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Original Article

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Changes in accelerometer-measured sleep during the transition to retirement: the Finnish Retirement and Aging (FIREA) study

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Abstract

Study Objectives: Retirement is associated with increases in self-reported sleep duration and reductions in sleep difficulties, but these findings need to be confirmed by using more objective measurement tools. This study aimed at examining accelerometer-based sleep before and after retirement and at identifying trajectories of sleep duration around retirement.

Methods: The study population consisted of 420 participants of the Finnish Retirement and Aging study. Participants' sleep timing, sleep duration, time in bed, and sleep efficiency were measured annually using a wrist-worn triaxial ActiGraph accelerometer on average 3.4 times around retirement. In the analyses, sleep on nights before working days and on nights before days off prior to retirement were separately examined in relation to nights after retirement.

Results: Both in bed and out bed times were delayed after retirement compared with nights before working days. Sleep duration increased on average by 41 min (95% confidence interval [CI] = 35 to 46 min) from nights before working days and decreased by 13 min (95% CI = −20 to −6 min) from nights before days off compared with nights after retirement. By using latent trajectory analysis, three trajectories of sleep duration around retirement were identified: (1) shorter mid-range sleep duration with increase at retirement, (2) longer mid-range sleep duration with increase at retirement, and (3) constantly short sleep duration.

Conclusions: Accelerometer measurements support previous findings of increased sleep duration after retirement. After retirement, especially out bed times are delayed, thus, closely resembling sleep on pre-retirement nights before non-working days.

Statement of Significance

This is the first cohort study to repeatedly measure sleep with accelerometers around retirement. Sleep duration was found to increase after retirement, which confirms earlier findings based on self-reported sleep. Sleep duration was also observed to be shorter and in bed and out bed times earlier on nights before working than on non-working days, and after retirement, sleep begins to resemble the latter. These results suggest that the possibility to sleep longer in the morning and at suitable times for the individual may be key reasons for sleep changes at retirement. Future research should examine whether retirement is associated with increasing frequency of daytime napping and less regular sleeping patterns, as these may affect the total sleep duration and sleep quality of retirees.

Key words: accelerometer; sleep duration; sleep efficiency; sleep timing; retirement

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Recent findings from longitudinal cohort studies suggest that retirement from work is associated with changes in sleep duration and quality [1]. When daily work-related schedule disappears and work stress eases at retirement, average sleep duration is observed to increase [2, 3], and sleep difficulties to reduce [4–7], especially difficulties with waking up too early in the morning and nonrestorative sleep [5]. However, in all previous studies, sleep has been measured with questionnaires and, thus, only changes in self-reported sleep duration and quality have been examined. This is somewhat problematic, as self-reports of sleep may either systematically overestimate or underestimate actual sleep time. Previous studies have shown that correlations between self-reported sleep and accelerometer-based sleep tend to vary by health status and sociodemographic characteristics, as well as by sleep characteristics of the individuals [8, 9]. For example, one study observed that accelerometer-based poor sleep (i.e. short sleep duration, low sleep efficiency, and longer sleep onset latency) was associated with overestimation of self-reported sleep duration compared with accelerometer-based sleep, whereas those with self-reported poor sleep tended to underestimate their sleep duration compared with accelerometer-based sleep [9]. In addition, self-reports do not allow detailed examination of wake time during the nights.

In many of the previous studies, sleep duration has been measured with a question concerning usual or typical sleep duration, such as "How much do you usually sleep per 24 h?" These questions on typical sleep duration have been found to poorly correspond with sleep assessed using an accelerometer [10]. However, usual sleep duration may be difficult to evaluate, especially if there is substantial variation in sleep duration, for example, between weekday nights and weekend nights. Sleep duration has typically been found to be longer on weekends and days off [11, 12], and for this reason, it would be important to measure both nights before working days and nights before non-working days. To the best of our knowledge, only one cohort study has previously examined changes in sleep duration by comparing both weekday and weekend nights prior to retirement to nights after retirement [2]. In the study by Hagen *et al.* [2], among adults with an average age of 60.1 ($SD = 6.0$) years, self-reported weekday sleep duration was observed to be longer among retirees than those who continued working full time, whereas weekend sleep duration was shorter among retirees than among those still working. They also found that self-reported bed times and wake times were delayed after retirement, suggesting that the timing of sleep might also change after retirement. However, self-reported sleep timing is susceptible to similar measurement challenges as self-reported sleep duration, because the usual timing of sleep may vary and people may report when they usually wake up instead of when they arise from bed.

Many of the limitations of the previous studies can be addressed by measuring sleep with a more objective way, such as using wrist-worn accelerometry, which is based on the movements of the arm. A wrist-worn accelerometer is regarded as a valid method for detecting sleep in healthy adults and provides a tool for assessing both the timing and duration of sleep, as well as for acquiring information on times spent awake during the night [13, 14]. To date, the only study to examine changes in sleep around retirement that is based on an accelerometer is a unique case study by Borbély [15], in which the author wore an accelerometer on his wrist continuously for three decades. He observed that after a declining sleep duration before retirement, a steep increase of sleep duration occurred during the first post-retirement year.

The aim of the current study was to examine changes in accelerometer-measured sleep around the transition to statutory retirement. Our study focused on following sleep indicators: in bed times, out bed times, sleep duration, time in bed, and sleep efficiency, which were measured on nights before working days and days off prior to retirement as well as while retired. Furthermore, since changes in sleep may differ between participants, it is useful to expand analysis beyond examining the average change in the study population. Thus, we also aimed at identifying trajectories of sleep duration around the retirement transition by using latent trajectory analysis and to assess preretirement predictors of belonging to these trajectories.

Methods

Study population and design

Data were drawn from the Finnish Retirement and Aging (FIREA) study, an ongoing longitudinal cohort study of older adults in Finland established in 2013 [16]. The FIREA survey cohort included all public sector employees whose statutory retirement date was between 2014 and 2019 and who were working in 1 of the 27 municipalities in Southwest Finland or in the 9 selected cities or 5 hospital districts around Finland in 2012. Participants were first contacted 18 months prior to their estimated retirement date, which was obtained from the pension insurance institute for the municipal sector in Finland (Keva). The study protocol of the FIREA study has been described in more detail elsewhere [16]. The FIREA study is conducted in line with the Declaration of Helsinki, and has been approved by the Ethics Committee of Hospital District of Southwest Finland.

The selection of the study sample is shown in a flow chart in Figure 1. The study population for the FIREA activity sub-study included those Finnish speaking FIREA study members whose estimated statutory retirement date was in 2016–2019, who had responded to the first questionnaire sent 18 months prior to their estimated retirement date and who were still working by the end of 2017 ($n = 2,663$). These responders were invited by mail to participate in the activity sub-study, and of them, 908 (34 per cent response rate) returned the informed consent and were sent an accelerometer. Thereafter, the participants were followed up annually with both the accelerometer measurements and questionnaires up to four times in total. The aim was to conduct two measurements before retirement and two measurements after retirement. Data were collected between September 2014 and April 2019 during all four seasons and the measurements of each participant were conducted at an approximately same time each year to avoid season to affect the measurements.

By the end of April 2019, 577 participants had successfully used the accelerometer at least once while working and once after the transition to full-time statutory retirement. The participants reported their working status at the time of each measurement, and this information was used to indicate the timing of the transition to statutory retirement. The rest of the consented participants either did not participate in the follow-up measurements or had not yet retired ($n = 332$). If participant had at least one night shift during the measurement week, the measurement

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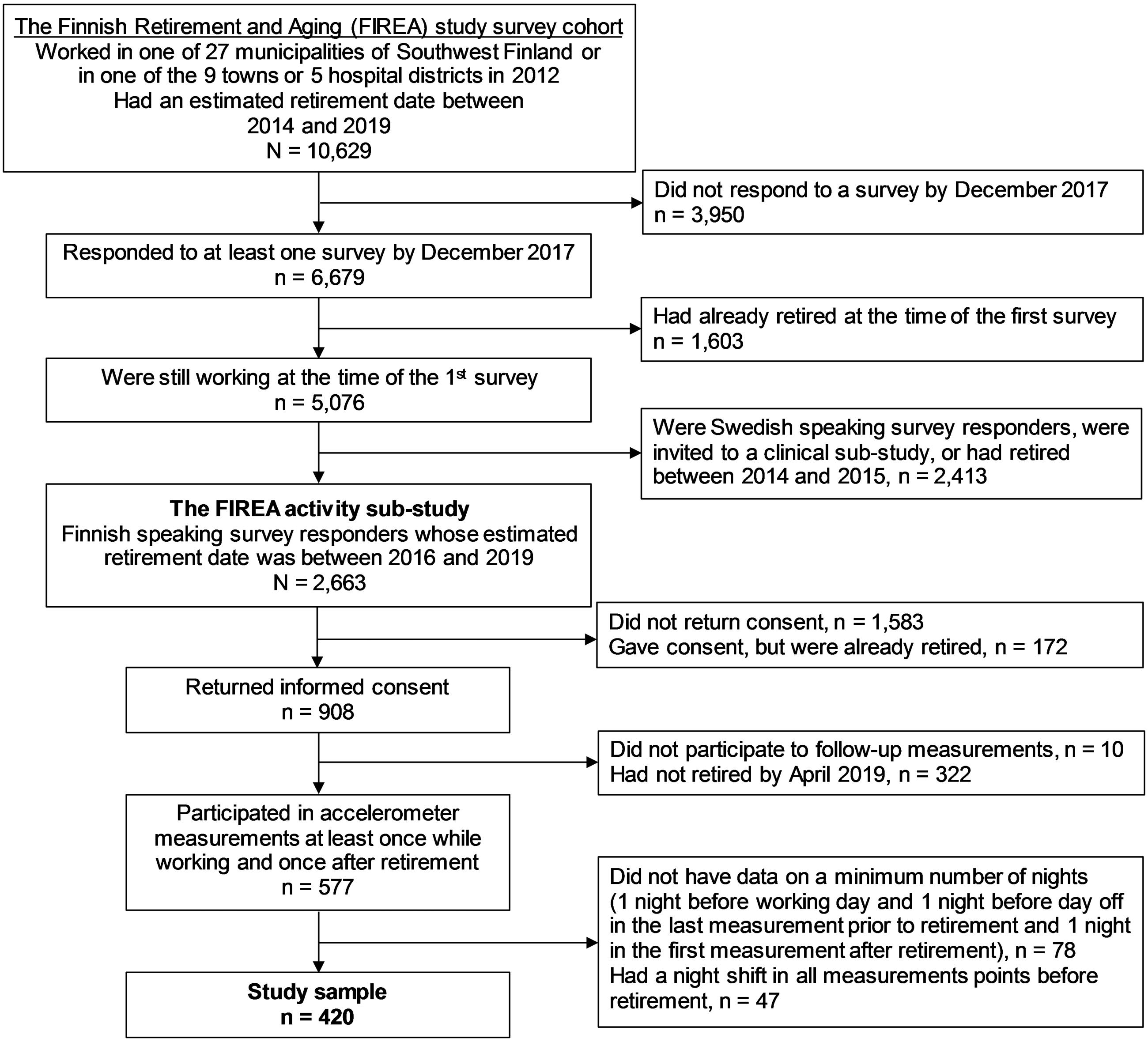

Figure 1. Flow chart of the selection of the study sample.

point was excluded to prevent the daytime sleep related to night work from affecting the results and those participants who had at least one night shift in all their pre-retirement measurements were, thus, excluded altogether ($n = 47$). We included those participants ($n = 420$) who had data from at least one night before working day and one night before day off in the last measurement prior to retirement and data from at least one night in the first measurement after retirement. On average, participants provided data from 3.4 (range 2–4) accelerometer measurement points around retirement.

Assessment of retirement

The retirement ages of the employees in Finland are regulated by the Public Sector Pensions Act. Until the end of 2016, the statutory retirement age in public sector was generally 63–68 years. Following a pension reform in January 2017, each age group has their own retirement ages, which are tied to their life expectancy [17]. Furthermore, the retirement age is flexible, which means that the pension may be taken out within a certain age range and there is also an upper limit for how long a person can continue working. Some employees have been able to keep their earlier retirement age from the previous pension acts in which pension ages were below 63 in some occupations, such as primary school teachers. The pension system in Finland is based on two complementing systems: earnings-related pension is accrued by paid work and entrepreneurial activities and the amount of the pension depends on the duration of the working career and the salary. National pension and guarantee pension are targeted for those pensioners who have no earnings-related pension or whose pension is very small. When individuals reach the statutory retirement age window and decide to retire, their pension depends on their age at retirement, as working longer accumulates higher pension.

Information on participants' retirement was based on information gathered from the daily logs completed during the

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accelerometer measurements. The year of the measurement in which the participant reported being on full-time retirement for the first time and had no working days was set as the year of retirement. In addition, if the participant reported being on an annual leave and transitioning directly from the leave into retirement, the year of that measurement was set as the year of retirement. Some of the participants ($n = 18$) also reported work days in the measurement waves that occurred after they had reported being on a full-time retirement, but as these were only temporary work shifts, the original year of retirement was used in the analysis.

Accelerometer measurements

Movements during sleep and wakefulness were measured with triaxial accelerometers, wActiSleep-BT and wGT3X-BT by ActiGraph (Pensacola, FL, USA). They are two models of the same accelerometer, and the newer model, wGT3X-BT, is fully backward compatible with the previous model wActiSleep-BT based on information provided by the manufacturer [18]. Nevertheless, each measurement of a single participant was conducted with the same accelerometer model, mainly to improve the reliability of the repeated measurements and to avoid confusion among participants concerning the appearance of the accelerometer. The accelerometers were sent to the participants by mail with instructions on how to use the device. The participants were instructed to wear the accelerometer continuously on their non-dominant wrist 24-h/d for 7 days and nights and to only remove the device during sauna to prevent overheating. While wearing the accelerometer, the participants were also asked to complete a daily log, in which they reported the date, bed time, and wake time for each measurement day, and whether the day in question was a working day or a day off. The accelerometers and the daily logs were returned after the measurement period in a postage-paid envelope. The median number of nights before working days was 4 (interquartile range [IQR] 3–5) and 1 night before days off (IQR 1–2) in the last measurement point prior to retirement. In the first measurement point after retirement, the median number of nights was 6 (IQR 6–6).

Raw data from the accelerometers were downloaded and converted into 60 s epochs using the manufacturer's ActiLife software, version 6.13 (ActiGraph, Pensacola, Florida, USA). To define each epoch as sleep or wake, we used the Cole–Kripke algorithm [19], which has originally been validated in adult population using wrist-worn accelerometers. Sleep periods were then detected using the ActiGraph algorithm available in the Actilife software [20], by using the Batch Sleep option provided by the software, which allows the detection of sleep periods for multiple participants at the same time [21]. The ActiGraph algorithm builds on Troiano Wear Time Validation Algorithm [22] and detects non-wear periods. The algorithm ignores non-wear periods of greater than 24 h and non-wear periods of 5 or more minutes of non-zeros and the remaining non-wear periods are defined as sleep time [20]. Before the analyses, multiple steps were taken to check and clean the accelerometer data and the sleep periods detected by the algorithms. All these steps were conducted by the same person, that is the first author, and are described in detail in Supplementary Table S1. We derived the following sleep variables from the accelerometer data: "in bed time", "out bed time", "time in bed" (total time spent in bed), "sleep duration" (minutes of sleep between sleep onset and out bed time provided by the algorithm), and "sleep efficiency" (the percentage of sleep duration from the time in bed).

Assessment of covariates

We obtained participants' gender, date of birth, and occupational title from the pension insurance institute for the municipal sector in Finland (Keva). The occupational titles of the last known occupation preceding retirement were coded according to the Standard Classification of Occupations (ISCO) 2001 by Statistics Finland [23] and occupational status was categorized into two groups: non-manual workers (ISCO classes 1–4) and manual workers (ISCO classes 5–9).

Information on all the other covariates was derived from the last FIREA questionnaire preceding retirement. The covariates were chosen because they are shown to be associated with sleep duration. Self-rated health was assessed with a 5-point scale (from 1 = good to 5 = poor) and response scores 3–5 were used to indicate suboptimal self-rated health (yes vs. no). Body mass index (BMI, kg/m^2) was calculated based on self-reported body weight and height and those with BMI of 30 kg/m^2 or more were regarded having obesity (yes vs. no). Physical activity was assessed by asking participants to estimate their average weekly hours of physical activity (including both leisure-time and commuting to work) within the previous year in walking, brisk walking, jogging, and running, or their equivalent activities. Weekly physical activity was expressed in metabolic equivalent (MET) hours and an average of 14 MET hours or less per week was regarded as low physical activity (no vs. yes) [24]. Alcohol consumption was assessed with self-reports on habitual frequencies of beer, wine, and spirits consumption and risk use of alcohol was defined as more than 16 drinks/week women and more than 24 drinks/week for men (yes vs. no). These limits were chosen as they correspond to the lower limit for heavy use of alcohol set by the Finnish Ministry of Health and Social Affairs [25]. Job strain was assessed using questions from the shorter version of the Job Content Questionnaire [26, 27] and participants with job strain (yes vs. no) were identified using previously defined cutoff points (a high demands and a low control score) [7]. Psychological distress was measured with the 12-item version of the General Health Questionnaire [28], and a cutoff point of four or more symptoms was used to indicate psychological distress (yes vs. no). Sleep difficulties were measured with the four-item Jenkins Sleep Problem Scale [29] in which the participants report the occurrence of difficulties falling asleep, difficulties maintaining sleep during the night, waking up too early in the morning, and nonrestorative sleep during the past 4 weeks (never, 1–3 nights per month, 1 night per week, 2–4 nights per week, 5–6 nights per week, and nearly every night); if the frequency of the most frequent symptom a participant reported was higher than four nights per week, they were considered to have sleep difficulties (yes vs. no). Information on sleep apnea was derived from a list of medical conditions diagnosed by a doctor and dichotomized into yes ("Yes, previously" or "Yes, currently") or no. Finally, information on self-reported sleep duration was used when comparing the included participants with the eligible population and it was assessed by asking the participants how many hours they usually sleep per 24 h.

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Statistical analyses

The data were centered around the actual retirement date so that the first measurement in which the participant reported being on a full-time retirement was set as measurement point +1. Before that measurement point, a participant may have had 1–3 measurements (i.e. measurement points −3, −2, and −1). However, as there were only 26 participants in the measurement point −3, this measurement point was omitted from the analyses. After retirement, a participant may have had 1–3 measurements (measurement points +1, +2, and +3).

To illustrate the average level of various sleep parameters in each measurement point before and after retirement, we used linear regression analyses with generalized estimating equations (GEE) and the results are shown as unadjusted mean estimates and their 95% CI. We calculated a mean for each sleep parameter across all "nights before working days" and across all "nights before days off." In addition, we calculated a weighted weekly average prior retirement for each measurement point, henceforth referred to as "nights prior to retirement," for each sleep parameter with the following formula: ([5 × mean of nights before working days] + [2 × mean of nights before days off])/7. For each measurement point after retirement, we calculated a mean across all the nights, henceforth referred to as "nights after retirement." In addition, we calculated a mean for sleep duration across all "weekday nights after retirement" and "weekend nights after retirement" to examine whether there is a day of the week effect after retirement.

To examine how sleep parameters changed during the transition to retirement, we compared each participant's first measurement after retirement (measurement point +1) with their last measurement prior to retirement (measurement point −1). The changes were calculated separately for (1) the changes from nights before working days to nights after retirement, (2) from nights before days off to nights after retirement, and (3) from nights prior to retirement to nights after retirement. The results were calculated using linear regression analysis with GEE models, which takes into account the intraindividual correlation between measurements. The analyses were adjusted for age, gender, and occupational status.

To identify distinctive groups of individuals who show similar developmental trajectories of sleep duration throughout the transition to retirement, we used latent trajectory analysis [30]. For this, we modeled the changes in sleep duration from nights prior to retirement to nights after retirement using all measurement points. To estimate latent trajectories, we used PROC TRAJ procedure in the statistical software SAS 9.4 (SAS Institute, Inc., Cary, NC, USA). Nagin's two-step procedure was used to determine the optimal number of trajectories and to choose the number and order of regression parameters [30]. First, an increasing number of trajectory groups with cubic polynomial shape were fitted for sleep duration until no improvement in model fit was observed. The model fit was assessed based on Bayesian information criterion values (BIC), Akaike information criterion values (AIC), and log-likelihood, as well as posterior probabilities of trajectory membership. Second, the models with quadratic and linear trajectories were tested for the model selected in the first step. We fitted models from one to five trajectories and the model fit statistics for the solutions are presented in Supplementary Table S2. Although the values indicating model fit continued to improve when the four trajectory solution was fitted, the improvement in log-likelihood values were only minor when comparing the solutions with three and four trajectories. In addition, in the four trajectory model, two of the trajectories with a polynomial shape were not statistically significant. Therefore, based on the parsimony principle, we selected the three trajectory model. In this model, two groups had a cubic and one group a linear order. Finally, to examine which pre-retirement factors best characterize belonging to the different trajectory groups, multinomial logistic regression analysis was used to calculate odds ratios (OR) and their 95% CIs for each pre-retirement factor (gender, occupational status, self-rated health, BMI, physical activity, alcohol use, job strain, psychological distress, and sleep difficulties) while adjusting for age and gender. The "Shorter mid-range sleep duration with increase at retirement" group was used as a reference category when examining pre-retirement factors associated with the "Constantly short sleep duration" and "Longer mid-range sleep duration with increase at retirement" groups. The "Longer mid-range sleep duration with increase at retirement" group was also compared against the "Constantly short sleep duration" group.

All statistical analyses were performed using SAS statistical software, version 9.4 (SAS Institute, Inc.).

Results

The study population ($n = 420$) consisted of aging public sector employees, who were mainly women (87 per cent) and working in a non-manual occupation (67 per cent) and were 63.3 years ($SD = 1.1$) in the last measurement prior to retirement. Detailed characteristics of the study population are described in Table 1. We defined the eligible population as those survey participants who had retired by the end of 2018 and had answered to

Table 1. Baseline characteristics of the study population included in the analyses ($n = 420$) and the eligible study population ($n = 1,200$) in the last measurement before retirement

Characteristics	Included participants ($n = 420$)	Eligible study population* ($n = 1,200$)
Age, M (*SD*)	63.3 (1.1)	63.1 (1.2)
Women, *n* (%)	366 (87)	1,005 (84)
Manual occupational status, *n* (%)	139 (33)	444 (37)
Suboptimal self-rated health, *n* (%)	94 (23)	321 (27)
Obese (BMI ≥ 30 kg/m^2), *n* (%)	75 (19)	267 (23)
Physically inactive, *n* (%)	150 (37)	438 (37)
Risk use of alcohol, *n* (%)	28 (7)	92 (8)
Job strain† *n* (%)	34 (18)	130 (22)
Psychological distress, *n* (%)	43 (11)	162 (14)
Sleep difficulties, *n* (%)	125 (30)	348 (29)
Sleep apnea, *n* (%)	24 (6)	67 (6)
Self-reported sleep duration, M (*SD*)	7 h 8 min (50 min)	7 h 10 min (52 min)

*Eligible population was defined as those survey participants who had retired by the end of 2018 and had answered to questions on sleep in the last measurement prior to retirement.
†The measurement of job strain is missing $n = 229$ in the included participants and $n = 600$ participants in the eligible study population, as this measurement was not included in the FIREA questionnaire until 2016.

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questions on sleep in the last measurement prior to retirement (n = 1,200). Compared with the eligible population, the final study population had slightly more women and less individuals working in manual occupations, having suboptimal self-rated health, obesity, or psychological distress before retirement, but was similar in regards to self-reported sleep (Table 1).

Figure 2 shows the observed average in bed times and out bed times for nights before working days and days off in the last measurement prior to retirement and for nights in the first measurement after retirement. After retirement, the mean in bed time was 11:01 pm (95% CI = 10:55 to 11:07 pm), that is, on average 43 min (95% CI = 38 to 48 min) later than on nights before working days and 9 min (95% CI = 2 to 15 min) later than on nights before days off. After retirement, the mean out bed time was 7:07 am (95% CI = 7:00 to 7:13 am), that is, 1 h and 30 min later (95% CI = 1 h 23 min to 1 h 36 min) than on working days prior to retirement. The change in out bed times from days off to after retirement was not statistically significant (–5 min, 95% CI = –12 to 2 min).

Figure 3 and Table 2 show sleep duration for nights before working days and for nights before days off, as well as sleep duration on nights after retirement. Sleep duration was 53 min (95% CI = 46 to 61 min) longer on nights before days off compared with nights before working days. Sleep duration increased during the retirement transition from nights before working days by 41 min (95% CI = 35 to 46 min) and decreased from nights before days off by 13 min (95% CI = –20 to –6 min) while adjusting for age, gender, and occupational status. There was no day of the week effect after retirement, as sleep duration was 7 h 4 min (95% CI = 6 h 56 min to 7 h 13 min) on weekdays and 7 h 14 min (95% CI = 7 h 3 min to 7 h 25 min) on weekends in the first measurement after retirement and continued to be at the same level in the later measurements (see Supplementary Figure S1). Changes in time in bed around the transition to retirement were very similar as for sleep duration (Figure 4), so that time in bed increased by 47 min (95% CI = 41 to 53 min) from nights before working days and decreased by 14 min (95% CI = –22 to –6 min) from nights before days off (Table 2). On the other hand, the estimates for sleep efficiency seemed to remain on a constant level throughout the measurement points around retirement (Figure 4). No statistically significant changes in sleep efficiency were observed from nights before days off, whereas a borderline significant decrease of 0.38 percentage points (95% CI = –0.75 to –0.02) was observed from nights before working days when compared with nights after retirement (Table 2). The changes in the sleep parameters from nights prior to retirement (the weighted weekly averages) into nights after retirement are provided in Supplementary Table S3 showing both sleep duration and time in bed to increase by 25 min (95% CI = 20 to 30 min) and by 30 min (95% CI = 24 to 35 min), respectively, and sleep efficiency to decrease by 0.4 percentage points (95% CI = –0.7 to –0.02) after retirement.

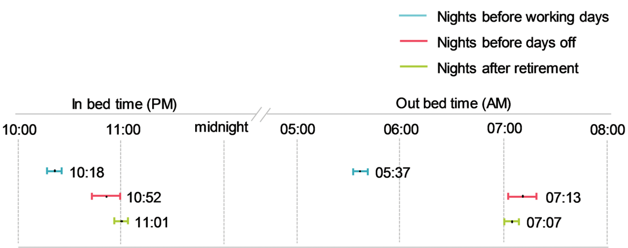

Figure 2. Accelerometer-based average in bed and out bed times and their 95% CIs for nights before working days and nights before days off in the last measurement prior to retirement, and for nights after retirement in the first measurement after retirement.

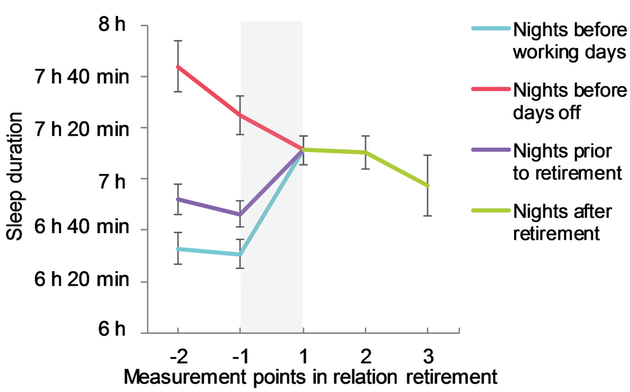

Figure 3. Accelerometer-based sleep duration and its 95% CIs for nights before working days, nights before days off, nights prior to retirement and nights after retirement. The interval between each measurement point is approximately 1 year. The transition to retirement is marked as grey.

Based on the latent trajectory analysis, three trajectories of sleep duration were identified (Figure 5). The trajectory with the largest proportion of individuals was "Shorter mid-range sleep duration with increase at retirement" (54 per cent) in which sleep duration was 6 h 38 min (95% CI = 6 h 31 min to 6 h 44 min) in the last measurement prior to retirement and sleep duration increased at retirement. The second-largest trajectory was "Longer mid-range sleep duration with increase at retirement" (33 per cent) and included individuals with a sleep duration of 7 h 37 min (95% CI = 7 h 29 min to 7 h 45 min) in the last measurement prior to retirement and an increase in sleep duration at retirement. The third trajectory, "Constantly short sleep duration," had the smallest proportion of individuals (13 per cent) and included individuals whose sleep duration was 5 h 42 min (95% CI = 5 h 33 min to 5 h 52 min) in the last measurement prior to retirement and continued to be less than 6 h throughout the measurements. The individuals belonging to each trajectory group did not differ from each other in their age, the average age before retirement was 63.1–63.6 in the trajectory groups. Those belonging to the "Longer mid-range sleep duration with increase at retirement" trajectory had the highest sleep efficiency in the last measurement prior to retirement (90.9 per cent, 95% CI = 90.2% to 91.7%), followed by those in the "Shorter mid-range sleep duration with increase at retirement" trajectory (89.5 per cent, 95% CI = 88.9% to 90.1%), while the "Constantly short sleep duration" trajectory had the lowest sleep efficiency (84.9 per cent, 95% CI = 83.8% to 85.9%) (after adjusting for age and gender).

Pre-retirement predictors that characterized belonging to the different trajectories adjusted for age and gender are presented in Table 3. Compared with the "Shorter mid-range sleep duration with increase at retirement" trajectory, those who belonged to the "Constantly short sleep duration" trajectory were more often male, had a non-manual occupation, and were more often obese, whereas those belonging to the "Longer mid-range sleep duration with increase at retirement" trajectory were more likely to report job strain. Those belonging to the "Longer mid-range sleep duration with increase at retirement" trajectory

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were more often female and less often obese than those in the "Constantly short sleep duration" trajectory.

Discussion

The current study is, to the best of our knowledge, the first longitudinal cohort study to examine changes in accelerometer-measured sleep around the transition to statutory retirement. We observed a shift toward a later sleep–wake rhythm, that is later in bed and out bed times, when nights before working days were compared with nights after retirement. This was particularly clear for the out bed times showing 1 h 30 min delay after retirement. As a result, both sleep duration and time in bed were observed to increase at retirement. No changes in sleep efficiency were observed from either the nights before working days or nights before days off. Furthermore, based on identified sleep duration trajectories, majority of the participants slept longer after retirement. Only 13 per cent of the participants had a constantly short sleep duration throughout the measurements, and thus, no increase in sleep duration at retirement.

Our results suggest that after retirement, both the timing and duration of sleep begin to resemble those of nights before non-working days, such as weekend nights and other free nights before retirement. Compared with pre-retirement nights before working days, both sleep duration and time in bed increased substantially and in bed and out bed times were delayed after retirement. These findings are logical, as after retirement all days are "days off" with no working hours determining the daily schedule.

As especially the out bed times were delayed after retirement compared with nights before working days, the increase in sleeping hours at retirement seems to occur mainly in the morning. These results seem to suggest that the main reason for the increase in sleep is the possibility to sleep longer. Sleep duration was observed to increase by 25 min from the weighted weekly average into retirement. Interestingly, this is very close to the previous findings based on self-reported sleep duration, that have showed 15–22 min increase in sleep duration at retirement depending on the cohorts studied and the lengths of the measurement intervals used around retirement [2, 3, 7]. Thus, although accelerometer-measured and self-reported sleep have been found to correlate only moderately with each other [8],

Table 2. Average level of different sleep characteristics before and after retirement

Sleep characteristics	Nights before working days		Nights before days off		Nights after retirement		Nights before working days vs. nights after retirement		Nights before days off vs. nights after retirement	
	Mean*	95% CI	Mean*	95% CI	Mean†	95% CI	Mean change	95% CI	Mean change	95% CI
Sleep duration (min)	6 h 26 min	6 h 18 min to 6 h 34 min	7 h 19 min	7 h 9 min to 7 h 29 min	7 h 6 min	6 h 58 min to 7 h 15 min	41	35 to 46	−13	−20 to −6
Time in bed (min)	7 h 12 min	7 h 4 min to 7 h 20 min	8 h 14 min	8 h 3 min to 8 h 25 min	7 h 59 min	7 h 51 min to 8 h 8 min	47	41 to 53	−14	−22 to −6
Sleep efficiency (%)	89.3	88.8 to 89.9	88.6	88.0 to 89.2	88.8	88.3 to 89.4	−0.4	−0.7 to −0.02	−0.3	−0.7 to 0.2

All models are adjusted for age, gender, and occupational status.
*Derived from the last measurement before retirement.
†Derived from the first measurement after retirement.

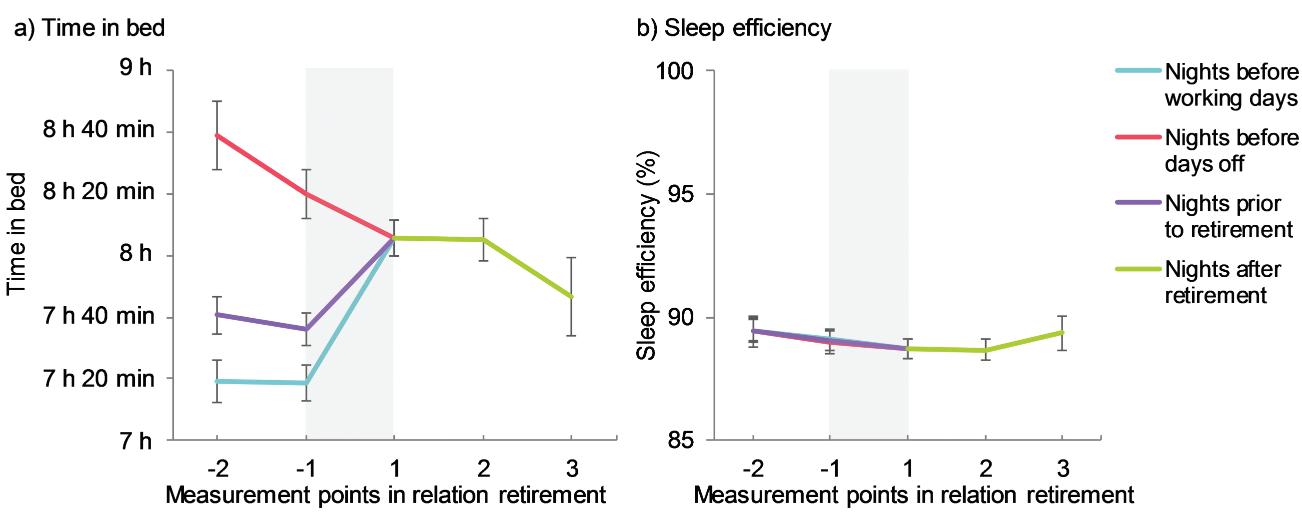

Figure 4. Accelerometer-based (A) time in bed and (B) sleep efficiency and their 95% CIs for nights before working days, nights before days off, nights prior to retirement, and nights after retirement. The interval between each measurement point is approximately 1 year. The transition to retirement is marked as grey.

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they seem to provide similar estimates of the sleep duration changes at retirement.

Our research is consistent with previous findings of extended weekend sleep, which means that longer sleep durations were observed on nights before non-working days compared with nights before working days while in working life [11, 12, 31]. After retirement, sleep duration was observed to increase from nights before working days, but to decrease from nights before days off. Similar finding has previously been observed in the actigraphy case study by Borbély [15] as well as with self-reported sleep duration [2]. After retirement, there is no longer a need for catch-up sleep, that is, an extension of sleep duration on non-working days to compensate for possible sleep debt from working days. This might explain why sleep duration increases at retirement compared with nights before working days, but not compared with nights before non-working days. The idea that there is no longer need for catch-up sleep after retirement is also supported by our earlier findings that sleep duration increases shortly or even immediately after retirement, but stays at the same level during the following months and years instead of further increasing [7]. Furthermore, we also observed that after retirement, there are no differences in sleep duration between weekdays and weekend days.

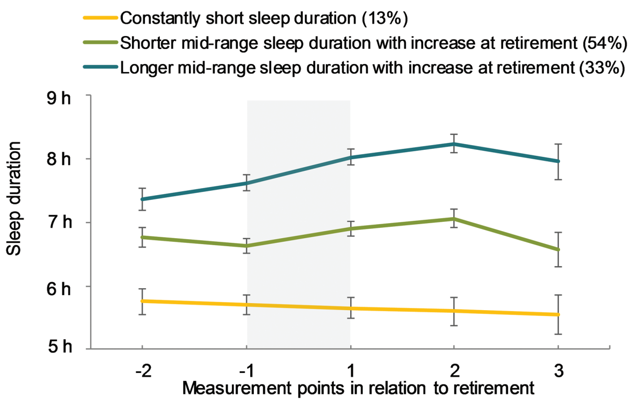

Figure 5. Trajectories of sleep duration and its 95% CIs around the transition to retirement from nights prior to retirement to nights after retirement. The interval between each measurement point is approximately 1 year. The transition to retirement is marked as grey.

Our study provides new insight into the sleep duration changes at retirement by identifying three homogenous subgroups of sleep duration trajectories by using latent trajectory analysis: the two largest trajectories showed a similar increase around retirement by only differing in their level and the third trajectory showed a constantly short sleep duration throughout the measurement points. Previous studies have focused on examining pre-retirement predictors of changes in self-reported sleep by conducting examinations separately for pre-specified subgroups, but this approach does not take into account the possible unobserved characteristics of the participants. We observed that belonging to the "Longer mid-range sleep duration with increase at retirement" trajectory was associated with a higher job strain and a higher sleep efficiency, whereas belonging to "Constantly short sleep duration" trajectory was associated with male gender, non-manual occupation, obesity, and lower sleep efficiency when compared with the "Shorter mid-range sleep duration with increase at retirement" trajectory. These results suggest that retirement is associated with increase in sleep duration for the majority, supported by previous findings of increased self-reported sleep duration in almost all sub-groups categorized by preretirement sociodemographic, work, lifestyle, and health factors [3, 7].

However, these results also indicate that there was a group of individuals, consisting of 13 per cent of the participants, whose sleep duration was less than 6 h throughout the measurements around retirement. Thus, these findings suggest that there are individuals who do not sleep more even when retirement provides a better opportunity for sleeping. It is not known whether this is due to them having a naturally short sleep duration, or conditions affecting their sleep duration and quality. Although those belonging to the "Constantly short sleep duration" trajectory did not report more sleep difficulties, their average sleep efficiency was lower than among those belonging to the two other trajectories.

In this study, we observed no changes in sleep efficiency from nights before days off into retirement, and only a minimal decrease from nights before working days and from the weighted

Table 3. Pre-retirement predictors for belonging to different trajectories based on multinomial logistic regression analysis

	Constantly short sleep duration vs. shorter mid-range sleep duration with increase at retirement		Longer mid-range sleep duration with increase at retirement vs. shorter mid-range sleep duration with increase at retirement		Longer mid-range sleep duration with increase at retirement vs. constantly short sleep duration	
Variable	OR	95% CI	OR	95% CI	OR	95% CI
Male vs. female	**2.12**	**1.00 to 4.53**	0.76	0.38 to 1.53	**0.36**	**0.15 to 0.86**
Manual vs. non-manual occupational status	**0.41**	**0.19 to 0.89**	0.89	0.57 to 1.39	2.16	0.96 to 4.87
Suboptimal vs. good health	1.65	0.81 to 3.37	1.22	0.73 to 2.03	0.74	0.35 to 1.56
Obese vs. non-obese	**3.04**	**1.53 to 6.07**	1.09	0.61 to 1.96	**0.36**	**0.17 to 0.76**
Low vs. moderate-high physical activity	1.18	0.63 to 2.23	1.00	0.64 to 1.56	0.85	0.43 to 1.67
Risk use vs. no risk use of alcohol	1.79	0.61 to 5.27	1.11	0.46 to 2.64	0.62	0.19 to 1.98
Job strain vs. no job strain	0.46	0.06 to 3.77	**2.46**	**1.12 to 5.40**	5.35	0.64 to 44.66
Psychological distress vs. no distress	0.71	0.23 to 2.16	0.96	0.48 to 1.92	1.35	0.42 to 4.40
Sleep difficulties vs. no sleep difficulties	0.77	0.38 to 1.58	1.11	0.70 to 1.76	1.44	0.67 to 3.07
Sleep apnea vs. no sleep apnea	0.59	0.12 to 2.86	2.10	0.86 to 5.16	3.58	0.71 to 17.93

The models are adjusted for age and gender. Statistically significant results are marked as bold. OR = odds ratio; CI = confidence interval.

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weekly average of sleep efficiency prior to retirement. Although retirement is associated with decreases in self-reported sleep difficulties, it may not necessarily be associated with increasing sleep efficiency. This is supported by the previous finding of no significant differences in sleep efficiency between nights before working days and non-working days [31]. However, it is also possible, that the wrist-worn accelerometer is not sensitive enough in detecting wakefulness or that it might, in fact, underestimate sleep efficiency [13]. The accelerometers and the sleep detection algorithm used in the current study are regarded as valid measures of sleep, having a high sensitivity, but their capability to detect periods of wake during the sleep periods has been found to be only moderate [13, 14]. The study by Slater *et al.* [13]. examined the validity of GTX3+ ActiGraph wrist accelerometer (a similar device, but different sleep detection algorithm than in the current study) and found it to overestimate time spent awake during the night by possibly scoring wrist movements during sleep as wakefulness, and thus, to underestimate sleep efficiency.

Although a valid measure of sleep, a wrist accelerometer is not the golden standard method to objectively measure sleep, and it is possible that some sleep is scored as wakefulness due to wrist movements or some immobile wakefulness as sleep. However, it can be assumed that the devices have measured the participants in a similar way in each measurement point and as the sleep scoring was conducted following the same principles in each measurement point, the accelerometer provides a reliable estimate of the changes in sleep occurring between the measurements.

Based on results from a recent study, the Cole–Kripke algorithm provides comparable and accurate data compared with polysomnography in regard to sleep (i.e. has a high sensitivity), but identifies wake episodes poorly (i.e. has a low specificity) and may, thus, slightly underestimate wakefulness [14]. In addition, detecting the time of sleep onset is challenging, as the individual may be motionless, yet awake, for a while before falling into sleep, and for this reasons, accelerometers typically underestimate sleep latency [13]. Therefore, estimates on wakefulness during the night, such as sleep onset latency, wake after sleep onset, and the number of awakenings, were chosen not to be included in the analyses. Further research is, thus, needed to examine changes in other accelerometer-based sleep parameters during the transition to retirement. Finally, with the algorithms used in the current study, it was not possible to detect sleep periods outside the main sleep period, such as naps during daytime. To date, no longitudinal studies have examined, to the best of our knowledge, either with self-reports or using objective measurements, whether retirement is associated with changes in daytime naps and less regular sleeping patterns. Daytime napping may affect the total sleep duration of a 24-h period by either increasing it or by deteriorating sleep quality during the night by reducing homeostatic sleep pressure [32, 33]. It would, thus, be important to examine whether changes occur also in the frequency of daytime napping and whether this has an effect on how the total sleep duration changes at retirement as well as the quality of sleep after retirement.

Our study has a number of significant strengths, including annual repeated accelerometer measurements for a considerably large cohort of aging public sector employees before and after statutory retirement. The accelerometers enable sleep measurements to be easily and reliably repeated, which is seen as a high compliance in our study. The drop-out rate was only 1.6 per cent in the second measurement, 2.76 per cent in the third measurement, and 2.56 per cent in the fourth measurement when compared with the first measurement. The measurements of each participant were conducted at the same time of each year and the same measurement procedures were used throughout the measurement points minimizing the seasonal variation and systematic measurement errors. Detailed information on whether the days following the measurement nights were working days or days off enabled us to separately examine nights before working days and non-working days, instead of categorizing the nights as solely weekday or weekend nights. Checking and cleaning of the accelerometer data was carefully done by the first author following the same principles in every measurement point. Furthermore, by using the latent trajectory analysis, we were able to examine the changes in sleep duration from a more person-oriented perspective that takes into account the possible unobserved characteristics of the participants.

This study has also some limitations that need to be taken into account. Firstly, only 38 per cent of the eligible population consented to participate in this accelerometer sub-study and this may limit the generalizability of our findings. In comparison with the eligible population, among the participants there were slightly more women and non-manual employees and those who reported less obesity, psychological distress and suboptimal health. However, no difference was observed in self-reported sleep duration and difficulties, suggesting that there should not be major bias in our results. Secondly, this study lacks the information on participants' chronotypes or circadian preferences, and thus, future studies are needed to determine their influence on the changes in accelerometer-based sleep during the transition to retirement. The changes in accelerometer-based sleep could be expected to differ based on participants' circadian preference and, in fact, those with an evening preference have previously been shown to have a longer extension in wake times after retirement based on self-reported data. Furthermore, possible changes in circadian patterns after retirement would be worth examining in future studies measuring sleep with accelerometers before and after retirement. Our study population consisted of public sector employees, majority of them being women, not involved in night work and retiring at their statutory retirement age, and thus, future studies are needed to confirm the findings in other study population and working sectors.

Conclusion

Accelerometer-measured sleep duration and time in bed increased substantially from nights before working days but decreased from nights before days off into nights after retirement. Later in bed times were observed after retirement compared with both pre-retirement nights before working days and nights before days off, but most marked changes were observed in out bed times, which were 1 h 30 min later after retirement compared with nights before working days. However, no changes in sleep efficiency were observed around the transition to retirement. Based on trajectories of sleep duration around retirement, majority of the participants slept longer after retirement with only 13 per cent of the participants having a constantly short sleep duration throughout the measurements and no increase in sleep duration at retirement. More research with objective

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sleep measurements should focus on the examination of sleep changes around retirement, especially on the changes in the total amount of sleep, including sleep occurring during daytime, and the regularity of sleeping patterns.

Supplementary Material

Supplementary material is available at *SLEEP* online.

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