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# Associations of sleep and individual characteristics with accelerometer-measured catch-up sleep among older employees

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ABSTRACT

There is limited knowledge on the characteristics of employees who engage in catch-up sleep, the extension of sleep duration on free days to compensate for sleep loss accumulating during workdays. This study examined associations of accelerometer-measured free day catch-up sleep with sleep duration, sleep timing, and socio-demographic, health and lifestyle factors among older employees. We measured sleep repeatedly with accelerometers among 824 public sector employees in Finland (mean age 63 years; 86% women). On average, the participants provided 1.7 annual accelerometer measurements and 1,437 person-observations in total. Catch-up sleep was defined as longer average sleep duration on free days compared with average sleep duration on workdays. Prevalence of catch-up sleep was 78%. On average, the catch-up sleep group extended their sleep on free days by 1 hour 22 min (95% confidence interval [CI] 1 h 19 min – 1 h 26 min), whereas the non-catch-up sleep group reduced their sleep duration by 45 min (95% CI -50 min – -40 min). Catch-up sleep was mainly associated with delayed awakening time on free days (by 1 h 57 min, 95% CI 1 h 52 min – 2 h 2 min). We also observed a greater social jetlag in the catch-up sleep group in comparison to the non-catch-up sleep group, whereas no differences were observed in chronotype, self-reported sleep, or other individual characteristic. In conclusion, accelerometer-measured catch-up sleep is common among older employees in Finland and major differences in duration and timing of sleep occur between those with and without catch-up sleep.

## 1. Introduction

Within the normal aging process, changes in sleep are apparent along with other physiological changes. The duration of nocturnal sleep, as well as the ability to maintain sleep decrease with age and sleep becomes more fragmented [1–3]. Studies examining changes in sleep duration and sleep difficulties after retirement from work have shown that insufficient and poor quality sleep are more common during the final working years than after retirement [4–7]. The clear impact of cessation of work on sleep suggests that work is one of the major factors influencing sleep and highlights the importance of promoting sufficient and good quality sleep among older employees.

Based on analyses of time use data over 24 h in the United States, work has been shown to be the main activity for which sleep is traded off among short sleepers [8]. When working hours do not determine sleep hours, that is, on weekends and other non-working days, sleep duration has been shown to be longer based on studies using self-reports [8,9]. Longer sleep duration on free days when compared to working days has also been observed using accelerometer measurements in studies conducted among the current study population [6] and a study population from Sweden [7] which focused on retirement-related changes in sleep duration. It has been hypothesized that to cope with insufficient sleep that has accumulated during workdays, people engage in "catch-up sleep" by extending their sleep duration on free days. This extension of sleep duration on free days to compensate for sleep deprivation has been suggested to counteract some of the negative health effects of short sleep duration, such as weight gain [10], hypertension and cardiovascular diseases [11,12], and low-grade systemic inflammation [13]. Fur-

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thermore, a recent cohort study from Sweden observed that the risk of death among individuals under 65 years was higher among short sleepers who did not catch-up on weekends compared to those who did [14].

Despite the considerable amount of research examining sleep duration on both workdays and free days, there is limited knowledge on the characteristics of those who engage in catch-up sleep. Previous studies on catch-up sleep [10–14] have mainly focused on the health outcomes of catch-up sleep rather than the factors that are associated with catch-up sleep, such as socio-demographic and prevalent health factors. Moreover, it is not known how the bedtimes and awakening times (i.e. sleep timing) during workdays and free days are associated with catch-up sleep. The differences in sleep timing between workdays and free days have been quite extensively studied and often assessed with the concept of social jetlag that indicates discrepancy between social and biological time [15,16]. It is unclear, however, how differences in timing of sleep (i.e. social jetlag) and differences in sleep duration (i.e. catch-up sleep) between workdays and free days are interlinked. Furthermore, previous research comparing those with and without catch-up sleep has relied on self-reported sleep duration on weekdays and weekends to define catch-up sleep [10–14]. Self-reports of sleep duration, however, are prone to inaccuracies, such as recall bias [17,18]. With more objective methods, such as accelerometry, differences in sleep duration and sleep timing between workdays and free days can be more accurately assessed.

The aim of this study was to examine the prevalence of free day catch-up sleep among older employees based on accelerometer measurements. Furthermore, groups with and without free day catch-up sleep were compared in terms of socio-demographic characteristics, work ability, health-related factors, and self-reported sleep and tiredness. Finally, to gain an overview of how sleep-wake rhythms are associated with catch-up sleep, the groups were compared in terms of accelerometer-based chronotype, social jetlag, and timing of sleep.

## 2. Material and methods

### 2.1. Participants and study design

We analyzed data from the Finnish Retirement and Aging (FIREA) study, an ongoing longitudinal cohort study of public sector employees in Finland established in 2013. The eligible study population of the FIREA survey cohort included all employees who were working in one of the 27 municipalities in Southwest Finland or in one of the nine selected cities or five hospital districts around Finland in 2012 and whose statutory retirement date was between 2014 and 2019. All Finnish speaking FIREA survey respondents whose estimated statutory retirement date was between 2016 and 2019 and who were still working by the end of 2017 ($n$ = 2663) were invited by mail to participate in an activity sub-study. Of them, 908 (34 percent response rate) were sent an accelerometer after they provided a written informed consent, and thereafter, the participants were followed up annually with both surveys and accelerometer measurements. Accelerometer data were collected between September 2014 and February 2020 during all four seasons with each measurement of each participant conducted at an approximately same time each year to avoid seasonal effects. The study cohort and protocol of the FIREA accelerometer sub-study have been described in more detail elsewhere [6,19]. 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.

For the current study, we included all measurement waves from each participant that included at least one workday night (i.e. night before a workday) and one free day night (i.e. night before a free day) (range 1 – 4 measurement waves). We excluded the measurements of those shift workers who reported doing night shifts during the measurement waves. This resulted in a study sample of 824 participants who provided 1437 person-observations in total. On average, the participants provided information from 1.7 (standard deviation [SD] 0.8) measurement waves.

### 2.2. Accelerometer measurements

Two versions of a triaxial accelerometer by ActiGraph (Pensacola, FL, USA), wActiSleep-BT and wGT3X-BT, were used (see details in [6]). The participants wore the device continuously on their on-dominant wrist 24 h/d for 7 days and nights. The participants were also asked to complete a daily log while wearing the device, in which they reported their bed times for each measurement day and whether the measurement day in question was a workday or free day. By using the manufacturer's ActiLife software (version 6.13; ActiGraph, Pensacola, Florida, USA), each 60 s epoch was defined as sleep or wake using the Cole-Kripke algorithm [20], and sleep periods were then detected using an ActiGraph algorithm [21].

#### 2.2.1. Sleep characteristics

The following sleep variables were derived from the accelerometer data separately for workdays (i.e., nights before workdays) and free days (i.e., nights before free days): *bedtime, awakening time, time in bed* (i.e. total time spent in bed), and *sleep duration* (i.e., total minutes of sleep during the night). We also calculated *midpoint of sleep* by adding half of the average time in bed to the average bedtime separately for workdays and free days.

#### 2.2.2. Catch-up sleep

Catch-up sleep on free days was defined as having longer average sleep duration on free days compared with the average sleep duration on workdays, similarly as in a previous study [10]. The participants were divided into two groups: a catch-up sleep group (difference in sleep duration >0 min) and a non-catch-up sleep group (difference 0 min or less). This was done separately for each measurement of each individual.

#### 2.2.3. Chronotype and social jetlag

Chronotype was assessed based on accelerometer-measured mid-point of sleep in local time on free days corrected for the confounding effect of sleep debt [16,22]. This was done by first calculating the average weekly sleep duration (using the formula ([5 × average sleep duration of workdays] + [2 × average sleep duration of free days)/7) and then subtracting half of the oversleep on free days from the mid-point of sleep. This correction is only applied when the participant has a longer sleep duration on free days than on workdays (i.e. the catch-up sleep group) [16]. For those without catch-up sleep, the uncorrected mid-point of sleep was used to assess chronotype.

Social jetlag, the discrepancy between individual's biological and social time, was calculated as the absolute difference in minutes between the mid-point of sleep on free days and the mid-point of sleep on workdays [15,16]. Positive values of social jetlag indicate later sleep timing on free days.

### 2.3. Assessment of confounding factors

Participants' gender, date of birth, and occupational title were obtained from the pension insurance institute for the public sector in Finland (Keva Public Pensions). Occupational status was defined based on occupational titles [23] and categorized into upper grade non-manual, lower grade non-manual, and service and manual occupations. Information on all the other factors was derived from the survey completed closest to the time of each measurement.

Perceived work ability was measured with a question concerning current work ability compared with the individual's lifetime best on a scale ranging from 0 ("not able to work at all") to 10 ("my best work ability ever") and dichotomized into good (options 8 to 10) and reduced (0 to 7) [24,25]. Self-rated health was assessed with a 5-point scale (from 1 = good to 5 = poor) and categorized into good (response option 1 and 2) and suboptimal (3 to 5). Psychological distress was assessed with a 12-item version of the General Health Questionnaire [26], with a cutoff point of four or more symptoms indicating psychological distress (yes vs. no).

Lifestyle factors included physical activity (low: <14 metabolic equivalent task [MET] hours; moderate: 14 – <30 MET hours, and high: >30 MET hours) [27], weekly alcohol use (none, moderate, and heavy [>24 units/week for men and >16 units/week for women]) [28], and body mass index (normal weight [<25 $kg/m^2$], overweight [25-<30 $kg/m^2$], and obese [≥30 $kg/m^2$]).

In addition, we included some self-reported measures of sleep and tiredness. Sleep difficulties were assessed with the Jenkins Sleep Problem Scale in which the participants report the occurrence of sleep difficulties (difficulties falling asleep, difficulties maintaining sleep during the night, waking up too early in the morning, and nonrestorative sleep) during the past four weeks (never, one–three nights per month, one night per week, two–four nights per week, five–six nights per week, and nearly every night), with a frequency higher than four nights per week for the most frequent symptom indicating sleep difficulties (yes vs. no) [29]. Insufficient sleep was assessed by asking participants whether they consider sleeping enough (no vs. yes). Daytime tiredness was measured by asking participants whether they are usually more tired during the daytime compared to other people of their age (no vs. yes).

### *2.4. Statistical analyses*

Unadjusted mean estimates and their 95% confidence intervals (CI) were calculated for sleep duration, bedtimes, awakening times, and mid-point of sleep in the catch-up sleep and non-catch-up sleep groups separately for workdays and free days. In addition, we calculated mean estimates and 95% CIs for chronotype and social jetlag in catch-up sleep and non-catch-up sleep groups.

Odds ratios (OR) and their 95% CIs for having free day catch-up sleep versus not with covariates, health factors, lifestyle factors, and self-reported sleep as independent variables were estimated using binary logistic regression analyses with generalized estimating equations (GEE). The results are reported from an unadjusted model and while adjusting for age, gender, and occupational status. As one participant may contribute to multiple measurement waves, the GEE model controls for the intra-individual correlation between repeated measurements. All analyses were performed using the SAS statistical software, version 9.4.

## 3. Results

Of the 1437 person-observations, each covering approximately 6 measurement nights (SD = 0.80) with accelerometers, 78% were categorized as catch-up sleep and 22% as non-catch-up sleep observations. Detailed description of the participants ($n$ = 824) by catch-up sleep group they belonged to in their first measurement is provided in Table 1. The groups were highly similar in terms of gender, occupational status, lifestyle and health factors, self-reported sleep difficulties, insufficient sleep, and daytime tiredness. There was no difference in the mean age in the catch-up sleep group ($M$ = 62.7, SD = 1.1) and the non-catch-up sleep group ($M$ = 62.8, SD = 1.1).

As seen in Table 2, no statistically significant differences were observed between any of the measured factors with regard to the odds for catch-up sleep in the unadjusted model or while adjusting for age, gender, and occupational status.

Regarding differences in sleep parameters, sleep duration on workdays was shorter in the catch-up sleep group (6 h 27 min, 95% CI 6 h 23 min – 6 h 30 min) than in the non-catch-up sleep group (6 h 51 min, 95% CI 6 h 45 min – 6 h 57 min). On free days, the catch-up sleep group had longer sleep duration (6 h 48 min, 95% CI 6 h 44 min – 6 h 53 min) than the non-catch-up sleep group (6 h 9 min, 95% CI 6 h 2 min – 6 h 17 min). On average, the catch-up sleep group extended their sleep by 1 hour 22 min (95% CI 1 h 19 min – 1 h 26 min) on free days, whereas the non-catch-up sleep group reduced their sleep by 45 min (95% CI −50 min – −40 min). The differences in sleep duration between workdays and free days showed a large variance (see supplementary (Fig. 1).

Major differences were observed in the bedtimes and awakening times on workdays and free days between the catch-up sleep and non-catch-up sleep groups (Fig. 2). On free days, the catch-up sleep group delayed their bedtime from workdays on average by 27 min (95% CI 22 min – 31 min) and the non-catch-up sleep group by 54 min (95% CI 45 min – 1 h 3 min). Awakening times were delayed on average by 1 hour 57 min (95% CI 1 h 52 min – 2 h 2 min) in the catch-up sleep group and by 12 min (95% CI 4 min – 21 min) in the non-catch-up sleep group. There was no statistically significant difference between the groups in the mid-point of sleep on workdays ($p$ = 0.173), whereas on free days, the mid-point of sleep was much later in the catch-up sleep group (03:14 h, 95% CI 03:09 h – 03:18 h) than the non-catch-up sleep group (02:40 h, 95% CI 02:31 h – 02:49 h). Consequently, we observed a greater social jetlag in the catch-up sleep group (72 min, 95% CI 68 min – 76 min) than in the non-catch-up sleep group (33 min, 95% CI 25 min – 41 min), as indicated by a greater delay in the mid-point of sleep on free days.

When the mid-point of sleep on free days was corrected for sleep debt to indicate chronotype, there was no difference between the catch-up sleep group (02:42 h, 95% CI 02:37 h – 02:47 h) and the non-catch-up sleep group (02:39 h, 95% CI 02:30 h – 02:48 h).

## 4. Discussion

Using accelerometer measurements of sleep, this study examined the characteristics of older employees in Finland who engage in catch-up sleep during free days. Catch-up sleep was highly common with 78% of the observations containing catch-up sleep. We observed major differences in sleep timing between the catch-up sleep and non-catch-up sleep groups. The differences in the timing of sleep were also demonstrated by the greater social jetlag in the catch-up sleep group. The groups did not differ from each other in terms of sociodemographic, health and lifestyle factors, self-reported sleep, or chronotype.

Catch-up sleep was highly prevalent among older employees in our study. On one hand, this is a positive finding, as catch-up sleep may be used to compensate for sleep debt that has accumulated during workdays. On average, those in the catch-up sleep group slept little less than 6.5 h on workdays, which is below the recommended 7 to 9 h for adults under 65 years [30]; a recommendation that is, however, based on self-reported sleep duration. A recent cohort study from Sweden observed that employees who had a short sleep duration on workdays had a higher risk of death if they did not engage in catch-up sleep on weekends [14]. In addition, compensating for sleep debt by extending sleep on free days has been suggested to counteract some negative health effects related to short sleep duration by for example, protecting from weight gain [10] and low-grade systemic inflammation [13], as well as by lowering the risk for hypertension and cardiovascular diseases [11,12]. It is not known, whether compensating for sleep deprivation by catch-up sleep could also have positive impacts on work ability and work performance and further research is thus needed.

On the other hand, our findings suggest that a considerable number of older employees do not get as much sleep as they need or want during workdays, as there is a need to catch-up on free days. Besides representing catch-up sleep, a variation of sleep duration between workdays and free days has been suggested to indicate sleep debt [31]. While catch-up sleep has been associated mainly with protective effects on health, sleep debt (i.e. a difference in weekday and weekend sleep duration of at least two hours) has been linked to poorer cardiovascular health in older women [31]. These different view points raise the question of whether the variation of sleep duration between workdays and free days is a beneficial behavior that may counteract the negative health effects of sleep debt, or whether it should be discouraged as potentially contributing to inconsistent sleep schedules and circadian misalignment. Some support to the latter hypothesis is given by our finding of extended sleep dura-

**Table 1**
Characteristics of the participants ($n$ = 824) in their first measurement by catch-up sleep group.

| Characteristics | Catch-up sleep group $n$ = 654 | | Non-catch-up sleep group $n$ = 170 | |
|---|---|---|---|---|
| | n | % | n | % |
| Gender | | | | |
| Men | 94 | 14 | 18 | 11 |
| Women | 559 | 86 | 152 | 89 |
| Occupational status | | | | |
| Upper grade non-manual | 268 | 41 | 66 | 39 |
| Lower grade non-manual | 194 | 30 | 41 | 24 |
| Service and manual | 185 | 29 | 63 | 37 |
| Perceived work ability | | | | |
| Good | 502 | 78 | 129 | 76 |
| Reduced | 140 | 22 | 40 | 24 |
| Self-rated health | | | | |
| Good | 481 | 75 | 119 | 70 |
| Suboptimal | 160 | 25 | 50 | 30 |
| Psychological distress | | | | |
| No | 558 | 87 | 149 | 88 |
| Yes | 83 | 13 | 20 | 12 |
| Physical activity | | | | |
| High | 235 | 37 | 47 | 28 |
| Moderate | 182 | 28 | 58 | 35 |
| Low | 222 | 35 | 62 | 37 |
| Alcohol use | | | | |
| None | 99 | 15 | 28 | 17 |
| Moderate | 491 | 77 | 127 | 76 |
| Heavy | 50 | 8 | 13 | 8 |
| Body mass index | | | | |
| Normal weight[a] | 259 | 41 | 72 | 43 |
| Overweight | 251 | 40 | 64 | 39 |
| Obese | 120 | 19 | 30 | 18 |
| Self-reported sleep difficulties | | | | |
| No | 445 | 69 | 121 | 72 |
| Yes | 196 | 31 | 48 | 28 |
| Self-reported insufficient sleep | | | | |
| No | 513 | 84 | 136 | 87 |
| Yes | 97 | 16 | 21 | 13 |
| Daytime tiredness | | | | |
| No | 433 | 82 | 120 | 88 |
| Yes | 93 | 18 | 16 | 12 |

[a] Normal weight group includes 9 underweight participants (BMI <18.5 kg/m$^2$).

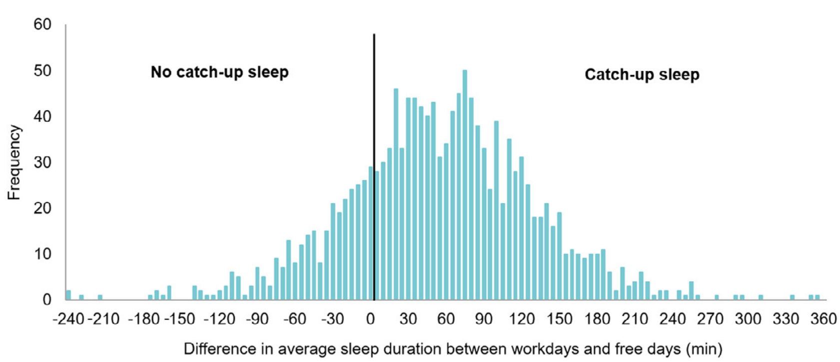


**Fig. 1.** Distribution of the differences in average sleep duration between workdays and free days.

tion on free days being associated also with a greater social jetlag, that is a greater discrepancy in bedtimes and awakening time times between workdays and free days.

While both the catch-up sleep group and non-catch-up sleep group sleeped less than recommended on workdays, it is unclear why only those in the catch-up sleep group increased their sleep duration on free days. None of the assessed socio-demographic or self-reported sleep- or health-related factors were associated with catch-up sleep. Defining why some employees with short workday sleep duration either cannot or choose not to catch-up on days off would be important. Only few studies carried out among younger populations have assessed these factors previously and found some differences in sociodemographic and health factors while relying on self-reported sleep duration [10,13].

The observed greater variation in sleep duration between workdays and days off seems to be associated also with greater discrepancy in sleep timings, as social jetlag was on average approximately 40 min greater in the catch-up sleep group than the non-catch-up sleep group. In our study, catch-up sleep seems to result mainly from a delayed time of awakening on free days. This phenomenon of “sleeping in” on free days has been observed previously among younger individuals [32]. The non-catch-up sleep group, on the other hand, delayed their bedtime, but not their wakeup time from workdays, and thus, ended up reducing their average sleep duration on free days. There may be several explanations for this type of reduced sleep duration. For example, they may have a tendency to stay up later in the evenings due to social activities or hobbies and have an early chronotype that reduces their possibility to

**Table 2**
Unadjusted and adjusted odd ratios (OR) and their 95% confidence intervals (CI) for free day catch-up sleep by characteristics of the participants.

| | Unadjusted free day catch-up sleep | | Adjusted free day catch-up sleep | |
|---|---|---|---|---|
| Characteristics | OR[a] | 95% CI | OR[b] | 95% CI |
| Gender | | | | |
| Men | 1 | | 1 | |
| Women | 1.10 | 0.76 to 1.57 | 1.06 | 0.74 to 1.53 |
| Occupational status | | | | |
| Upper grade non-manual | 1 | | 1 | |
| Lower grade non-manual | 1.29 | 0.94 to 1.78 | 1.27 | 0.92 to 1.75 |
| Service and manual | 0.94 | 0.69 to 1.29 | 0.92 | 0.67 to 1.26 |
| Perceived work ability | | | | |
| Good | 1 | | 1 | |
| Reduced | 0.86 | 0.64 to 1.15 | 0.84 | 0.62 to 1.13 |
| Self-rated health | | | | |
| Good | 1 | | 1 | |
| Suboptimal | 0.89 | 0.65 to 1.22 | 0.87 | 0.63 to 1.20 |
| Psychological distress | | | | |
| No | 1 | | 1 | |
| Yes | 0.93 | 0.61 to 1.41 | 0.92 | 0.60 to 1.40 |
| Physical activity | | | | |
| High | 1 | | 1 | |
| Moderate | 0.81 | 0.60 to 1.10 | 0.80 | 0.59 to 1.09 |
| Low | 1.14 | 0.82 to 1.58 | 1.13 | 0.81 to 1.57 |
| Alcohol use | | | | |
| None | 1 | | 1 | |
| Moderate | 1.19 | 0.85 to 1.68 | 1.18 | 0.83 to 1.67 |
| Heavy | 1.08 | 0.60 to 1.93 | 1.08 | 0.60 to 1.94 |
| Body mass index | | | | |
| Normal weight | 1 | | 1 | |
| Overweight | 1.02 | 0.76 to 1.36 | 1.03 | 0.76 to 1.39 |
| Obese | 1.19 | 0.82 to 1.72 | 1.20 | 0.83 to 1.74 |
| Self-reported sleep difficulties | | | | |
| No | 1 | | 1 | |
| Yes | 1.23 | 0.91 to 1.65 | 1.22 | 0.90 to 1.66 |
| Self-reported insufficient sleep | | | | |
| No | 1 | | 1 | |
| Yes | 1.13 | 0.78 to 1.65 | 1.11 | 0.76 to 1.62 |
| Daytime tiredness | | | | |
| No | 1 | | 1 | |
| Yes | 1.13 | 0.78 to 1.65 | 1.22 | 0.77 to 1.92 |

[a] Unadjusted.
[b] Adjusted for age, gender, and occupational status.

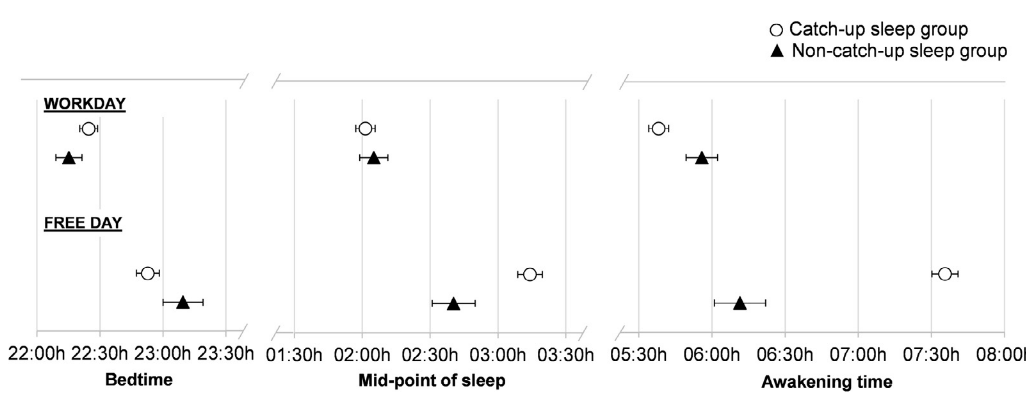


**Fig. 2.** Timing of sleep in the catch-up sleep group and the non-catch-up sleep group. Unadjusted mean estimates and their 95% confidence intervals for bedtime, mid-point of sleep, and awakening time on workdays and free days in the catch-up sleep group and the non-catch-up sleep group.

sleep longer on the mornings of the free days [15]. Although the non-catch-up sleep group indeed had an earlier mid-point of sleep on free days than the catch-up sleep group, which indicates an earlier sleep-wake rhythm, no differences were observed between the groups on the basis of chronotype. However, these results may be affected by the fact that the correction applied to calculate chronotype is only applied for people who sleep longer on free days than on workdays [16], and that consequently, only the mid-point of sleep of the catch-up sleep group is corrected to obtain chronotype.

In this study, we have considered catch-up sleep mainly as a compensatory phenomenon. However, recent studies have pointed out that the extended sleep on free days could be appetitive and rise from the increased opportunity to sleep on free days, rather than from the need for compensatory sleep [7,14]. This would indicate also that sleep duration on free days represents the preferred average nightly sleep duration. However, in our previous study among this same cohort, we observed that the “day of the week effect” on sleep duration diminished after retirement, and that the average weekly sleep duration after retirement was actually shorter than sleep duration on pre-retirement free days [6]. Furthermore, in the light of the non-catch-up group reducing their sleep duration on free days even though sleep opportunities should be increased, the hypothesis of free day sleep behavior being appetitive does not seem as credible.

The main strength of this study was the use of accelerometer measurement to define catch-up sleep as well as to examine the sleep timings contributing to catch-up sleep. In addition, we had exact information from the daily logs completed during the accelerometer measurements of whether the measurement day in question was a workday. This allowed us to compare workdays to free days rather than comparing weekdays and weekends in general without the knowledge of whether working occurred during these days.

A number of limitations of the current study need to be discussed. Firstly, some misclassification of the groups may have occurred: the relatively large number of observations close to the cut-off point of catch-up sleep may have resulted in participants with similar characteristics being classified into catch-up sleep and non-catch-up sleep groups. Furthermore, although wrist-worn accelerometers have been observed to have a high sensitivity in detecting sleep, the algorithms have been shown to identify wake episodes poorly [33]. This may signify that some immobile periods of wakefulness may have been scored as sleep, which may have impacted the estimates of sleep duration obtained in this study. However, the accelerometers could be expected to score sleep periods of each participant in a similar way on both workdays and free days and should, thus, not impact the categorization of the participants into catch-up sleep and non-catch-up sleep groups. An additional source of error is the dependency in the same measures to define both catch-up sleep and chronotype, as the calculation of chronotype depends on whether the person is experiencing sleep debt or not (i.e. the same definition for whether the person engages in catch-up sleep). Perhaps a separate measure of chronotype, such as the Munich Chronotype Questionnaire [34], could have allowed a more independent analyses between chronotype and catch-up sleep. Finally, our study population consisted of a rather homogenous and healthy sample of older employees, majority of them being women, which may have limited the statistical power to observe differences between the groups.

In conclusion, our findings suggest that accelerometer-measured free day catch-up sleep is highly prevalent among older employees. Catch-up sleep seems to be associated mainly with delayed awakening time on free days and those with catch-up sleep have also greater social jetlag in comparison to those without catch-up sleep. However, we did not observe any differences between those with and without catch-up sleep in chronotype, self-reported sleep, or sociodemographic, health, or lifestyle factors. Overall, more research is warranted on the determinants of catch-up sleep, especially in situations in which short sleep on workdays is not compensated for.

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## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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