Association of Sedentary and Physically-Active Behaviors With Cognitive-Function Decline in Community-Dwelling Older Adults: Compositional Data Analysis From the NEIGE Study

Shiho Amagasa1, Shigeru Inoue1, Hiroshi Murayama2, Takeo Fujiwara3, Hiroyuki Kikuchi1, Noritoshi Fukushima1, Masaki Machida1, Sebastien Chastin4,5, Neville Owen6,7, and Yugo Shobugawa8,9

1Department of Preventive Medicine and Public Health, Tokyo Medical University, Tokyo, Japan
2Institute of Gerontology, The University of Tokyo, Tokyo, Japan
3Department of Global Health Promotion, Tokyo Medical and Dental University, Tokyo, Japan
4School of Health and life Science, Institute of Applied Health Research, Glasgow Caledonian University, Glasgow, United Kingdom
5Department of Sport and Movement Science, Ghent University, Ghent, Belgium
6Behavioral Epidemiology Laboratory, Baker Heart & Diabetes Institute, Melbourne, Victoria, Australia
7Centre for Urban Transitions, Swinburne University of Technology, Melbourne, Victoria, Australia
8Division of International Health, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan
9Department of Active Ageing, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan

ABSTRACT

Background: Physical activity can help to protect against cognitive decline in older adults. However, little is known about the potential combined relationships of time spent in sedentary behavior (SB), light-intensity physical activity (LPA), and moderate-to-vigorous physical activity (MVPA) with indices of cognitive health. We examined the cross-sectional associations of objectively-determined sedentary and physically-active behaviors with an indicator of cognitive function decline (CFD) in older adults.

Methods: A randomly-recruited sample of 511 Japanese older adults (47% male; aged 65–84 years) wore a tri-axial accelerometer for 7 consecutive days in 2017. Cognitive function was assessed by interviewers using the Japanese version of Mini-Mental State Examination, with a score of ≤23 indicating CFD. Associations of sedentary and physically-active behaviors with CFD were examined using a compositional logistic regression analysis based on isometric log-ratio transformations of time use, adjusting for potential confounders.

Results: Forty one (9.4%) of the participants had an indication of CFD. Activity compositions differed significantly between CFD and normal cognitive function (NCF); the proportion of time spent in MVPA was 39.1% lower, relative to the overall mean composition in those with CFD, and was 5.3% higher in those with NCF. There was a significant beneficial association of having a higher proportion of MVPA relative to other activities with CFD. LPA and SB were not associated with CFD when models were corrected for time spent in all activity behaviors.

Conclusions: Larger relative contribution of MVPA was favorably associated with an indicator of CFD in older adults.

Key words: accelerometer; aging; exercise; sedentary lifestyle; neurocognitive disorders

INTRODUCTION

Dementia is an increasing public health concern worldwide.1 A meta-analysis of the global literature on the prevalence of dementia estimated that 35.6 million people lived with dementia across the world in 2010, with numbers expected to almost double every 20 years, to 65.7 million in 2030 and 115.4 million in 2050.2 High prevalence of dementia also represents a huge global economic cost.3 Effective preventive strategies are urgently needed.

Physical activity can help in preventing the onset of dementia and decline of cognitive function. However, some studies have identified protective effects,4,5 whereas many have shown no apparent benefits.6–8 Sedentary behavior (SB; time spent sitting) may have a deleterious effect on cognitive health.9–11 Longer time spent in SB has been found to be associated with poorer cognitive function in older adults, but this association was attenuated after taking into account moderate-to-vigorous physical activity (MVPA).11 Light-intensity physical activity (LPA) has also been examined in this context.12,13 A longitudinal study indicated longer time spent in LPA may prevent cognitive decline, after controlling for time spent in MVPA.12 Such studies of the relationships of sedentary and physically-active behaviors with indices of cognitive health have included basic statistical

Address for correspondence. Shigeru Inoue, MD, PhD, Department of Preventive Medicine and Public Health, Tokyo Medical University, 6-1-1 Shinjuku, Shinjuku-ku, Tokyo 160-8402, Japan (e-mail: inoue@tokyo-med.ac.jp).

DOI http://doi.org/10.2188/jea.JE20190141
HOMEPAGE http://jeaweb.jp/english/journal/index.html

JE20190141-1
adjustment for time spent in the other behaviors. The combined relationships of time spent in SB and intensity-specific physical activity with cognitive health remain to be examined.

Time is finite during the day, and activity behaviors are not independent. Compositional data analysis (CoDa) allows the examination of co-dependence of time spent in all behaviors arising within a day or part of the day. For example, if time spent in MVPA increases or decreases, this can influence the time spent in SB and LPA. Findings obtained using basic statistical adjustment for physical activity have differed from those of studies using CoDa. Conventional statistical models can be misleading, with some effects being over- or under-estimated. To date, no previous study has investigated a role of each activity behavior with indices of cognitive health when time spent in other activities is taken into account.

We examined the associations of objectively-determined SB, LPA, and MVPA with cognitive function in community-dwelling older adults using the CoDa approach. We also explored relationships of bout-length specific MVPA with an index of cognitive function.

METHODS

Study sample and data collection
This cross-sectional study was a part of the Neuron to Environmental Impact across Generations (NEIGE) study. Participants were community-dwelling older adults without long-term care in Tokamachi city, Niigata Prefecture, Japan. Tokamachi is a rural city located in the southernmost region of Niigata Prefecture (area: 590.4 km²; population: 54,515, as of February 8, 2018). A total of 1,346 residents (aged 65–84 years) were selected from a resident registry using stratified random sampling. In the fall of 2017, we conducted a questionnaire survey and health examination to 527 participants who agreed to enroll in NEIGE study, and at the same time they were asked to wear an accelerometer. Detailed methods have been reported elsewhere.

The University Ethics Committee (Niigata University and Tokyo Medical University) granted ethics approval. Written informed consent was obtained from all participants.

Assessment of activity behaviors (independent variable)
Participants were instructed to wear an accelerometer, the Active style Pro HJA-750C (Omron Healthcare, Kyoto, Japan), over the waist on an elasticated belt for 7 consecutive days while awake, except during water-based activities (eg, swimming and hot springs). Active style Pro is a validated accelerometer. Only use of medication for subarachnoid hemorrhage and the use of medication for hypertension, dyslipidemia, and diabetes. Body mass index (BMI) was calculated from height and weight (kg/m²) measured using a body composition analyzer MC-780A (TANITA Corporation, Tokyo, Japan).

Statistical analyses
R version 3.5.2 (R Foundation for Statistical Computing, Vienna, Austria) was used to perform all statistical analyses. We used R package ‘compositions’, ‘robCompositions’, and ‘zCompositions’ for CoDa approach. Statistical significance was set at $P < 0.05$.

The chi-square test, Fisher’s exact test, or t-test was performed to compare participant characteristics between those who with CFD and normal cognitive function (NCF). We adopted a CoDa approach, as detailed in previous research. Variability in the data, in terms of variability of each behavior relative to the variability of other behaviors, was described through a variation matrix. A log ratio expectation-maximization algorithm was used to impute zeros in compositional data sets, since zero does not allow for log-ratio transformation. One participant (0.2%) and 138 (27.0%) participants had no time spent in MVPA and bouted MVPA, respectively. We graphically described the difference of activity behaviors by cognitive status to initially appraise the relative differences between these groups. To support the graphical interpretation, we used multivariate analysis of variance (MANOVA) to test whether the activity compositions significantly differed overall between CFD and NCF.
for the first ilr transformations for SB, LPA, and MVPA. When analyzed the associations of bout-specific MVPA with CFD, we reworked the ilr transformations using four activities (SB, LPA, sporadic MVPA, and bouted MVPA). Model 1 was unadjusted. Model 2 was adjusted for gender and age. Model 3 was additionally adjusted for socio-demographic and behavioral factors, including residential area, educational attainment, working status, living arrangement, and BMI. Model 4 was additionally adjusted for past history of stroke and the use of medication for hypertension, dyslipidemia, and diabetes. If activity behaviors were found to be significantly associated with CFD, we estimated percent change in being CFD when fixed durations of time were reallocated from one part of a particular composition to another, while the remaining parts were kept constant.33,34

RESULTS

Participant enrollment and descriptive statistics

Of the 527 older adults who agreed to wear an accelerometer (response rate: 39.2%), 16 were excluded for: not meeting accelerometer wearing time criteria (n = 13), hospitalization (n = 2), and accelerometer system error (n = 1). The final analytic sample was 511 in this study.

Table 1 presents the characteristics of the participants. Overall, the mean age was 73.4 (standard deviation [SD], 5.6) years (53.0% women) and mean value of accelerometer wear time was 887.7 (SD, 108.3) min/day. Participants spent 445.6 (SD, 129.8) min/day in SB, 388.8 (SD, 103.0) min/day in LPA, 52.4 (SD, 39.9) min/day in MVPA. 48 (9.4%) older adults had CFD. Compared to NCF, those identified with CFD were significantly more likely to be older age and non-workers, and to have experienced stroke. There was no significant difference in the proportion of those adhering to global physical activity guidelines (NCF: 23.3%, CFD: 12.5%).

Table 3 shows the variation matrix indicating the dispersion of each behavior. The highest log-ratio variances all involved MVPA, which indicated that time spent in MVPA was the least co-dependent on the other behaviors. The largest variability was observed in ratio of MVPA to SB.

The activity composition of the day grouped by CFD status is presented in Figure 1. The MANOVA test showed a statistically significant difference in time-use activity composition between those with CFD and those with NCF. The proportion of time spent in total MVPA was reduced by 39.1% relative to the overall mean composition in CFD, while that was increased by 5.3% in NCF, the proportion of SB was higher by 7.4% and that of LPA was lower by 4.5%, relative to the mean composition. When looking at differences of bout-specific MVPA, participants with CFD had 37% less sporadic MVPA and 62% less bouted MVPA.

Associations of sedentary and physically-active with cognitive function

Results of multiple logistic regression models are presented in Table 3. In both unadjusted and adjusted models, longer proportion of time spent in total MVPA was significantly associated with lower odds of CFD (model 4; Odds ratio [OR] 0.59; 95% confidential interval [CI], 0.36–0.94). Proportion of time spent in LPA (OR 2.19; 95% CI, 0.66–7.74) and SB (OR 1.06; 95% CI, 0.42–2.72) relative to the other behaviors were not associated with cognitive function. In bout-specific analysis, no significant associations were observed in both sporadic MVPA

**Table 1. Participant’s characteristics by cognitive status**

|                | CFD  | NCF |
|----------------|------|-----|
| Gender, n (%)  |      |     |
| Men            | 23 (47.9) | 217 (46.6) |
| Age, years     | 77.6 (5.4) | 73.0 (6.4) |
| Residential area, city side | 24 (50.0%) | 243 (52.5%) |
| Education, ≥13 years | 7 (14.6%)  | 94 (20.3%)  |
| Living arrangement, with others | 41 (85.4%)  | 425 (91.8%)  |
| Working status, working | 10 (20.8%)  | 203 (43.8%) |
| Body mass index, kg/m² | 22.5 (2.9) | 22.9 (3.6) |
| Alcohol use, yes | 25 (52.1%) | 251 (54.2%) |
| Smoking, yes   | 3 (6.3%)  | 41 (8.9%)  |
| Use of medication, yes | 28 (58.3%) | 208 (44.9%) |
| Hypertension   | 14 (29.2%) | 158 (34.1%) |
| Dyslipidemia   | 5 (10.4%)  | 46 (9.9%)  |
| Diabetes       | 9 (18.8%)  | 33 (7.1%)  |
| Physical activity guidelines, meeting | 6 (12.5%)  | 108 (23.3%) |
| Accelerometer wear time, min/day | 880.9 (159.9) | 887.4 (100.5) |
| Activity time, arithmetic mean |         |      |
| SB, min/day    | 476.2 (153.9) | 442.4 (126.8) |
| LPA, min/day   | 370.9 (109.7) | 390.7 (102.2) |
| Total MVPA, min/day | 33.8 (30.2) | 54.3 (40.3) |
| sporadic MVPA, min/day | 26.6 (20.5) | 39.2 (25.9) |
| bouted MVPA, min/day | 7.2 (14.8) | 15.1 (22.1) |

**Table 2. Variation matrix of time spent in activity behaviors**

|                  | SB     | LPA    | MVPA   |
|------------------|--------|--------|--------|
| SB               | 0      |        |        |
| LPA              | 0.273  | 0      |        |
| MVPA             | 1.299  | 0.789  | 0      |

LPA, light-intensity physical activity; MVPA, moderate-to-vigorous physical activity; NCF, normal cognitive function; SB, sedentary behavior; SD, standard deviation. P-value was calculated using χ² test, χ²-hisquare test, or Fisher’s exact test, as appropriate.

DISCUSSION

The proportion of time spent in MVPA relative to other behaviors (SB and LPA) was favorably associated with an index of cognitive function decline in our sample of community-dwelling older adults, even when time spent in other activity behaviors was taken into account. However, the proportion of time spent in bout-specific MVPA, LPA, and SB relative to the other behaviors were not associated with CFD when models were corrected for time spent in all activity behaviors. The current study adds novel evidence to the emerging body of research on physical activity and cognitive health using CoDa.

In this study, MVPA but not LPA had a significant association with CFD. These results are in line with previous studies
indicating that intensity of physical activity may be of importance for better cognitive function.\textsuperscript{35,36} Physical activity intensity (peak counts), as measured by accelerometry, was found to be associated with better cognitive performance in older Australian adults.\textsuperscript{35} A study with older Japanese adults with MCI found device-based moderate physical activity but not LPA to be associated with hippocampal volume.\textsuperscript{36} Findings from randomized trials suggest that moderate-intensity exercise increases hippocampal perfusion\textsuperscript{37} and the size of hippocampus\textsuperscript{38} among healthy older adults. Although LPA makes much larger contribution to energy expenditure than MVPA in the older population,\textsuperscript{28} higher intensity of physical activity may be needed for maintaining cognitive health.

To date, the associations of SB with cognitive function have been inconsistent; some have suggested unfavorable associations,\textsuperscript{9,10} while others have suggested no associations.\textsuperscript{11,39} This inconsistency could be partly due to the differences of statistical approach. Most previous studies did not accurately control for time spent in other activities (ie, LPA and MVPA) when analyzing the effect of SB. Sufficient levels of MVPA may attenuate associations of SB with cognitive health.\textsuperscript{11} Another potential reason is that different types of SB have different impacts on cognitive function.\textsuperscript{40,41} A prospective cohort study with a large sample of United Kingdom adults showed television viewing and driving time to be unfavorably associated with cognitive decline, whereas non-occupational computer use was found to be favorably associated.\textsuperscript{40} There is also evidence that higher volumes of time spent in computer use and lower volumes of television viewing time can be related to better cognitive performance.\textsuperscript{41} Domain-specific SB, as distinct from overall sedentary time, should thus be considered in examining relationships with cognitive health.

Table 3. Associations of sedentary and physically-active behaviors with cognitive function in older adults

| Activity behaviors | Model 1 OR (95% CI) | Model 2 OR (95% CI) | Model 3 OR (95% CI) | Model 4 OR (95% CI) |
|--------------------|---------------------|---------------------|---------------------|---------------------|
| SB                 | 1.30 (0.63, 2.70)   | 1.03 (0.46, 2.27)   | 0.90 (0.36, 2.20)   | 0.96 (0.38, 2.39)   |
| LPA                | 1.55 (0.61, 3.92)   | 1.34 (0.51, 3.83)   | 2.04 (0.65, 6.74)   | 1.84 (0.58, 6.18)   |
| MVPA               | 0.49 (0.33, 0.74)   | 0.71 (0.45, 1.12)   | 0.55 (0.32, 0.91)   | 0.57 (0.33, 0.96)   |
| sporadic MVPA      | 0.64 (0.34, 1.19)   | 0.85 (0.44, 1.68)   | 0.67 (0.33, 1.36)   | 0.67 (0.33, 1.37)   |
| bouted MVPA        | 0.87 (0.68, 1.11)   | 0.93 (0.72, 1.29)   | 0.91 (0.70, 1.18)   | 0.93 (0.71, 1.20)   |

LPA, light-intensity physical activity; MVPA, moderate-to-vigorous physical activity; OR, odds ratio; SB, sedentary behavior.

Model 1: crude model.
Model 2: adjusted for gender and age.
Model 3: adjusted for model 2+ education, body mass index, living arrangement, working status, smoking, and alcohol use.
Model 4: adjusted for model 3+ past history of stroke, and medication for hypertension, dyslipidemia, and diabetes.

Note. Isometric log-ratio (ilr) transformation was used in compositional logistic regression analyses. The odds ratio corresponds to one increase ilr coordinates.

Figure 1. Composition of the day by cognitive status.
Compositional analysis of the relative importance of the group mean time spent in SB, LPA and MVPA with respect to the overall mean time composition. In the left axis presents the log-ratio value and the right axis displays the actual proportion relative to the mean composition (eg, 1.053 means 1.053 times the compositional mean or a proportion higher by 5.3%). LPA, light-intensity physical activity; MVPA, moderate-to-vigorous physical activity; SB, sedentary behavior.
Strengths and limitations
We have reported novel findings on the relationships of older adult’s sedentary and physically-active behaviors with an indicator of CFD, through an explicit consideration of the co-dependence of time-use domains. Also, we conducted objective assessments of both sedentary and physically-active behaviors and cognitive function. Compared to self-report which involves reporting bias, device-based assessment using accelerometers can provide more accurate and reliable understanding of activity behaviors.42,43

The most important limitation in our study was the cross-sectional design, which does not allow us to infer any causal relationship. Longitudinal studies using CoDa approach are required to establish the links of sedentary and physically active behaviors with cognitive health. Another limitation was that the Active style Pro device cannot detect sleep, which can be associated with cognitive impairment.44 Although evidence of decline in cognitive function was objectively assessed using MMSE-J, which is valid and commonly used to screen dementia, further research using medical diagnose are needed to more accurately detect those who with dementia. There is also the need to consider selection bias. Accelerometry responders can be healthier and more active than non-responders,45 which would influence the generalizability of the present findings.

In conclusion, objectively measured time spent in MVPA, taking into account SB and LPA, was favorably associated with cognitive function in community-dwelling older adults. On the other hand, time spent in bout-specific MVPA, LPA, and SB relative to time spent in other behaviors were not associated with cognitive function when our models controlled for time spent in all activity behaviors. The shift of time from any behavior toward any form of MVPA (bouted or sporadic) is therefore likely to be beneficial for cognitive health. Our findings also suggest intensity of physical activity may be important for preventing cognitive decline. Further research using CoDa are needed to confirm our conclusions.

ACKNOWLEDGEMENTS
We express our sincere thanks to all the participants who enrolled in the NEIGE study and those who supported this research. This study was funded by grant from ‘the Policy Research Institute, Ministry of Agriculture, Forestry and Fisheries in Japan’ and ‘the Pfizer Health Research Foundation’, and by JSPS KAKENHI Grant Number 16H03249, 17K19794, 18K10829, and 19H03910. Shiho Amagasa is supported by JSPS Research Fellowships for Young Scientists. Neville Owen is supported by National Health and Medical Research Council of Australia (NHMRC) Senior Principal Research Fellowship, a NHMRC Centre for Research Excellence Grant and by the Victorian Government’s Operational Infrastructure Support Program.

Conflicts of interest: None declared.

REFERENCES
1. Livingston G, Sommerlad A, Orgeta V, et al. Dementia prevention, intervention, and care. Lancet. 2017;390(10113):2673–2734.
2. Prince M, Bryce R, Albanese E, Wimo A, Ribeiro W, Ferri CP. The global prevalence of dementia: a systematic review and meta-analysis. Alzheimers Dement. 2013;9(1):63–75.e2.
3. Wimo A, Jönsson L, Bond J, Prince M, Winblad B; Alzheimer Disease International. The worldwide economic impact of dementia 2010. Alzheimers Dement. 2013;9(1):1–11.e3.
4. Blondell SJ, Hammersley-Mather R, Veerman JL. Does physical activity prevent cognitive decline and dementia?: a systematic review and meta-analysis of longitudinal studies. BMC Public Health. 2014;14:510.
5. Plassman BL, Williams JW Jr, Burke JR, Holsinger T, Benjamin S. Systematic review; factors associated with risk for and possible prevention of cognitive decline in later life. Ann Intern Med. 2010;
6. Sabia S, Dugravot A, Dartigues JF, et al. Physical activity, cognitive decline, and Alzheimer’s disease: 28 year follow-up of Whitehall II cohort study. BMJ. 2017;357:j2079.

7. Brasure M, Desai P, Davila H, et al. Physical activity interventions in preventing cognitive decline and Alzheimer-type dementia: a systematic review. Ann Intern Med. 2018;168(1):30–38.

8. Kivimäki M, Singh-Manoux A, Pentti J, et al. Physical inactivity, cardiometabolic disease, and risk of dementia: an individual-participant meta-analysis. BMJ. 2019;365:l1495.

9. Fulck RS, Davis JC, Liu-Ambrose T. What is the association between sedentary behaviour and cognitive function? A systematic review. Br J Sports Med. 2017;51(10):800–811.

10. Wheeler MJ, Dempsey PC, Grace MS, et al. Sedentary behavior as a risk factor for cognitive decline? A focus on the influence of glycemic control in brain health. Alzheimers Dement. 2017;3(3):291–300.

11. Edwards MK, Loprinzi PD. The association between sedentary behavior and cognitive function among older adults may be attenuated with adequate physical activity. J Phys Act Health. 2017;14(1):52–58.

12. Lee S, Yuki A, Nishita Y, et al. Research relationship between light-intensity physical activity and cognitive function in a community-dwelling elderly population—an 8-year longitudinal study. J Am Geriatr Soc. 2016;61(3):452–453.

13. Johnson LG, Butson ML, Polman RC, et al. Light physical activity is positively associated with cognitive performance in older community dwelling adults. J Sci Med Sport. 2016;19(11):877–882.

14. Chastin SF, Palarea-Albaladejo J, Döntje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. PLoS One. 2015;10(10):e0139984.

15. Dumuid D, Stanford TE, Martin-Fernández JA, et al. Compositional data analysis for physical activity, sedentary time and sleep research. Stat Methods Med Res. 2018;27(12):3726–3738.

16. Gupta N, Mathiassen SE, Mateu-Figueras G, et al. A comparison of standard and compositional data analysis in studies addressing group differences in sedentary behavior and physical activity. Int J Behav Nutr Phys Act. 2018;15(1):53.

17. Shobugawa Y, Murayama H, Fujiwara T, Inoue S. Cohort profile of the NEIGE study in Tokamachi city, Japan. J Epidemiol. 2019 (in press).

18. Ohkawara K, Oshima Y, Hikihara Y, Ishikawa-Takata K, Tabata I, Tanaka S. Real-time estimation of daily physical activity intensity by a triaxial accelerometer and a gravity-removal classification algorithm. Br J Nutr. 2011;105(11):1681–1691.

19. Oshima Y, Kawaguchi K, Tanaka S, et al. Classifying household activity and sleep on obesity and cardio-metabolic health markers: a novel compositional approach. Chemom Intell Lab Syst. 2016;153(3):182–193.

20. Park J, Ishikawa-Takata K, Tanaka S, Bessyo K, Tanaka S, Kimura K. Real-time estimation of daily physical activity intensity: findings from the NEIGE study in Tokamachi city, Japan. J Epidemiol. 2019;143:85–96.

21. Dumuid D, Pedišić Ž, Stanford TE, et al. The compositional isotemporal substitution model: a method for estimating changes in a health outcome for reallocation of time between sleep, physical activity and sedentary behaviour. Stat Methods Med Res. 2019;28(3):846–857.

22. Fairclough SJ, Dumuid D, Taylor S, et al. Fitness, fatness and the reallocation of time between children’s daily movement behaviours: an analysis of compositional data. Int J Behav Nutr Phys Act. 2017;14(1):64.

23. Brown BM, Peiffer JJ, Sohrabi HR, et al. Intense physical activity is associated with cognitive performance in the elderly. Transl Psychiatry. 2012;2:e191.

24. Makizako H, Liu-Ambrose T, Shimada H, et al. Moderate-intensity physical activity, hippocampal volume, and memory in older adults with mild cognitive impairment. J Gerontol A Biol Sci Med Sci. 2015;70(4):480–486.

25. Burdette JH, Lauriентi PJ, Espeland MA, et al. Using network science to evaluate exercise-associated brain changes in older adults. Proc Natl Acad Sci USA. 2011;108(7):3017–3022.

26. Ćukić I, Shaw R, Der G, et al. Cognitive ability does not predict objectively measured sedentary behavior: Evidence from three older cohorts. Psychol Aging. 2018;33(2):288–296.

27. Bakkarania K, Edvardson CL, Khunti K, Bandelow S, Davies MJ, Yates T. Associations between sedentary behaviors and cognitive function: cross-sectional and prospective findings from the UK biobank. Am J Epidemiol. 2018;187(3):441–454.

28. Kesse-Guyot E, Chareire H, Andreeva VA, et al. Cross-sectional and longitudinal associations of different sedentary behaviors with cognitive performance in older adults. Front Aging Neurosci. 2010;2:23.

29. Trost SG, Mclver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. Med Sci Sports Exerc. 2005;37(11(Suppl)):S531–S543.

30. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc. 2008;40(1):181–188.

31. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Med Sci Sports Exerc. 2007;39(8):1423–1434.

32. Pate RR, O’Neill JR, Lobelo F. The evolving definition of “sedentary”. Exerc Sport Sci Rev. 2008;36(4):173–178.

33. Amagasa S, Fukushima N, Kikuchi H, Takamiya T, Oka K, Inoue S. Light and sporadic physical activity overlooked by current guidelines makes older women more active than older men. Int J Behav Nutr Phys Act. 2017;14(1):59.

34. Sugishita M, Hemmi I, Takeuchi T. Reexamination of the validity and reliability of the Japanese version of the Mini-Mental State Examination (MMSE-J). Japanese Journal of Cognitive Neuroscience. 2016;18(3–4):168–183.

35. Folstein MF, Folstein SE, McHugh PR. “Mini–mental state”: A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975;12(3):193–198.

36. Aitchison J. The statistical analysis of compositional data. J R Stat Soc B. 1982;44(2):139–160.

37. Palarea-Albaladejo J, Martín-Fernández JA. zCompositions—R package for multivariat imputation of left-censored data under a compositional approach. Chemom Intell Lab Syst. 2015;143:85–96.

38. Dumuid D, Pedisič Ž, Stanford TE, et al. The compositional isotemporal substitution model: a method for estimating changes in a health outcome for reallocation of time between sleep, physical activity and sedentary behaviour. Stat Methods Med Res. 2019;28(3):846–857.

39. Fairclough SJ, Dumuid D, Taylor S, et al. Fitness, fatness and the reallocation of time between children’s daily movement behaviours: an analysis of compositional data. Int J Behav Nutr Phys Act. 2017;14(1):64.

40. Brown BM, Peiffer JJ, Sohrabi HR, et al. Intense physical activity is associated with cognitive performance in the elderly. Transl Psychiatry. 2012;2:e191.

41. Makizako H, Liu-Ambrose T, Shimada H, et al. Moderate-intensity physical activity, hippocampal volume, and memory in older adults with mild cognitive impairment. J Gerontol A Biol Sci Med Sci. 2015;70(4):480–486.

42. Burdette JH, Laurientii PJ, Espeland MA, et al. Using network science to evaluate exercise-associated brain changes in older adults. Proc Natl Acad Sci USA. 2011;108(7):3017–3022.

43. Ćukić I, Shaw R, Der G, et al. Cognitive ability does not predict objectively measured sedentary behavior: Evidence from three older cohorts. Psychol Aging. 2018;33(2):288–296.

44. Bakkarania K, Edvardson CL, Khunti K, Bandelow S, Davies MJ, Yates T. Associations between sedentary behaviors and cognitive function: cross-sectional and prospective findings from the UK biobank. Am J Epidemiol. 2018;187(3):441–454.

45. Kesse-Guyot E, Chareire H, Andreeva VA, et al. Cross-sectional and longitudinal associations of different sedentary behaviors with cognitive performance in older adults. Front Aging Neurosci. 2010;2:23.

46. Sallis JS, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. Res Q Exer Sport. 2000;71(sup2):1–14.

47. Shepard RJ, Tudor-Locke C. The Objective Monitoring of Physical Activity: Contributions of Accelerometry to Epidemiology, Exercise Science and Rehabilitation. Springer International Publishing; 2016.

48. Bubu OM, Brannick M, Mortimer J, et al. Sleep, cognitive impairment, and Alzheimer’s disease: a systematic review and meta-analysis. Sleep. 2016;40(1).

49. Inoue S, Ohyya Y, Odagiri Y, et al. Characteristics of accelerometer respondents to a mail-based surveillance study. J Epidemiol. 2010;20(6):446–452.