Sleep Health 8 (2022) 701–704

Contents lists available at ScienceDirect

Sleep Health

Journal of the National Sleep Foundation

journal homepage: sleephealthjournal.org

Time spent in physical activity, sedentary behavior, and sleep: Associations with self-rated sleep quality in middle-aged and older adults

Amy Hofman, MSc[a], Trudy Voortman, PhD[a], Mohammad Arfan Ikram, PhD[a], Annemarie I. Luik, PhD[a,b*]

[a] Department of Epidemiology, Erasmus MC, University Medical Center Rotterdam, Rotterdam, the Netherlands
[b] Department of Child and Adolescent Psychiatry/Psychology, Erasmus MC, University Medical Center Rotterdam, Rotterdam, the Netherlands

ARTICLE INFO

Article History:
Received 15 February 2022
Revised 19 May 2022
Accepted 20 June 2022

Keywords:
Compositional data analysis
Isotemporal substitution
Sleep quality
Accelerometry
Population-based

ABSTRACT

Objectives: We examined the associations of estimated allocations of time spent in physical activity, sedentary behavior and sleep with self-rated sleep quality.
Methods: Between 2011 and 2016, 1918 participants (mean age 71 ± 9 years, 51% women) from the population-based Rotterdam Study were included. Durations of light physical activity, moderate-to-vigorous physical activity, sedentary behavior, and sleep were assessed by accelerometry, self-rated sleep quality with the Pittsburgh Sleep Quality Index. Associations were assessed with compositional isotemporal substitution analyses.
Results: Spending 30 minutes more in sedentary behavior (adjusted mean difference in PSQI score: 0.21, 95% confidence interval [0.15; 0.28] or in light physical activity (adjusted mean difference in PSQI score: 0.25 [0.03; 0.46], and 30 minutes less in sleep, was associated with poorer sleep quality.
Conclusions: Our findings suggest reducing sedentary behavior and increasing sleep duration might be a potential intervention target to improve sleep quality in this population of middle-aged and older adults.

Introduction

Perceived poor sleep quality is common in middle-aged and older adults and improving sleep quality has been suggested as an important factor in promoting general health.[1,2] Increasing physical activity and reducing sedentary behavior might improve sleep quality,[3,4] but these behaviors have mainly been studied as single exposures, not taking into account that the durations of physical activity, sedentary behavior and sleep occur in the context of the 24-hour day.[3-5] Consequently, an increase in time spent on one behavior must be offset by time spent on other behavior. To explain how this is related to perceived sleep quality and which allocations of time might help improve perceived sleep quality, we studied the full 24-hour composition of activity behaviors and sleep in a population of middle-aged and older adults.

Compositional isotemporal substitution analyses account for the 24-hour constrained nature of activity behaviors and sleep[5] and enable estimating the effect of substituting time spent on one behavior (eg, physical activity) by another (eg, sleep) on the outcome of interest. We used these methods to examine how estimated allocation of time spent on light physical activity, moderate-to-vigorous physical activity, sedentary behavior, and sleep were associated with self-rated sleep quality. These findings will inform which allocations of time should receive particular interest in promoting sleep quality.

Participants and methods

Study design and population

This cross-sectional study was performed within the population-based Rotterdam Study, a prospective cohort of participants aged 45 years and over.[6] The Rotterdam Study has been approved by the Medical Ethics Committee of Erasmus MC University Medical Center (registration number MEC 02.1015) and by the Dutch Ministry of Health, Welfare and Sport (Population Screening Act WBO, license number 1071272-159521-PG). All participants provided written informed consent.

Between 2011 and 2016, a random subsample of 2778 participants were invited to wear an accelerometer for 7 consecutive days and nights, of which 2338 (84%) agreed. Of these, we included 1918 participants who had accelerometer data (≥4 days of ≥1200 mins/d)

*Corresponding author: Annemarie I. Luik, PhD, P.O. Box 2040, 3000 CA Rotterdam, the Netherlands. Tel.: +31 107032183; fax: +31 107044657.
E-mail address: a.luik@erasmusmc.nl (A.I. Luik).

https://doi.org/10.1016/j.sleh.2022.06.009

with no technical errors, sleep diary data, and a Pittsburgh Sleep Quality Index (PSQI).

The Rotterdam Study has been approved by the Medical Ethics Committee of the Erasmus MC (registration number MEC 02.1015) and by the Dutch Ministry of Health, Welfare and Sport (Population Screening Act WBO, license number 1071272-159521-PG). The Rotterdam Study Personal Registration Data collection is filed with the Erasmus MC Data Protection Officer under registration number EMC1712001. The Rotterdam Study has been entered into the Netherlands National Trial Register (NTR; www.trialregister.nl) and into the WHO International Clinical Trials Registry Platform (ICTRP; www.who.int/ictrp/network/primary/en/) under shared catalogue number NTR6831. All participants provided written informed consent to participate in the study and to have their information obtained from treating physicians.

Measurements

Physical activity, sedentary behavior, and sleep duration

Participants wore a triaxial accelerometer (GeneActiv; Activinsights Ltd, Kimbolton, UK) on the non-dominant wrist and simultaneously filled out a sleep diary details are published elsewhere.[7] Accelerometer data were processed using PAMPRO software in Python (2.6.6). Activity was categorized based on acceleration relative to gravity (g units; 1g = 9.81 m/s^2) into durations of sedentary time (<48 mg), light (48-154 mg), and moderate-to-vigorous (>154 mg) physical activity.[8] Night-time sleep duration was estimated using the validated GGIR algorithm, version 1.6-7.[9] Sleep duration was subtracted from total sedentary time to estimate sedentary behavior (in and out of bed). Sedentary behavior was additionally divided into sedentary time in bed (ie, time spent awake during the nocturnal sleep period) and out of bed based on the sleep diary.

Sleep quality

Sleep quality was measured using the 19-item PSQI, which measures sleep quality and disturbance over the past month.[10] The global score (range 0-21, higher scores indicate poorer sleep quality) is the sum of 7 subscale scores (range 0-3): subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleep medication, and daytime drowsiness.

Other variables

During a home interview, self-reported age and sex, living situation (living alone or living with partner), education (primary, lower, intermediate, or higher education according to the UNESCO classification), paid employment (currently employed or currently not employed), smoking (current, former, or never smoker), alcohol use (drinks per day), and depressive symptoms (Center for Epidemiological Studies Depression Scale[11]) were assessed.

During a research center visit, height and weight were measured on calibrated scales to calculate body mass index. Information on several chronic diseases (history of cancer, coronary heart disease, stroke and diabetes)and medication use (psycholeptics and psychoanaleptics) was obtained from both self-report and by linking medical records from general practitioners and pharmacies in the study area.

Statistical analysis

Based on the average daily durations of light physical activity, moderate-to-vigorous physical activity, sedentary behavior, and sleep, a compositional variable was constructed using the "Compositions" package in R. This variable is expressed in isometric log ratio coordinates and represents the proportions of time spent in each activity.[5]

Linear and logistic regression models were used to assess the associations of the composition of activity behaviors and sleep with the PSQI total score and subscales.[5,12] Subscales were analyzed as dichotomous outcomes (≤1 vs. ≥2), due to the ordinal nature and skewed distribution. The compositional isotemporal substitution models were used to estimate the difference in outcome when a fixed duration of 30 minutes of time spent on one behavior (eg, physical activity) was instead spent in another behavior (eg, sleep), while other behaviors remained constant.[5]

Analyses were adjusted for age, sex, and covariates mentioned above. Multiple imputation (m = 5) was used to impute missing data on covariates (<2%). We included sedentary time in and out of bed as separate components of the compositions to assess whether time awake in bed was driving associations that included sedentary behavior. Data were handled and analyzed using SPSS Statistics version 24.0.0.1 (IBM Corp., Armonk, NY) and R version 3.5.1 (The R Foundation for Statistical Computing, Vienna, Austria), using the mice, compositions and deltacomp packages.

Table 1
Age- and sex-adjusted and confounder-adjusted results of isotemporal substitution analyses for sleep quality

		30 mins more..							
		Sleep		Sedentary behavior		Light PA		Moderate-to-vigorous PA	
		Age- and sex-adjusted model							
Replacing..	Sleep			**0.21**	**0.15, 0.28**	**0.25**	**0.03, 0.46**	0.13	-0.13, 0.38
	Sedentary behavior	**-0.20**	**-0.27, -0.14**			0.03	-0.19, 0.25	-0.09	-0.34, 0.15
	Light PA	-0.25	-0.52, 0.01	-0.05	-0.32, 0.21			-0.14	-0.63, 0.35
	Moderate-to-vigorous PA	-0.10	-0.47, 0.28	0.10	-0.26, 0.47	0.14	-0.42, 0.70		
		Confounder-adjusted model							
	Sleep			**0.21**	**0.15, 0.27**	**0.27**	**0.06, 0.48**	0.11	-0.13, 0.36
Replacing..	Sedentary behavior	**-0.20**	**-0.26, -0.14**			0.05	-0.15, 0.26	-0.10	-0.34, 0.13
	Light PA	**-0.28**	**-0.53, -0.03**	-0.08	-0.33, 0.17			-0.18	-0.65, 0.28
	Moderate-to-vigorous PA	-0.08	-0.44, 0.28	0.12	-0.23, 0.47	0.18	-0.36, 0.71		

PA, physical activity.
Bold indicates a significant association ($P < .05$).
Values represent the estimated differences in the outcome (Pittsburgh Sleep Quality Index) between the mean composition of the study population and a new composition, for example, in which 30 minutes more times were spent in sleep and 30 minutes less in sedentary behavior (while light and moderate-to-vigorous physical activity were unchanged). The confounder adjusted model was adjusted for age, sex, living situation, educational level, employment, body mass index, history of cancer, coronary heart disease, stroke and diabetes, use of psycholeptics and psychoanaleptics, smoking status and alcohol use.

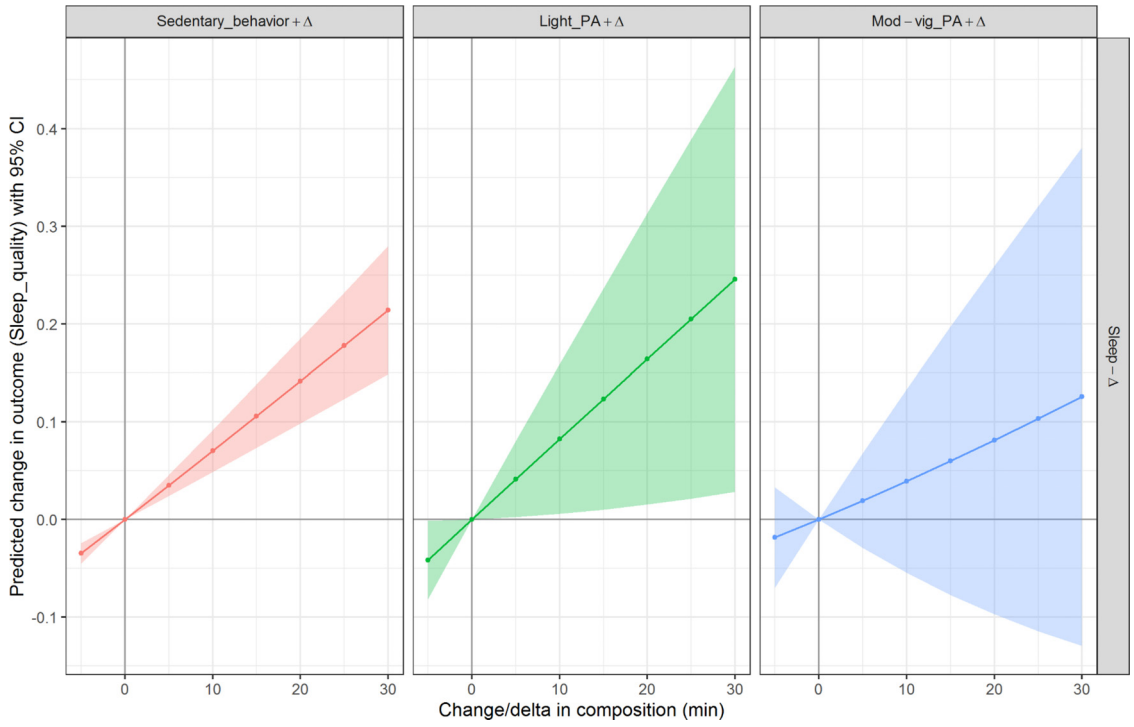

Fig. 1. Age- and sex adjusted results of isotemporal substitution analyses for sleep quality.

Plots represent the estimated differences in the outcome (Pittsburgh Sleep Quality Index) when sleep time is reallocated by sedentary behavior (left graph), light physical activity (middle graph) or moderate-to-vigorous physical activity (right graph). The mean composition of the population was used as reference. PA, physical activity; Mod-vig, moderate-to-vigorous; CI, confidence interval; min, minutes.

Results

In this sample (mean age 71 ± 9 years, 51% women, see Supplementary Table A), spending 30 minutes more time in sedentary behavior (adjusted mean difference: 0.21, 95% confidence interval [0.15; 0.28]) or in light physical activity (adjusted mean difference: 0.25 [0.03; 0.46]), and 30 minutes less in sleep, was associated with a higher PSQI score, indicating poorer sleep quality (Table 1, Fig. 1). More sedentary time out of bed instead of sleep was similarly associated with poorer sleep quality as total sedentary behavior (adjusted mean difference: 0.28 [0.21; 0.34] ; Supplementary Table C). More sedentary time in bed instead of light physical activity was associated with better perceived sleep quality (adjusted mean difference: -0.44 [-0.71; -0.16], Supplementary Table C).

Regarding the PSQI subscales, spending 30 minutes more sedentary behavior and 30 minutes less sleep was significantly associated with higher odds of poorer perceived sleep quality (odds ratio [OR]: 1.10 [1.04; 1.16]), sleep duration (OR: 1.17 [1.13; 1.21]) and sleep efficiency (OR: 1.06 [1.01; 1.12]), and with higher odds of daytime drowsiness (OR: 1.13 [1.00; 1.28], Supplementary Table B). Additionally, 30 minutes more light physical activity instead of 30 minutes more sleep was also associated with higher odds of poorer perceived sleep quality (OR: 1.26 [1.04; 1.52]) and sleep duration (OR: 1.15 [1.04; 1.27]) . Lastly, spending 30 minutes more in moderate-to-vigorous physical activity and 30 minutes less in sleep was associated with lower perceived sleep duration (OR: 1.15 [1.02; 1.28]). No other associations were found.

Discussion

Spending more time in sedentary behavior or light physical activity and less time in sleep was associated with poorer sleep quality in this population of middle-aged and older adults. Associations of estimated reallocations of time spent in sleep were similar for most quantitative measures of sleep (sleep quality, sleep duration and sleep efficiency) and daytime drowsiness., No associations with sleep latency, sleep disturbances and use of sleep medication were found.

Consistent with other observational studies,[4,13] less sedentary time was associated with a better sleep quality, but only when that time was used for sleep, and not any other activities. The association of sedentary time with poorer sleep quality could not be explained merely by more sedentary time in bed, suggesting that sleep research and interventions should focus beyond reducing sleep onset latency and wake after sleep onset. In contrast, more sedentary time in bed was associated with better perceived sleep quality in our sample. This could be due to sedentary time in bed being used for relaxing activities, which might positively affect perceived sleep quality,[14] or due to more sedentary time in bed signaling that one has spent enough time in bed to acquire needed sleep (i.e., no sedentary time in bed may indicate that the sleep window is too short). Otherwise, we could speculate that this finding can be explained by using accelerometry, as it might denote periods as wake although these might not be experienced as such.[15] Additionally, although we used a high sensitivity threshold, awake time in bed may have been overestimated.[9]

Contrary to previous literature, we did not find any associations between moderate-to-vigorous physical activity and self-rated sleep quality,[3] but previous studies typically did not take sleep duration into account. We could speculate that persons who perform more physical activity are generally more aware of their health and lifestyle, including sleep. Therefore, the effect of physical activity on sleep quality might have been overestimated and is likely not a target for improving sleep quality in this age group.

Several limitations should be considered, such as the cross-sectional design of the study, the underestimation of certain physical activity behaviors by accelerometry (eg, cycling),[16] and lack of information on other dimensions of behaviors, for example, context or

timing. Also, accelerometry is not the gold standard for determining sleep.

Conclusions

Spending more time in sedentary behavior or light physical activity instead of sleep, but not instead of any other activities, is associated with a poorer sleep quality. Overall, this suggests that mainly sedentary behavior, as opposed to physical activity, is a potential intervention target in this population of middle-aged and older adults, but only if replaced by sleep.

Declaration of conflict of interest

The authors have no conflict of interest to disclose.

Funding

The Rotterdam Study is funded by Erasmus Medical Center and Erasmus University, Rotterdam, Netherlands Organization for the Health Research and Development (ZonMw), the Research Institute for Diseases in the Elderly (RIDE), the Ministry of Education, Culture and Science, the Ministry for Health, Welfare and Sports, the European Commission (DG XII), and the Municipality of Rotterdam.

Data availability statement

Data can be obtained upon request. Requests should be directed toward the management team of the Rotterdam Study (secretariat.epi@erasmusmc.nl), which has a protocol for approving data requests. Because of restrictions based on privacy regulations and informed consent of the participants, data cannot be made freely available in a public repository.

Acknowledgments

We acknowledge the dedication, commitment, and contribution of the inhabitants, general practitioners, and pharmacists of the Ommoord district who took part in the Rotterdam Study. We acknowledge Frank van Rooij as data manager and Brenda C.T. Kieboom as study coordinator. We thank Jolande Verkroost-van Heemst for her invaluable contribution to the collection of the data.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.sleh.2022.06.009.

References

1. Irwin MR. Why sleep is important for health: a psychoneuroimmunology perspective. *Annu Rev Psychol*. 2015;66:143–172.
2. Crowley K. Sleep and sleep disorders in older adults. *Neuropsychol Rev*. 2011;21(1):41–53. https://doi.org/10.1007/s11065-010-9154-6.
3. Kredlow MA, Capozzoli MC, Hearon BA, Calkins AW, Otto MW. The effects of physical activity on sleep: a meta-analytic review. *J Behav Med*. 2015;38(3):427–449.
4. Vancampfort D, Stubbs B, Firth J, et al. Sedentary behaviour and sleep problems among 42,489 community-dwelling adults in six low-and middle-income countries. *J Sleep Res*. 2018;27(6):e12714.
5. 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.
6 Ikram MA, Brusselle G, Ghanbari M, et al. Objectives, design and main findings until 2020 from the Rotterdam Study. *Eur J Epidemiol*. 2020;35:483–517.
7. Koolhaas CM, van Rooij FJA, Schoufour JD, et al. Objective measures of activity in the elderly: distribution and associations with demographic and health factors. *J Am Med Dir Assoc*. 2017;18(10):838–847.
8. White T, Westgate K, Wareham NJ, Brage S. Estimation of physical activity energy expenditure during free-living from wrist accelerometry in UK adults. *PLoS One*. 2016;11(12): e0167472.
9. Van Hees VT, Sabia S, Anderson KN, et al. A novel, open access method to assess sleep duration using a wrist-worn accelerometer. *PloS One*. 2015;10(11): e0142533.
10. Buysse DJ, Reynolds III CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res*. 1989;28(2):193–213.
11. Radloff LS. The CES-D scale: a self-report depression scale for research in the general population. *Appl Psychol Meas*. 1977;1(3):385–401.
12. Kitano N, Kai Y, Jindo T, Tsunoda K, Arao T. Compositional data analysis of 24-hour movement behaviors and mental health in workers. *Prev Med Rep*. 2020;20:101213.
13. Sloan RA, Kim Y, Sawada SS, Asakawa A, Blair SN, Finkelstein EA. Is less sedentary behavior, more physical activity, or higher fitness associated with sleep quality? A cross-sectional study in Singapore. *Int J Environ Res Public Health*. 2020;17(4):1337.
14. Irish LA, Kline CE, Gunn HE, Buysse DJ, Hall MH. The role of sleep hygiene in promoting public health: a review of empirical evidence. *Sleep Med Rev*. 2015;22:23–36. https://doi.org/10.1016/j.smrv.2014.10.001.
15. Lauderdale DS, Knutson KL, Yan LL, et al. Objectively measured sleep characteristics among early-middle-aged adults: the CARDIA study. *Am J Epidemiol*. 2006;164(1):5–16.
16. Schrack JA, Cooper R, Koster A, et al. Assessing daily physical activity in older adults: unraveling the complexity of monitors, measures, and methods. *J Gerontol A Biol Sci Med Sci*. 2016;71(8):1039–1048.