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Seasonality of physical activity, sedentary behavior, and sleep in a middle-aged and elderly population: The Rotterdam study

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A R T I C L E I N F O

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A B S T R A C T

Introduction: Physical activity (PA) and sedentary behavior (SB) have seasonal patterns. It remains unclear how these patterns are associated with sleep, meteorological factors, and health.

Methods: Activity levels were continuously measured with an accelerometer for seven days between July 2011 and May 2016, among middle-aged (50–64 years), young-elderly (65–74 years) and old-elderly (≥75 years) participants of a population-based Dutch cohort study (n = 1116). Meteorological factors (ambient temperature, wind speed, sunlight hours, precipitation, and minimum visibility) were locally recorded. We first examined the seasonality of PA, SB, and nighttime sleep, stratified by age group. Second, we examined the influence of meteorological factors. Third, we modeled the potential seasonality of the all-cause mortality risk due to the seasonality of PA and SB, by using previously published relative risks.

Results: Levels of light and moderate-to-vigorous PA were higher in summer than in winter among middle-aged (seasonal variation = 18.1 and 14.8 min/day) and young-elderly adults (12.8 and 8.6 min/day). The pattern was explained by ambient temperature and sunlight hours. Nighttime sleep was 31.8 min/day longer in winter among middle-aged adults. SB did not show a seasonal pattern. No seasonality in activity levels was observed among old-elderly adults. The all-cause mortality risk may be higher in winter than in summer due to the accumulation of low levels of moderate to vigorous PA and high levels of SB.

Conclusion: PA has a larger degree of seasonality than SB and nighttime sleep among middle-aged and young-elderly adults. SB appears strongly ingrained in daily routine. Recommending the interruption of SB with light PA might be a good starting point for public health institutions.

1. Introduction

Population ageing, urbanization, and automatization of daily activities have contributed to a predominantly sedentary lifestyle, with low levels of physical activity (PA) and high levels of sedentary behavior (SB), but also to suboptimal nighttime sleep duration (i.e. not sleeping 7–8 h) [1,2]. However, although low levels of PA cluster with high SB and suboptimal nighttime sleep duration [1,3], these are partly independent phenomena. Moreover, the proportions of the various types of daily (in)activity (i.e. PA, SB, sleep) may influence cardiometabolic health beyond their independent effects [4–6]. Therefore, there is increasing interest in the factors determining the composition of daily activity levels.

Objective measurements with accelerometers have demonstrated that levels of PA and SB are not constant throughout the year. Studies performed in young and middle-aged populations report that time spent in PA decreases in winter [7,8], whereas sedentary time increases [9,10]. However, it is unclear whether sleep duration is related to this variation, because previous studies either used sleep diaries [10] rather than objective measures or omitted sleep as a variable of interest [9].

Several factors determine the seasonality of activity levels. For example, with increasing age, time spent in PA and nighttime sleep tends

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to decrease, while sedentary behavior increases [11,12]. Retirement may also explain this pattern, as leisure PA is more sensitive to seasonal changes than occupational PA [8]. Additionally, age interacts with meteorological factors to influence PA levels [13,14] and PA seasonality is more marked in geographical regions with more climatic variation [15,16]. However, an age-specific assessment of the impact of meteorological factors on the seasonality of activity levels has not been performed.

The seasonality of activity levels is of relevance to public health, as PA is often prescribed as a first means to improve health, e.g. to reduce dyslipidemia and high blood pressure [17]. Indeed, it is hypothesized that the seasonal pattern of cardio-metabolic risk and mortality can be partly explained by the seasonality of PA [7,18]. Nevertheless, it is not clear whether this seasonality is large enough to influence all-cause mortality on a seasonal basis.

We therefore examined the seasonality of objectively measured daily levels of PA, SB, and nighttime sleep duration according to age, using around-the-clock measurements. Furthermore, we examined to what extent meteorological factors explained the seasonality of activity levels. Finally, we modeled the seasonality of the all-cause mortality risk produced by the seasonal variation in levels of moderate to vigorous PA and SB.

2. Methods

2.1. Study design

We performed a cross-sectional study to analyze the annual seasonal variation in PA, SB and nighttime sleep duration. This study was embedded in the Rotterdam Study (RS), a prospective population-based cohort established in 1989, which has invited the participation of all middle-aged and elderly people living in the Ommoord district of Rotterdam, The Netherlands. Baseline invitations were sent to all the home addresses within the district, including senior housing facilities, retirement homes and assisted-living facilities. The aim of the Rotterdam Study was to examine the incidence of risk factors for neurological, cardiovascular, psychiatric, and other chronic diseases [19]. The study is composed of three cohorts (RS-I, RS-II and RS-III) and follow-up visits are performed every five years [19]. The Rotterdam Study has been approved by the Medical Ethics Committee of the Erasmus MC (MEC 02.1015) and by the Ministry of Health, Welfare and Sport of The Netherlands, implementing the Wet Bevolkingsonderzoek: ERGO (Population Studies Act: Rotterdam Study). All participants provided written informed consent to their involvement in the study and to obtain information from their treating physicians.

Between June 2011 and June 2014 (wave 1) and between July 2014 and May 2016 (wave 2), 3507 participants were invited to wear an accelerometer for seven days, to measure their activity levels; 482 participants were invited in both waves. Along with wearing the accelerometer, participants reported overnight sleep periods in a sleep diary. For the current study, we selected 1166 sets of observations (48 from participants who participated in both wave 1 and wave 2) obtained from non-disabled participants. Disability was defined as having a disability index > 0.5 [20]. The participation flowchart is provided in Appendix S1.

2.2. Physical activity, sedentary behavior, and nighttime sleep duration

To measure activity, we used a GENEActiv device (GENEActiv; Activinsights Ltd, Kimbolton, Cambridgeshire, UK, http://www.GENEActiv.org/), a tri-axial accelerometer that can be worn like a watch. Participants were instructed to wear the accelerometer on the non-dominant wrist for 7 consecutive days and nights. Accelerometer data were extracted and used to designate SB, as well as light, moderate, or vigorous PA. Detailed information on the assessment of accelerometer-derived PA can be found in Appendix S2 and has been presented elsewhere [21]. Nighttime sleep duration was detected using a validated algorithm [22], which combines the accelerometer data and the time when participants reported they went to bed and the reported time of waking from the sleep diary. Time-in-bed was also extracted from sleep diaries. Sleep efficiency was calculated as (nighttime sleep duration/time in bed)*100.

2.3. Meteorological factors

Daily information on meteorological factors in Rotterdam was obtained from the Koninklijk Nederlands Meteorologisch Instituut (KNMI) [23]. The monitor is located approximately 8 km from the Ommoord district (coordinates: 51° 58′ N, 04° 27′ E). The daily meteorological data were linked to the dates on which the accelerometer was worn. In the current study, we included daily average temperature (°C), average relative humidity (percentage), total number of sunlight hours, accumulated precipitation (mm), average wind speed (m/s), and minimum visibility (km), classified as < 1.8 km, 1.8–3.9 km, 3.9–7 km, 7–12 km and ≥ 12 km.

2.4. Covariates

Data on covariates were collected through home interviews or measured at the Rotterdam Study research center by trained research assistants [19], and included sex, age (years), body mass index (BMI) (kg/m^2), history of comorbidities (cardiovascular disease, diabetes, cancer or chronic obstructive pulmonary disease), smoking behavior, housing status, disability score, occupation, and alcohol intake. Data collection procedures are described in detail in Appendix S2.

2.5. Statistical methods

All analyses were stratified by age group: 50–64 years (middle-aged), 65–74 years (young-elderly) and aged 75 years or older (old-elderly). General characteristics of the population are presented as absolute frequencies and percentage for categorical variables and as median and interquartile range (25th and 75th percentile) for continuous variables. Differences in distributions between the age groups were evaluated using the Kruskal-Wallis test for continuous variables and the χ^2 test for categorical variables.

In our analysis, we first examined the seasonality of light and moderate to vigorous PA, SB, and nighttime sleep duration (in minutes/day) using a linear mixed-effects model to account for the correlation within days contributed per participant. We used the participant id as a clustering variable. Because 48 participants wore the accelerometer in both waves, we accounted for the correlation between these repeated measurements by adding a second random intercept, using the wave as a clustering variable. The seasonality was evaluated using a cosinor model assuming a sinusoidal pattern with a period of one year [8], by adding sine and cosine terms of the accelerometer wear-date in the fixed part of the model [24]. All models were adjusted for the covariates listed above, plus the day of the week (weekday or weekend day).

The seasonality is reported as the seasonal variation, corresponding to the peak-to-nadir difference in activity levels throughout the year. Procedures to estimate the seasonal variation are provided elsewhere [24]. A subgroup analysis stratified by sex was performed, including the seasonal variation in time in bed (minutes/day) and sleep efficiency (%).

Second, to examine to what extent the meteorological factors explained the seasonality of activity levels, we included one meteorological factor at a time in the fully adjusted model. Then, we calculated the difference in the seasonal variation before and after the inclusion of the meteorological factor. The influence of a meteorological factor on the seasonality of activity levels was considered significant if the seasonal variation became non-significant or was reduced by more than 5%. Average temperature was categorized in quintiles to