may contribute to less depression in older adults. Potential favorable effects can be observed for replacing only 30 minutes per day of SB with LPA.

*Key words:* active behaviors, mental health, sitting time, objective measurements, aging.

## Article Summary

### Strength and limitations of this study

- The use of accelerometers to objectively measure participants' sedentary and active behaviors was the main strength of this study.

- We examined the impacts of substituting sedentary behavior with physical activity on older adults' depression by using the isotemporal substitution approach.

- As a cross-sectional study, we were unable to infer a cause-and-effect relationship between sedentary behavior, physical activity, and depressive symptoms.

## INTRODUCTION

Regular physical activity (PA), especially moderate-to-vigorous PA (MVPA) (e.g., exercise, sports, and brisk walking), has been found to be associated with less depression among older adults [1,2]. Recent studies have also demonstrated that sedentary behavior (SB) (e.g., television viewing, computer use, and sitting in cars) and light-intensity PA (LPA) (e.g., housework, gardening, and casual walking) are closely related to depression : less SB [3] and more LPA [4] were found to be favorably associated with older adults' depression.

Several recent studies have examined how replacing one activity with another (e.g., replacing SB with LPA or MVPA) can affect various health outcomes such as all-cause mortality and cardiovascular disease using the isotemporal substitution (IS) approach [5,6]. The IS approach enables researchers to simultaneously model a specific activity being performed and an activity being displaced in an equal time-exchange manner [6]. There is only one previous study, in our knowledge, examining the potential benefits on depression, when SB is replaced with LPA or MVPA [7]. Mekary et al. found that replacing 60 minutes/day of television watching with the same time of fast walking was associated with lower depression risk [7]. However, they used self-reported measures of PA and SB, which are subject to recall bias (i.e., lack of accuracy, validity, and reproducibility) [8]. In addition, their sample included middle- and older-aged people. It is not clear yet how replacing SB with other activities may affect depression among a total sample of elderly people.

Therefore, this study aims to examine the associations of objectively-assessed SB, LPA, and MVPA with depression among a sample of Japanese older adults, and to explore impacts of substituting SB with PA on older adults' depression by using the IS approach.

## METHODS

**Participants and Data Collection**

This study used cross-sectional data from a larger epidemiological study conducted in Matsudo city, Japan. A postal survey was sent to 3,000 residents aged 65-85 years who were randomly-selected from the registry of residential addresses. A total number of 349 participants (of 1,250 people who responded to the postal survey) attended in a sub-study, in which PA/SB were objectively calculated. Written informed consent was obtained from all participants.

**Measurements**

Accelerometers (Active style Pro HJA-350IT, Omron Healthcare, Kyoto, Japan) were used to objectively measure participants' PA and SB. The detailed algorithm and validity of the accelerometer device have been described elsewhere [9-11]. The device evaluates the intensity of activity by METs using a built-in algorithm. Participants were guided to wear the accelerometer on their waist for at least 7 days —except when sleeping or during water-based activities. To be included in the study, participants needed to wear the accelerometer for ≥4 days (including 1 weekend day), with at least 10 hour/day of wear time each day (Healy, Matthews, Dunstan, Winkler, & Owen, 2011). Non-wear time was defined as at least consecutive 60 minutes of 0 cpm, with allowance for up to 2 min of some limited movement (<50 cpm) [12]. The daily average time spent on SB (≤1.5 METs), LIPA (>1.5 to <3.0 METs) and MVPA (≥3.0 METs) were calculated. These MET levels have been used by previous studies examining functional decline among older adults [13,14].

Depression was assessed using the Japanese language version of the 15-item Geriatric Depression scale (GDS-15) [15]. The score ranges from 0 to 15 and higher scores indicated stronger depression tendency.

The following individual-level variables were considered as covariates: gender, age,

body mass index, physical function, marital status, and educational attainment. Body mass index was objectively calculated by measuring the participants' height and weight. Physical function was assessed using the Japanese language version of the Medical Outcomes Survey Short Form-8 questionnaire [16].

**Statistical Analysis**

Three multiple linear regression models including a single-activity, a partition, and an IS model were conducted to examine the associations of SB, LPA, and MVPA with depression. Since a 30 minutes was used as a unit for activity, the IS models assessed the effect of replacing a 30-minute of one activity with the equal time of another activity. The single-activity model analyzed each activity component separately (e.g., SB only), without considering the other activity types, adjusting for total wear time and confounders. The model (in the case of SB) is shown as follows:

The GDS-15 score = (b0) SB + (b3) total wear time + (b4) covariates.

The partition model analyzed all the activities simultaneously, without adjusting for total wear time. It is shown as below:

The GDS-15 score = (b0) SB + (b1) LPA + (b2) MVPA + (b4) covariates.

The coefficient for one type of activity represents the effect of increasing this type of activity while holding the other activities constant in this model. The model represents the effects of adding rather than substituting an activity type, because the total wear time is not included in the model (thus is not held constant).

The IS model assessed the effect of substituting one activity type with another for the equal amount of time (e.g., replacing LPA with SB, by removing SB from the model). The IS model (in the case of omitting SB from the model) is shown as follows:

The GDS-15 score = (b1) LPA + (b2) MVPA + (b3) total wear time + (b4) covariates.

The coefficients b1 and b2 in this model represent the effect of a 30 minutes substitution of SB with one of the activity types (LPA, or MVPA), while holding the other activity types and total wear time constant. For instance, b1 can be interpreted as the effect of replacing SB with LPA for 30 minutes, while holding MVPA and total wear time constant.

All analyses were conducted using IBM SPSS Statistics 20.0 for Windows (IBM Japan Corp., Tokyo, Japan), and the level of significance was set at $p < 0.05$.

## RESULTS

After excluding those with missing data (missing covariates and lacking valid PA accelerometer data), data from 276 participants (171 men, 105 women) were analyzed. Table 1 shows the characteristics of study participants. The mean number of valid days of participant's wearing accelerometer was 7.2 days (SD = 0.9). On average, participants wore accelerometers for 15 hours/day, and the mean proportion of SB, LPA, and MVPA times to total accelerometer wearing time were 58%, 36%, and 6%, respectively. Correlation coefficients were −0.68 between SB and LPA, −0.34 between SB and MVPA, and 0.21 between LPA and MVPA. Table 2 shows the results for the single activity, partition, and IS models with adjusting for covariates. The single-activity model shows that LPA was significantly and favorably associated with the GDS-15 score ($\beta$ = −.138, $p < .05$), and SB was significantly and positively associated with the GDS-15 score ($\beta$ = .129, $p < .05$). The partition model showed no significant associations between all activities with the GDS-15 score. The IS model showed that a 30-minutes unit of SB replaced with LPA to be significantly and negatively associated with the GDS-15 score ($\beta$ = −.131, $p < .05$).

## DISCUSSION

This study examined how objectively-measured SB, LPA, and MVPA are associated with

depression among Japanese older adults, and how replacing these behaviors may influence depression. Although many studies suggested that PA has favorable effects on depression in both clinical and non-clinical population [17-19], there is yet no consistent evidence on how PA intensity is effective for less depression. We found less SB and more LPA to be negatively associated with older adults' depression in a single-activity model (including total time held constant). Our findings are consistent with some recent studies that demonstrated the favorable effects of LPA or reducing SB on depression for older adults [4,20,21].

In contrast with some previous studies [22], we did not find any favorable effects of MVPA on depression in the three multiple linear regression models. This may be because of the age group (older adults), which was targeted in the current study. While relatively consistent effects of MVPA on depression among children and adults were reported by previous studies [22], there are mixed findings among older adults [23]. For example, Jung et al. found that LPA was favorably associated with preventing depressive symptoms among older adults, but MVPA was not. Nevertheless, our findings showed that replacing SB with LPA had beneficial effects on older adults' depression [23]. We found that replacing only 30 minutes of SB with equal time of LPA during one day was associated with approximately 5% less depression score. For older adults including physical frail people, it will be effective to reduce SB time and increase LPA that accounts for a large proportion of activities in daily life in order to decrease depression. Among older adults, it may be more practical to increase 30 minutes of LPA per day compared with MVPA. The limitations of this study include its cross-sectional design and the exclusion of contents (e.g. mentally stimulating activity, or different activity) of activity on depression. The strength of this study is the use of accelerometers to objectively measure participants' sedentary and active behaviors.

## CONCLUSION

Our findings indicated that replacing even small amounts of SB (e.g. watching TV and working at a desk) with LPA (e.g. indoor house-work and slow walking) are associated with less depression among older adults. Potential favorable effects were identified for replacing only 30 minutes per day of SB with LPA. These findings are useful in promoting mental health among older adults with better compliance, lower risk of injuries, and long-term sustainability

**Acknoulege**

None.

**Contributers**

All authors contributed equally to this work. Oka: Study concept and design. Yasunaga, Shibata, Ishii, and Oka: Data analysis and interpretation and Statistical analysis. Yasunaga and Koohsari: Drafting of manuscript. Yasunaga, Koohsari, and Oka: Critical revision of manuscript for intellectual content, final approval of version to be published.

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**Cmpeting interest**

None declared.

**Ethics approval**

The study was approved by the Waseda University Institutional Committee on Human Research (2013-265), and the Institutional Review Board of Chiba Prefectural University of Health Sciences (2012-042).

**Data sharing statement**

No additional data sharing available.

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Table 1. Characteristics of study participants

| | n or M (SD), % | |
|---|---|---|
| Gender | | |
| *Women* | 105 | 38.0% |
| Age (years) | 74.4 | 5.3 |
| Body mass index (kg/m$^2$) | 23.5 | 3.2 |
| Physical function | 49.7 | 5.3 |
| Marital status | | |
| *Married* | 228 | 82.6% |
| Educational attainment | | |
| *University, junior college, vocational school, or higher-level degree* | 109 | 39.5% |
| Total accelerometer wear time (min/day) | 902.9 | 86.7 |
| SB (min/day) | 524.6 | 113.3 |
| LPA (min/day) | 328.8 | 101.3 |
| MVPA (min/day) | 50.0 | 32.8 |
| GDS-15 score | 2.8 | 3.0 |

*Note*. SB=Sedentary behavior, LPA=Light-intensity physical activity, MVPA= Moderate-to-vigorous physical activity, GDS-15 = the 15-item Geriatric Depression scale.

Table 2. The associations of SB, LPA, and MVPA with depression

| | SB | | LPA | | MVPA | |
|---|---|---|---|---|---|---|
| | *β* | 95%CI | *β* | 95%CI | *β* | 95%CI |
| Single-activity model | 0.129 | (0.015, 0.243)* | -0.138 | (-0.265, -0.011)* | -0.173 | (-0.530, 0.184) |
| Partition model | 0.101 | (-0.031, 0.233) | -0.030 | (-0.184, 0.124) | -0.011 | (-0.390, 0.367) |
| Isotemporal model | | | | | | |
| Replace SB with | | Dropped | -0.131 | (-0.260, -0.002)* | -0.113 | (-0.473, 0.247) |
| Replace LPA with | 0.132 | (0.003, 0.261)* | | Dropped | 0.020 | (-0.383, 0.422) |
| Replace MVPA with | 0.118 | (-0.242, 0.477) | -0.013 | (-0.395, 0.361) | | Dropped |

*Note*. SB=Sedentary behavior, LPA=Light-intensity physical activity, MVPA=Moderate-to-vigorous physical activity, *β*= Regression coefficients correspond to a 30-minutes increment of each activity, CI= Confidence intervals, * $p < 0.05$.

All models adjusted for gender, age, body mass index, physical function, marital status, educational attainment, and total accelerometer wear time.

| Item | # | Recommendation | Response |
|---|---|---|---|
| **Title and Abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | Yes |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | Yes |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | Yes |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | Yes |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | Yes |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | Yes (see "Participants and Data Collection") |
| Participants | 6 | (*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up<br>*Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls<br>*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants | Yes (see "Participants and Data Collection") |
| | | (*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed<br>*Case-control study*—For matched studies, give matching criteria and the number of controls per case | NA |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | Yes (see "Measurements") |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | Yes (see "Measurements") |
| Bias | 9 | Describe any efforts to address potential sources of bias | Yes (see "Results" for the list of excluded participants) |
| Study size | 10 | Explain how the study size was arrived at | This is a secondary analysis of a study |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | Yes (see "Statistical Analysis") |

| | | | |
|---|---|---|---|
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | Yes (see "Statistical Analysis") |
| | | (*b*) Describe any methods used to examine subgroups and interactions | Yes (see "Statistical Analysis") |
| | | (*c*) Explain how missing data were addressed | Yes (see "Results") |
| | | (*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed<br>*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy | NA |
| | | (*e*) Describe any sensitivity analyses | NA |
| **Results** | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | Yes (see "Results") |
| | | (b) Give reasons for non-participation at each stage | NA |
| | | (c) Consider use of a flow diagram | This is not a complicated study. We think that text explanation is sufficient. |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Yes (see Table 1) |
| | | (b) Indicate number of participants with missing data for each variable of interest | Yes |
| | | (c) *Cohort study*—Summarise follow-up time (eg, average and total amount) | NA |
| Outcome data | 15* | *Cohort study*—Report numbers of outcome events or summary measures over time | NA |
| | | *Case-control study*—Report numbers in each exposure category, or summary measures of exposure | NA |
| | | *Cross-sectional study*—Report numbers of outcome events or summary measures | Yes (see Table 1) |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | We reported only the adjusted estimates in order not to inflate the results with too many estimates. |
| | | (*b*) Report category boundaries when continuous variables were categorized | Yes |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | NA |

| | | | |
|---|---|---|---|
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | NA |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | Yes |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | Yes |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Yes |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | Yes |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | Yes |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

# Cross-Sectional Associations of Sedentary Behavior and Physical Activity on Depression in Japanese Older Adults: An Isotemporal Substitution Approach.

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**Title Page**

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Akitomo Yasunaga[1], Ai Shibata[2], Kaori Ishii[3], Mohammad Javad Koohsari.[3, 4, 5], and Koichiro Oka.[3]

[1] Faculty of Liberal Arts and Sciences, Bunka Gakuen University, Shibuya-ku, Tokyo, Japan

[2] Faculty Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan

[3] Faculty of Sport Sciences, Waseda University, Tokorozawa, Japan

[4] Behavioural Epidemiology Laboratory, Baker Heart and Diabetes Institute, Melbourne, Australia

[5] Mary MacKillop Institute for Health Research, Australian Catholic University, Melbourne, Australia

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Address for correspondence: Akitomo Yasunaga, Faculty of Liberal Arts and Sciences, Bunka Gakuen University, 3-22-1 Yoyogi, Shibuya-ku, Tokyo, Japan

Telephone and Fax number: +81-3-3299-2361 E-mail: yasunaga@bunka.ac.jp

## ABSTRACT

**Objectives** Reducing sedentary behavior (SB) and increasing physical activity (PA) have been shown to be associated with decreased depression. However, there are yet few studies examining the potential benefits on older adults' depression, when SB is replaced with PA. This study aimed to examine the associations of objectively-assessed SB, light-intensity PA (LPA), and moderate-to-vigorous PA (MVPA) with depression among a sample of Japanese older adults, and to explore impacts of substituting SB with PA on older adults' depression.

**Design** Cross-sectional analysis.

**Setting** General community.

**Participants** A total of 276 older adults aged 65–85 years living in Japan.

**Main outcome measures** Three behaviors including the average daily time spent in SB (≤1.5 METs); LPA (>1.5 to <3.0 METs); and MVPA (≥3.0 METs) per day were calculated by accelerometers. Depression was assessed using the Japanese version of the 15-item Geriatric Depression scale (GDS-15).

**Results** Less SB ($\beta$ = 0.129, 95%CI 0.015 to 0.243) and more LPA ($\beta$ = -0.138, 95%CI -0.265 to -0.011) were found to be significantly and negatively associated with the GDS-15 score in the single-activity model. The isotemporal substitution model found that replacing 30 minutes/day of SB with the same amount of LPA was significantly and negatively associated with the GDS-15 score ($\beta$ = −0.131, 95%CI -0.260 to -0.002).

**Conclusions** These findings indicated that substituting even small amounts of SB with LPA may contribute to less depression in older adults. Potential favorable effects can be observed for replacing only 30 minutes per day of SB with LPA.


*Key words:* active behaviors, mental health, sitting time, objective measurements, aging.

## Article Summary

### Strength and limitations of this study

- The use of accelerometers to objectively measure participants' sedentary and active behaviors was the main strength of this study.

- We examined the impacts of substituting sedentary behavior with physical activity on older adults' depression by using the isotemporal substitution approach.

- As a cross-sectional study, we were unable to infer a cause-and-effect relationship between sedentary behavior, physical activity, and depressive symptoms.

## INTRODUCTION

Regular physical activity (PA), especially moderate-to-vigorous PA (MVPA) (e.g., exercise, sports, and brisk walking), has been found to be associated with less depression among older adults [1,2]. Recent studies have also demonstrated that sedentary behavior (SB) (e.g., television viewing, computer use, and sitting in cars) and light-intensity PA (LPA) (e.g., housework, gardening, and casual walking) are closely related to depression : less SB [3] and more LPA [4] were found to be favorably associated with older adults' depression.

Several recent studies have examined how replacing one activity with another (e.g., replacing SB with LPA or MVPA) can affect various health outcomes such as all-cause mortality and cardiovascular disease using the isotemporal substitution (IS) approach [5,6]. For example, a cross-sectional study found the reallocation of 30 minutes/day of SB with equal time of sleep, or LPA, or MVPA to be associated with better cardiovascular risk biomarkers [5]. Another prospective study including a large sample of middle-aged and older adults found that replacing SB with same amount of standing, sleeping (in low sleepers only), walking, or MVPA were associated with the lowest mortality risk [6]. Thus, the IS approach enables researchers to simultaneously model a specific activity being performed and an activity being displaced in an equal time-exchange manner [6]. There are few previous studies examining the potential benefits on depression, when SB was replaced with LPA or MVPA [7,8]. For instance, a prospective study with 10 years follow-up among a large sample of US women found that replacing 60 minutes/day of television viewing time with the same amount of fast walking was associated with a lower depression [7]. Another study examining association between objectively-measured PA and depression demonstrated that replacing 30 minutes/day of SB

with LPA was associated with a lower depression [8]. However, one of these studies used self-reported measures of PA and SB [7], which are subject to recall bias (i.e., lack of accuracy, validity, and reproducibility) [9] and two studies included middle- and older-aged people [7,8]. Hallgren et al. suggested that further research is needed to better understand the complex relationships between PA, SB, and depression [10]. It is not clear yet how replacing SB with PA may affect depression among a total sample of elderly people, especially among Asian older sample.

Therefore, this study aims to examine the associations of objectively-assessed SB, LPA, and MVPA with depression among a sample of Japanese older adults, and to explore impacts of substituting SB with PA on older adults' depression by using the IS approach.

## METHODS

### Participants and Data Collection

This study used cross-sectional data from a larger epidemiological study conducted in Matsudo city, Japan. A postal survey was sent to 3,000 residents aged 65-85 years who were randomly-selected from the registry of residential addresses. A total number of 349 participants (of 1,250 people who responded to the postal survey) attended in a sub-study, in which PA/SB were objectively calculated. Written informed consent was obtained from all participants.

### Measurements

Accelerometers (Active style Pro HJA-350IT, Omron Healthcare, Kyoto, Japan) were used to objectively measure participants' PA and SB. The detailed algorithm and validity of the

accelerometer device have been described elsewhere [11-13]. The device evaluates the intensity of activity by METs using a built-in algorithm. A previous study, in which METs for household and locomotive activities were calculated, reported a linear relationship between filtered synthetic accelerations with PA intensity [12]. Participants were guided to wear the accelerometer on their waist for at least 7 consecutive days —except when sleeping or during water-based activities. To be included in the study, participants needed to wear the accelerometer for ≥4 days (including 1 weekend day), with at least 10 hour/day of wear time each day [14]. Non-wear time was defined as at least consecutive 60 minutes of 0 cpm, with allowance for up to 2 min of some limited movement (<50 cpm) [14]. The daily average time spent on SB (≤1.5 METs), LIPA (>1.5 to <3.0 METs) and MVPA (≥3.0 METs) were calculated. These MET levels have been used by previous studies examining functional decline among older adults [15,16].

Depression was assessed using the Japanese language version of the 15-item Geriatric Depression scale (GDS-15) [17]. GDS-15 questionnaire includes 15 questions about participants' feelings in the past week. For example, "Do you often get bored? Yes / No". The score ranges from 0 to 15 and higher scores indicated stronger depression tendency. The GDS-15 has been widely used to assess depression symptom among older adults all over the world. In this study, the reliability of the GDS-15 (Cranach's alpha) was 0.81.

The following individual-level variables were considered as covariates: gender, age, body mass index, physical function, marital status, and educational attainment. Body mass index was objectively calculated by measuring the participants' height and weight. Physical function was assessed using the Japanese language version of the Medical Outcomes Survey Short Form-8 questionnaire [18].

**Statistical Analysis**

We tested the assumption that replacing SB with PA on may contribute to better older adults' depression. Three multiple linear regression models including a single-activity, a partition, and an IS model were conducted to examine the associations of SB, LPA, and MVPA with depression. Since a 30 minutes was used as a unit for activity, the IS models assessed the effect of replacing a 30-minute of one activity with the equal time of another activity. Many previous studies using IS model have examined the effects of replacing a 30 minute [5,8] or a 60-minute [6,7] unit of SB with equal time of LPA or MVPA on various health outcomes. From the viewpoint of feasibility, replacing 60 minutes a day may be difficult for older adults [19,20], therefore we chose the replacing 30 minutes in this study. The single-activity model analyzed each activity component separately (e.g., SB only), without considering the other activity types, adjusting for total wear time and confounders. The model (in the case of SB) is shown as follows:

The GDS-15 score = (b0) SB + (b3) total wear time + (b4) covariates.

The partition model analyzed all the activities simultaneously, without adjusting for total wear time. It is shown as below:

The GDS-15 score = (b0) SB + (b1) LPA + (b2) MVPA + (b4) covariates.

The coefficient for one type of activity represents the effect of increasing this type of activity while holding the other activities constant in this model. The model represents the effects of adding rather than substituting an activity type, because the total wear time is not included in the model (thus is not held constant).

The IS model assessed the effect of substituting one activity type with another for the equal amount of time (e.g., replacing LPA with SB, by removing SB from the model). The IS model (in the case of omitting SB from the model) is shown as follows:

The GDS-15 score = (b1) LPA + (b2) MVPA + (b3) total wear time + (b4) covariates.

The coefficients b1 and b2 in this model represent the effect of a 30 minutes

substitution of SB with one of the activity types (LPA, or MVPA), while holding the other activity types and total wear time constant. For instance, b1 can be interpreted as the effect of replacing SB with LPA for 30 minutes, while holding MVPA and total wear time constant.

All analyses were conducted using IBM SPSS Statistics 20.0 for Windows (IBM Japan Corp., Tokyo, Japan), and the level of significance was set at $p < 0.05$.

**Patient and Public Involvement statement**

Patients and public were not involved in developing the hypothesis, the specific aims or the research questions, nor were they involved in developing plans for design or implementation of the study.

**RESULTS**

Of 349 participants, data from 276 participants (171 men, 105 women) were analyzed after excluding those with missing data; missing depression (4%) and covariates (0 to 3.7%) and lacking valid PA accelerometer data (12.6%).

Table 1 shows the characteristics of study participants. The mean number of valid days of participant's wearing accelerometer was 7.2 days (SD = 0.9). On average, participants wore accelerometers for 15 hours/day, and the mean proportion of SB, LPA, and MVPA times to total accelerometer wearing time were 58%, 36%, and 6%, respectively. Correlation coefficients were −0.68 between SB and LPA, −0.34 between SB and MVPA, and 0.21 between LPA and MVPA. Table 2 shows the results for the single activity, partition, and IS models with adjusting for covariates. The single-activity model shows that LPA was significantly and favorably associated with the GDS-15 score ($\beta = -.138$, $p < .05$), and SB

was significantly and positively associated with the GDS-15 score ($\beta$ = .129, $p$ < .05). The partition model showed no significant associations between all activities with the GDS-15 score. The IS model showed that a 30-minutes unit of SB replaced with LPA to be significantly and negatively associated with the GDS-15 score ($\beta$ = −.131, $p$ < .05).

## DISCUSSION

This study examined how objectively-measured SB, LPA, and MVPA are associated with depression among Japanese older adults, and how replacing these behaviors may influence depression. Although many studies suggested that PA has favorable effects on depression in both clinical and non-clinical population [21-23], there is currently no consensus regarding the optimal amount of PA needed to treat depression [10]. We found less SB and more LPA to be negatively associated with older adults' depression in a single-activity model (including total time held constant). Our findings are consistent with some recent studies that demonstrated the favorable effects of LPA or reducing SB on depression for older adults [4,24,25].

In contrast with some previous studies [26], we did not find any favorable effects of MVPA on depression in the three multiple linear regression models. This may be because of the age group (older adults), which was targeted in the current study. While relatively consistent effects of MVPA on depression among children and adults were reported by previous studies [26], there are mixed findings among older adults [27]. For example, a randomized controlled trial study with a large sample aged 18 to 71 years reported that the mean reduction in depression scores were significantly larger in the physical exercise and internet-based cognitive-behavioral therapy groups compared with treatment as usual [28,29]. Furthermore, they compared the effects of different exercise intensities on post-treatment

depression severity and found although there were no significant differences among light exercise, moderate-exercise, and vigorous exercise groups at post-treatment; the light exercise group reduced their depression score more than the moderate and vigorous exercise groups [30]. Jung et al. found that LPA was favorably associated with preventing depressive symptoms among older adults, but MVPA was not [27]. Nevertheless, our findings showed that replacing SB with LPA had beneficial effects on older adults' depression. We found that replacing only 30 minutes of SB with equal time of LPA during one day was associated with approximately 5% less depression score. Since our participants were relatively healthy, we did not consider the clinical meaning of decreasing depression score. However, a 5% reduction in depression score leads to 14 out of 62 people with a depression tendency (GDS score is over 5 point) return to normal range (GDS score is from 0 to 4 point). Currently, the evidence-based for the prescription of different PA and exercise intensities for depression is weak [30]. For older adults including physical frail people, however, our results may suggest that it will be effective to reduce SB time and increase LPA that accounts for a large proportion of activities in daily life in order to decrease depression. Among older adults, it may be more practical to increase 30 minutes of LPA per day compared with MVPA.

This study has some limitations. The cause-and-effect relationship between SB, PA, and depression cannot be inferred from a cross-sectional study like ours. In addition, our findings may not be generalizable to the Japanese population, as relatively healthy, active, and well educated older adults appeared to have participated in this study. Thus, we suggest future intervention studies such as randomized controlled trial studies, using more participants and including frailer individuals, are needed in order to provide a more definitive interpretation of the present findings. Further, the context and type of SB was not assessed in this study. SB consists of different types: passive sedentary time (e.g. TV viewing and just sitting) and mentally-active sedentary time (e.g., computer and reading) [31,32]. Several recent

studies have shown that these different types of SB may be differently associated with health outcomes including mental health [31,33]. Such a co-existence of different types of SB may play a role in the observed associations in this study. Further research is needed to explore the effects of replacing different types of SB with LPA and MVPA on depression symptoms. In addition, previous PA levels and exercise participation of participants (i.e. the amount of PA in the past 12 months) were not considered in this study. It is likely that previous amount of PA may affect the current depression status [34]. It is necessary to consider this point in further research. The strength of this study is the use of accelerometers to objectively measure participants' sedentary and active behaviors.

## CONCLUSION

Our findings indicated that replacing even small amounts of SB (e.g. watching TV and working at a desk) with LPA (e.g. indoor house-work and slow walking) are associated with less depression among older adults. Potential favorable effects were identified for replacing only 30 minutes per day of SB with LPA. These findings are useful in promoting mental health among older adults with better compliance, lower risk of injuries, and long-term sustainability

**Acknoulege**

None.

**Contributers**

All authors contributed equally to this work. Oka: Study concept and design. Yasunaga, Shibata, Ishii, and Oka: Data analysis and interpretation and Statistical analysis. Yasunaga and Koohsari: Drafting of manuscript. Yasunaga, Koohsari, and Oka: Critical revision of

manuscript for intellectual content, final approval of version to be published.

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**Cmpeting interest**

None declared.

**Ethics approval**

The study was approved by the Waseda University Institutional Committee on Human Research (2013-265), and the Institutional Review Board of Chiba Prefectural University of Health Sciences (2012-042).

**Data sharing statement**

No additional data sharing available.

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Table 1. Characteristics of study participants

| | n or M (SD), % | |
|---|---|---|
| Gender | | |
| *Women* | 105 | 38.0% |
| Age (years) | 74.4 | 5.3 |
| Body mass index (kg/m$^2$) | 23.5 | 3.2 |
| Physical function | 49.7 | 5.3 |
| Marital status | | |
| *Married* | 228 | 82.6% |
| Educational attainment | | |
| *University, junior college, vocational school, or higher-level degree* | 109 | 39.5% |
| Total accelerometer wear time (min/day) | 902.9 | 86.7 |
| SB (min/day) | 524.6 | 113.3 |
| LPA (min/day) | 328.8 | 101.3 |
| MVPA (min/day) | 50.0 | 32.8 |
| GDS-15 score | 2.8 | 3.0 |

*Note*. SB=Sedentary behavior, LPA=Light-intensity physical activity, MVPA= Moderate-to-vigorous physical activity, GDS-15 = the 15-item Geriatric Depression scale.

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Table 2. The associations of SB, LPA, and MVPA with depression

| | SB | | LPA | | MVPA | |
|---|---|---|---|---|---|---|
| | *β* | 95%CI | *β* | 95%CI | *β* | 95%CI |
| Single-activity model | 0.129 | (0.015, 0.243)* | -0.138 | (-0.265, -0.011)* | -0.173 | (-0.530, 0.184) |
| Partition model | 0.101 | (-0.031, 0.233) | -0.030 | (-0.184, 0.124) | -0.011 | (-0.390, 0.367) |
| Isotemporal model | | | | | | |
| Replace SB with | | Dropped | -0.131 | (-0.260, -0.002)* | -0.113 | (-0.473, 0.247) |
| Replace LPA with | 0.132 | (0.003, 0.261)* | | Dropped | 0.020 | (-0.383, 0.422) |
| Replace MVPA with | 0.118 | (-0.242, 0.477) | -0.013 | (-0.395, 0.361) | | Dropped |

*Note*. SB=Sedentary behavior, LPA=Light-intensity physical activity, MVPA=Moderate-to-vigorous physical activity, *β*= Regression coefficients correspond to a 30-minutes increment of each activity, CI= Confidence intervals, * $p < 0.05$.

All models adjusted for gender, age, body mass index, physical function, marital status, educational attainment, and total accelerometer wear time.

| Item | # | Recommendation | Response |
|---|---|---|---|
| **Title and Abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | Yes (see page 1 and 2; *Title Page* and *Abstract*) |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | Yes (see page 2; *Abstract*) |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | Yes (see page 4-5; *Introduction*) |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | Yes (see page 5; *Introduction*) |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | Yes (see page 6-7; *Statistical Analysis*) |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | Yes (see page 5;*Participants and Data Collection*) |
| Participants | 6 | (*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up<br>*Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls<br>*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants | Yes (see page 5; *Participants and Data Collection*) |
| | | (*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed<br>*Case-control study*—For matched studies, give matching criteria and the number of controls per case | NA |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | Yes (see page5-6; *Measurements*) |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | Yes (see page 5-6; *Measurements*) |
| Bias | 9 | Describe any efforts to address potential sources of bias | Yes (see page 8; "*Result*s" for the list of excluded participants) |
| Study size | 10 | Explain how the study size was arrived at | This is a secondary analysis of a study |

| | | | |
|---|---|---|---|
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | Yes (see page 6-7; *Statistical Analysis*) |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | Yes (see page 6-7; *Statistical Analysis*) |
| | | (*b*) Describe any methods used to examine subgroups and interactions | Yes (see page 6-7; *Statistical Analysis*) |
| | | (*c*) Explain how missing data were addressed | Yes (see page 8; *Results*) |
| | | (*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed<br>*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy | NA |
| | | (*e*) Describe any sensitivity analyses | NA |
| **Results** | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | Yes (see page 8; *Results*) |
| | | (b) Give reasons for non-participation at each stage | NA |
| | | (c) Consider use of a flow diagram | This is not a complicated study. We think that text explanation is sufficient. |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Yes (see page16;*Table 1*) |
| | | (b) Indicate number of participants with missing data for each variable of interest | Yes (see page 8; *Results*) |
| | | (c) *Cohort study*—Summarise follow-up time (eg, average and total amount) | NA |
| Outcome data | 15* | *Cohort study*—Report numbers of outcome events or summary measures over time | NA |
| | | *Case-control study*—Report numbers in each exposure category, or summary measures of exposure | NA |
| | | *Cross-sectional study*—Report numbers of outcome events or summary measures | Yes (see page16;*Table 1*) |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | We reported only the adjusted estimates in order not to inflate the results with too many |

| | | | |
|---|---|---|---|
| | | | estimates. |
| | | (*b*) Report category boundaries when continuous variables were categorized | NA |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | NA |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | NA |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | Yes (see page 11; *Conclusion*) |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | Yes (see page 10-11; *Discussion*) |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Yes (see page 10-11; *Discussion*) |
| | | | |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | Yes (see page 10-11; *Discussion*) |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | Yes (see page 11-12; *Funding*) |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

# Cross-Sectional Associations of Sedentary Behavior and Physical Activity on Depression in Japanese Older Adults: An Isotemporal Substitution Approach.

| | |
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| | |

1

**Title Page**

Title of the article:

Cross-Sectional Associations of Sedentary Behavior and Physical Activity on Depression in Japanese Older Adults: An Isotemporal Substitution Approach.

Akitomo Yasunaga[1], Ai Shibata[2], Kaori Ishii[3], Mohammad Javad Koohsari.[3, 4, 5], and Koichiro Oka.[3]

[1] Faculty of Liberal Arts and Sciences, Bunka Gakuen University, Shibuya-ku, Tokyo, Japan

[2] Faculty Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan

[3] Faculty of Sport Sciences, Waseda University, Tokorozawa, Japan

[4] Behavioural Epidemiology Laboratory, Baker Heart and Diabetes Institute, Melbourne, Australia

[5] Mary MacKillop Institute for Health Research, Australian Catholic University, Melbourne, Australia

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Tables: 2

Address for correspondence: Akitomo Yasunaga, Faculty of Liberal Arts and Sciences, Bunka Gakuen University, 3-22-1 Yoyogi, Shibuya-ku, Tokyo, Japan

Telephone and Fax number: +81-3-3299-2361 E-mail: yasunaga@bunka.ac.jp

## ABSTRACT

**Objectives** Reducing sedentary behavior (SB) and increasing physical activity (PA) have been shown to be associated with decreased depression. However, there are yet few studies examining the potential benefits on older adults' depression, when SB is replaced with PA. This study aimed to examine the associations of objectively-assessed SB, light-intensity PA (LPA), and moderate-to-vigorous PA (MVPA) with depression among a sample of Japanese older adults, and to explore impacts of substituting SB with PA on older adults' depression.

**Design** Cross-sectional analysis.

**Setting** General community.

**Participants** A total of 276 older adults aged 65–85 years living in Japan.

**Main outcome measures** Three behaviors including the average daily time spent in SB (≤1.5 METs); LPA (>1.5 to <3.0 METs); and MVPA (≥3.0 METs) per day were calculated by accelerometers. Depression was assessed using the Japanese version of the 15-item Geriatric Depression scale (GDS-15).

**Results** Less SB ($\beta$ = 0.129, 95%CI 0.015 to 0.243) and more LPA ($\beta$ = -0.138, 95%CI -0.265 to -0.011) were found to be significantly and negatively associated with the GDS-15 score in the single-activity model. The isotemporal substitution model found that replacing 30 minutes/day of SB with the same amount of LPA was significantly and negatively associated with the GDS-15 score ($\beta$ = −0.131, 95%CI -0.260 to -0.002).

**Conclusions** These findings indicated that substituting even small amounts of SB with LPA may contribute to less depression in older adults. Potential favorable effects can be observed for replacing only 30 minutes per day of SB with LPA.


*Key words:* active behaviors, mental health, sitting time, objective measurements, aging.

## Article Summary

### Strength and limitations of this study

- The use of accelerometers to objectively measure participants' sedentary and active behaviors was the main strength of this study.

- We examined the impacts of substituting sedentary behavior with physical activity on older adults' depression by using the isotemporal substitution approach.

- As a cross-sectional study, we were unable to infer a cause-and-effect relationship between sedentary behavior, physical activity, and depressive symptoms.

## INTRODUCTION

Regular physical activity (PA), especially moderate-to-vigorous PA (MVPA) (e.g., exercise, sports, and brisk walking), has been found to be associated with less depression among older adults [1,2]. Recent studies have also demonstrated that sedentary behavior (SB) (e.g., television viewing, computer use, and sitting in cars) and light-intensity PA (LPA) (e.g., housework, gardening, and casual walking) are closely related to depression : less SB [3] and more LPA [4] were found to be favorably associated with older adults' depression.

Several recent studies have examined how replacing one activity with another (e.g., replacing SB with LPA or MVPA) can affect various health outcomes such as all-cause mortality and cardiovascular disease using the isotemporal substitution (IS) approach [5,6]. For example, a cross-sectional study found the reallocation of 30 minutes/day of SB with equal time of sleep, or LPA, or MVPA to be associated with better cardiovascular risk biomarkers [5]. Another prospective study including a large sample of middle-aged and older adults found that replacing SB with same amount of standing, sleeping (in low sleepers only), walking, or MVPA were associated with the lowest mortality risk [6]. Thus, the IS approach enables researchers to simultaneously model a specific activity being performed and an activity being displaced in an equal time-exchange manner [6]. There are few previous studies examining the potential benefits on depression, when SB was replaced with LPA or MVPA [7,8]. For instance, a prospective study with 10 years follow-up among a large sample of US women found that replacing 60 minutes/day of television viewing time with the same amount of fast walking was associated with a lower depression [7]. Another study examining association between objectively-measured PA and depression demonstrated that replacing 30 minutes/day of SB

with LPA was associated with a lower depression [8]. However, one of these studies used self-reported measures of PA and SB [7], which are subject to recall bias (i.e., lack of accuracy, validity, and reproducibility) [9] and two studies included middle- and older-aged people [7,8]. Hallgren et al. suggested that further research is needed to better understand the complex relationships between PA, SB, and depression [10]. It is not clear yet how replacing SB with PA may affect depression among a total sample of elderly people, especially among Asian older sample.

Therefore, this study aims to examine the associations of objectively-assessed SB, LPA, and MVPA with depression among a sample of Japanese older adults, and to explore impacts of substituting SB with PA on older adults' depression by using the IS approach.

## METHODS

### Participants and Data Collection

This study used cross-sectional data from a larger epidemiological study conducted in Matsudo city, Japan. A postal survey was sent to 3,000 residents aged 65-85 years who were randomly-selected from the registry of residential addresses. A total number of 349 participants (of 1,250 people who responded to the postal survey) attended in a sub-study, in which PA/SB were objectively calculated. Written informed consent was obtained from all participants.

### Measurements

Accelerometers (Active style Pro HJA-350IT, Omron Healthcare, Kyoto, Japan) were used to objectively measure participants' PA and SB. The detailed algorithm and validity of the

accelerometer device have been described elsewhere [11-13]. The device evaluates the intensity of activity by METs using a built-in algorithm. A previous study, in which METs for household and locomotive activities were calculated, reported a linear relationship between filtered synthetic accelerations with PA intensity [12]. Participants were guided to wear the accelerometer on their waist for at least 7 consecutive days —except when sleeping or during water-based activities. To be included in the study, participants needed to wear the accelerometer for ≥4 days (including 1 weekend day), with at least 10 hour/day of wear time each day [14]. Non-wear time was defined as at least consecutive 60 minutes of 0 cpm, with allowance for up to 2 min of some limited movement (<50 cpm) [14]. The daily average time spent on SB (≤1.5 METs), LIPA (>1.5 to <3.0 METs) and MVPA (≥3.0 METs) were calculated. These MET levels have been used by previous studies examining functional decline among older adults [15,16].

Depression was assessed using the Japanese language version of the 15-item Geriatric Depression scale (GDS-15) [17]. GDS-15 questionnaire includes 15 questions about participants' feelings in the past week. For example, "Do you often get bored? Yes / No". The score ranges from 0 to 15 and higher scores indicated stronger depression tendency. The GDS-15 has been widely used to assess depression symptom among older adults all over the world. In this study, the reliability of the GDS-15 (Cranach's alpha) was 0.81.

The following individual-level variables were considered as covariates: gender, age, body mass index, physical function, marital status, and educational attainment. Body mass index was objectively calculated by measuring the participants' height and weight. Physical function was assessed using the Japanese language version of the Medical Outcomes Survey Short Form-8 questionnaire [18].

**Statistical Analysis**

We tested the assumption that replacing SB with PA on may contribute to better older adults' depression. First, we confirmed that there are linear associations between PA, SB, and depression score and there was also no multicollinearity between independent variables. And then three multiple linear regression models including a single-activity, a partition, and an IS model were conducted to examine the associations of SB, LPA, and MVPA with depression. Since a 30 minutes was used as a unit for activity, the IS models assessed the effect of replacing a 30-minute of one activity with the equal time of another activity. Many previous studies using IS model have examined the effects of replacing a 30 minute [5,8] or a 60-minute [6,7] unit of SB with equal time of LPA or MVPA on various health outcomes. From the viewpoint of feasibility, replacing 60 minutes a day may be difficult for older adults [19,20], therefore we chose the replacing 30 minutes in this study. The single-activity model analyzed each activity component separately (e.g., SB only), without considering the other activity types, adjusting for total wear time and confounders. The model (in the case of SB) is shown as follows:

The GDS-15 score = (b0) SB + (b3) total wear time + (b4) covariates.

The partition model analyzed all the activities simultaneously, without adjusting for total wear time. It is shown as below:

The GDS-15 score = (b0) SB + (b1) LPA + (b2) MVPA + (b4) covariates.

The coefficient for one type of activity represents the effect of increasing this type of activity while holding the other activities constant in this model. The model represents the effects of adding rather than substituting an activity type, because the total wear time is not included in the model (thus is not held constant).

The IS model assessed the effect of substituting one activity type with another for the equal amount of time (e.g., replacing LPA with SB, by removing SB from the model). The IS model (in the case of omitting SB from the model) is shown as follows:

The GDS-15 score = (b1) LPA + (b2) MVPA + (b3) total wear time + (b4) covariates.

The coefficients b1 and b2 in this model represent the effect of a 30 minutes substitution of SB with one of the activity types (LPA, or MVPA), while holding the other activity types and total wear time constant. For instance, b1 can be interpreted as the effect of replacing SB with LPA for 30 minutes, while holding MVPA and total wear time constant.

All analyses were conducted using IBM SPSS Statistics 20.0 for Windows (IBM Japan Corp., Tokyo, Japan), and the level of significance was set at $p < 0.05$.

**Patient and Public Involvement statement**

Patients and public were not involved in developing the hypothesis, the specific aims or the research questions, nor were they involved in developing plans for design or implementation of the study.

**RESULTS**

Of 349 participants, data from 276 participants (171 men, 105 women) were analyzed after excluding those with missing data; missing depression (4%) and covariates (0 to 3.7%) and lacking valid PA accelerometer data (12.6%). There were no significantly differences in a rate of gender and a mean of age between analysis sample and those with missing data.

Table 1 shows the characteristics of study participants. The mean number of valid days of participant's wearing accelerometer was 7.2 days (SD = 0.9). On average, participants wore accelerometers for 15 hours/day, and the mean proportion of SB, LPA, and MVPA times to total accelerometer wearing time were 58%, 36%, and 6%, respectively. Correlation coefficients were −0.68 between SB and LPA, −0.34 between SB and MVPA, and 0.21

between LPA and MVPA. Table 2 shows the results for the single activity, partition, and IS models with adjusting for covariates. The single-activity model shows that LPA was significantly and favorably associated with the GDS-15 score ($\beta = -.138$, $p < .05$), and SB was significantly and positively associated with the GDS-15 score ($\beta = .129$, $p < .05$). The partition model showed no significant associations between all activities with the GDS-15 score. The IS model showed that a 30-minutes unit of SB replaced with LPA to be significantly and negatively associated with the GDS-15 score ($\beta = -.131$, $p < .05$).

## DISCUSSION

This study examined how objectively-measured SB, LPA, and MVPA are associated with depression among Japanese older adults, and how replacing these behaviors may influence depression. Although many studies suggested that PA has favorable effects on depression in both clinical and non-clinical population [21-23], there is currently no consensus regarding the optimal amount of PA needed to treat depression [10]. We found less SB and more LPA to be negatively associated with older adults' depression in a single-activity model (including total time held constant). Our findings are consistent with some recent studies that demonstrated the favorable effects of LPA or reducing SB on depression for older adults [4,24,25].

In contrast with some previous studies [26], we did not find any favorable effects of MVPA on depression in the three multiple linear regression models. This may be because of the age group (older adults), which was targeted in the current study. While relatively consistent effects of MVPA on depression among children and adults were reported by previous studies [26], there are mixed findings among older adults [27]. For example, a

randomized controlled trial study with a large sample aged 18 to 71 years reported that the mean reduction in depression scores were significantly larger in the physical exercise and internet-based cognitive-behavioral therapy groups compared with treatment as usual [28,29]. Furthermore, they compared the effects of different exercise intensities on post-treatment depression severity and found although there were no significant differences among light exercise, moderate-exercise, and vigorous exercise groups at post-treatment; the light exercise group reduced their depression score more than the moderate and vigorous exercise groups [30]. Jung et al. found that LPA was favorably associated with preventing depressive symptoms among older adults, but MVPA was not [27]. Nevertheless, our findings showed that replacing SB with LPA had beneficial effects on older adults' depression. We found that replacing only 30 minutes of SB with equal time of LPA during one day was associated with approximately 5% less depression score. Since our participants were relatively healthy, we did not consider the clinical meaning of decreasing depression score. However, a 5% reduction in depression score leads to 14 out of 62 people with a depression tendency (GDS score is over 5 point) return to normal range (GDS score is from 0 to 4 point). Currently, the evidence-based for the prescription of different PA and exercise intensities for depression is weak [30]. For older adults including physical frail people, however, our results may suggest that it will be effective to reduce SB time and increase LPA that accounts for a large proportion of activities in daily life in order to decrease depression. Among older adults, it may be more practical to increase 30 minutes of LPA per day compared with MVPA.

This study has some limitations. The cause-and-effect relationship between SB, PA, and depression cannot be inferred from a cross-sectional study like ours. In addition, our findings may not be generalizable to the Japanese population, as relatively healthy, active, and well educated older adults appeared to have participated in this study. Thus, we suggest future intervention studies such as randomized controlled trial studies, using more

participants and including frailer individuals, are needed in order to provide a more definitive interpretation of the present findings. Further, the context and type of SB was not assessed in this study. SB consists of different types: passive sedentary time (e.g. TV viewing and just sitting) and mentally-active sedentary time (e.g., computer and reading) [31,32]. Several recent studies have shown that these different types of SB may be differently associated with health outcomes including mental health [31,33]. Such a co-existence of different types of SB may play a role in the observed associations in this study. Further research is needed to explore the effects of replacing different types of SB with LPA and MVPA on depression symptoms. In addition, previous PA levels and exercise participation of participants (i.e. the amount of PA in the past 12 months) were not considered in this study. It is likely that previous amount of PA may affect the current depression status [34]. It is necessary to consider this point in further research. The strength of this study is the use of accelerometers to objectively measure participants' sedentary and active behaviors.

## CONCLUSION

Our findings indicated that replacing even small amounts of SB (e.g. watching TV and working at a desk) with LPA (e.g. indoor house-work and slow walking) are associated with less depression among older adults. Potential favorable effects were identified for replacing only 30 minutes per day of SB with LPA. These findings are useful in promoting mental health among older adults with better compliance, lower risk of injuries, and long-term sustainability

**Acknoulege**

None.

**Contributers**

All authors contributed equally to this work. Oka: Study concept and design. Yasunaga, Shibata, Ishii, and Oka: Data analysis and interpretation and Statistical analysis. Yasunaga and Koohsari: Drafting of manuscript. Yasunaga, Koohsari, and Oka: Critical revision of manuscript for intellectual content, final approval of version to be published.

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**Cmpeting interest**

None declared.

**Ethics approval**

The study was approved by the Waseda University Institutional Committee on Human Research (2013-265), and the Institutional Review Board of Chiba Prefectural University of Health Sciences (2012-042).

**Data sharing statement**

No additional data sharing available.

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Table 1. Characteristics of study participants

| | n or M (SD), % | |
|---|---|---|
| Gender | | |
| *Women* | 105 | 38.0% |
| Age (years) | 74.4 | 5.3 |
| Body mass index (kg/m$^2$) | 23.5 | 3.2 |
| Physical function | 49.7 | 5.3 |
| Marital status | | |
| *Married* | 228 | 82.6% |
| Educational attainment | | |
| *University, junior college, vocational school, or higher-level degree* | 109 | 39.5% |
| Total accelerometer wear time (min/day) | 902.9 | 86.7 |
| SB (min/day) | 524.6 | 113.3 |
| LPA (min/day) | 328.8 | 101.3 |
| MVPA (min/day) | 50.0 | 32.8 |
| GDS-15 score | 2.8 | 3.0 |

*Note*. SB=Sedentary behavior, LPA=Light-intensity physical activity, MVPA= Moderate-to-vigorous physical activity, GDS-15 = the 15-item Geriatric Depression scale.

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Table 2. The associations of SB, LPA, and MVPA with depression

| | SB | | LPA | | MVPA | |
|---|---|---|---|---|---|---|
| | *β* | 95%CI | *β* | 95%CI | *β* | 95%CI |
| Single-activity model | 0.129 | (0.015, 0.243)* | -0.138 | (-0.265, -0.011)* | -0.173 | (-0.530, 0.184) |
| Partition model | 0.101 | (-0.031, 0.233) | -0.030 | (-0.184, 0.124) | -0.011 | (-0.390, 0.367) |
| Isotemporal model | | | | | | |
| Replace SB with | | Dropped | -0.131 | (-0.260, -0.002)* | -0.113 | (-0.473, 0.247) |
| Replace LPA with | 0.132 | (0.003, 0.261)* | | Dropped | 0.020 | (-0.383, 0.422) |
| Replace MVPA with | 0.118 | (-0.242, 0.477) | -0.013 | (-0.395, 0.361) | | Dropped |

*Note*. SB=Sedentary behavior, LPA=Light-intensity physical activity, MVPA=Moderate-to-vigorous physical activity, *β*= Regression coefficients correspond to a 30-minutes increment of each activity, CI= Confidence intervals, * $p < 0.05$.

All models adjusted for gender, age, body mass index, physical function, marital status, educational attainment, and total accelerometer wear time.

| Item | # | Recommendation | Response |
|---|---|---|---|
| **Title and Abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | Yes (see page 1 and 2; *Title Page* and *Abstract*) |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | Yes (see page 2; *Abstract*) |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | Yes (see page 4-5; *Introduction*) |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | Yes (see page 5; *Introduction*) |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | Yes (see page 6-7; *Statistical Analysis*) |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | Yes (see page 5;*Participants and Data Collection*) |
| Participants | 6 | (*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up<br>*Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls<br>*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants | Yes (see page 5; *Participants and Data Collection*) |
| | | (*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed<br>*Case-control study*—For matched studies, give matching criteria and the number of controls per case | NA |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | Yes (see page5-6; *Measurements*) |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | Yes (see page 5-6; *Measurements*) |
| Bias | 9 | Describe any efforts to address potential sources of bias | Yes (see page 8; "*Result*s" for the list of excluded participants) |
| Study size | 10 | Explain how the study size was arrived at | This is a secondary analysis of a study |

| | | | |
|---|---|---|---|
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | Yes (see page 6-7; *Statistical Analysis*) |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | Yes (see page 6-7; *Statistical Analysis*) |
| | | (*b*) Describe any methods used to examine subgroups and interactions | Yes (see page 6-7; *Statistical Analysis*) |
| | | (*c*) Explain how missing data were addressed | Yes (see page 8; *Results*) |
| | | (*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed<br>*Case-control study*—If applicable, explain how matching of cases and controls was addressed<br>*Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy | NA |
| | | (*e*) Describe any sensitivity analyses | NA |
| **Results** | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | Yes (see page 8; *Results*) |
| | | (b) Give reasons for non-participation at each stage | NA |
| | | (c) Consider use of a flow diagram | This is not a complicated study. We think that text explanation is sufficient. |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Yes (see page16;*Table 1*) |
| | | (b) Indicate number of participants with missing data for each variable of interest | Yes (see page 8; *Results*) |
| | | (c) *Cohort study*—Summarise follow-up time (eg, average and total amount) | NA |
| Outcome data | 15* | *Cohort study*—Report numbers of outcome events or summary measures over time | NA |
| | | *Case-control study*—Report numbers in each exposure category, or summary measures of exposure | NA |
| | | *Cross-sectional study*—Report numbers of outcome events or summary measures | Yes (see page16;*Table 1*) |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | We reported only the adjusted estimates in order not to inflate the results with too many |

| | | | |
|---|---|---|---|
| | | | estimates. |
| | | (*b*) Report category boundaries when continuous variables were categorized | NA |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | NA |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | NA |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | Yes (see page 11; *Conclusion*) |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | Yes (see page 10-11; *Discussion*) |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Yes (see page 10-11; *Discussion*) |
| | | | |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | Yes (see page 10-11; *Discussion*) |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | Yes (see page 11-12; *Funding*) |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.