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# Smoking, Screen-Based Sedentary Behavior, and Diet Associated with Habitual Sleep Duration and Chronotype: Data from the UK Biobank

**Freda Patterson, PhD**[1], **Susan Kohl Malone, PhD, RN**[2], **Alicia Lozano, MS**[2,3], **Michael A. Grandner, PhD, MTR**[4], and **Alexandra L. Hanlon, PhD**[2]

[1]Department of Behavioral Health and Nutrition, University of Delaware, Bob Carpenter Sports Building, 26 N College Avenue, Newark, DE 19716, USA

[2]School of Nursing, University of Pennsylvania, 418 Curie Blvd, Philadelphia, PA 19104, USA

[3]Drexel University School of Public Health, Nesbitt Hall, 3215 Market Street, Philadlephia, PA 19104, USA

[4]Sleep and Health Research Program, Department of Psychiatry, University of Arizona College of Medicine, 1501 N Campbell Ave, Box 245002, Tucson, AZ 85724-5002, USA

## Abstract

**Background—**Sleep duration has been implicated in the etiology of obesity but less is known about the association between sleep and other behavioral risk factors for cardiovascular disease.

**Purpose—**The aim of this study was to examine the associations among sleep duration, chronotype, and physical activity, screen-based sedentary behavior, tobacco use, and dietary intake.

**Methods—**Regression models were used to examine sleep duration and chronotype as the predictors and cardiovascular risk factors as outcomes of interest in a cross-sectional sample of 439,933 adults enrolled in the UK Biobank project.

**Results—**Short sleepers were 45 % more likely to smoke tobacco than adequate sleepers (9.8 vs. 6.9 %, respectively). Late chronotypes were more than twice as likely to smoke tobacco than intermediate types (14.9 vs. 7.4 %, respectively). Long sleepers reported 0.61 more hours of television per day than adequate sleepers. Early chronotypes reported 0.20 fewer daily hours of computer use per day than intermediate chronotypes. Early chronotypes had 0.25 more servings of fruit and 0.13 more servings of vegetables per day than late chronotypes.

✉ Freda Patterson, fredap@UDel.edu.

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**Compliance with Ethical Standards**: **Conflict of Interest**: Authors' Statement of Conflict of Interest and Adherence to Ethical Standards Authors Freda Patterson, Susan Kohl Malone, Alicia Lozano, Michael A. Grandner, and Alexandra L. Hanlon declare that they have no conflict of interest. All procedures, including the informed consent process, were conducted in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

**Conclusions—**Short and long sleep duration and late chronotype are associated with greater likelihood of cardiovascular risk behaviors. Further work is needed to determine whether these findings are maintained in the context of objective sleep and circadian estimates, and in more diverse samples. The extent to which promoting adequate sleep duration and earlier sleep timing improves heart health should also be examined prospectively.

### Keywords

Sleep duration; Chronotype; Physical activity; Sedentary behavior; Tobacco use; Dietary intake

## Introduction

Low levels of physical activity, poor dietary intake, and tobacco use are likely causal behaviors in 40 % of all cardiovascular deaths in the USA and UK [1, 2]. Prevention efforts to address these risk behaviors have made modest progress. Currently, 49 % of adults do not meet the recommendations for regular aerobic physical activity [3], only 20 % consume sufficient fruits and vegetables [4], and while smoking rates have steadily declined in the last 30 years, approximately one-in-five adults smoke tobacco and this rate climbs to as high as 47.5 % in General Educational Development (GED) test graduates [5]. All told, less than 5 % of adults meet standards for ideal behaviors that support heart health as defined by the American Heart Association [6]. To accelerate progress toward reduced mortality from poor health behaviors, there is a need to identify novel behavioral targets that are central to the disease risk factors of physical inactivity, screen-based sedentary behavior, dietary intake, and tobacco use.

As a common physiologic function that has been implicated in the etiology of cardiovascular risk behaviors [7–11], and diseases [12], sleep may be such a target. Sleep is a complex and multidimensional function that encompasses independent, but related, metrics including duration (e.g., hours of sleep in a 24-h period) and chronotype [13]. Chronotype is a demonstrated preference for morning or eveningness that results from endogenous biological rhythms and is influenced by environmental (e.g., light) and socio-occupational (e.g., employment hours) factors [14–16]. Importantly, sleep duration and chronotype are potentially modifiable [17]. If sleep were identified as being independently associated with several behavioral cardiovascular risk factors (e.g., tobacco use and physical inactivity), then hypothetically, sleep may be a common function that could be leveraged to optimize response to interventions designed to address these heart health behaviors.

Before sleep can be identified as a central risk factor for poor heart health behaviors, the magnitude of the relationship between sleep and cardiovascular risk behaviors must be quantified, and a profile of at-risk sleep behaviors defined. To date, there is evidence that sleep duration, and to a lesser extent, chronotype, are associated with physical inactivity, diet intake, and tobacco use. For example, higher levels of physical activity have been positively associated with sleep duration in younger and middle-aged men, but showed a curvilinear relationship in those aged 60 years or older [18]. Higher levels of physical activity were observed in younger and middle-aged women who achieved at least 8 hours of sleep per day [18]. Low levels of physical activity have been associated with sleep disorders [19]. In terms of sleep chronotype, a small number of studies have shown later bedtime, waketime, and midpoint of sleep to be associated with lower levels of physical activity [20]. Early chronotypes perform activities better during the morning hours [21] while late chronotypes may have poorer recovery from morning exercise [22].

With regard to dietary intake, both short and long sleep are predictive of poorer dietary intake [23, 24]. Chronotype has been shown to influence dietary intake such that late chronotypes consume more calories in the evening [25], eat fewer fruits and vegetables and more saturated fats [25–28] than early chronotypes. This is important because later meal timing has been associated with weight gain [29] as well as resistance to weight loss interventions [30].

Increasing sleep duration may improve eating habits while shifting caloric intake towards the morning or limiting intake after 8 pm [25]. In addition, some data show sleep duration and chronotype are associated with tobacco use. Short sleep is associated with current or former smoking status [31, 32] while both short and long sleep are associated with higher cigarette consumption [31, 33]. Tobacco use is more prevalent among late chronotypes in adults [34–36] and adolescents [37, 38]. Smokers have also been shown to have delayed sleep onset as compared to non-smokers, [39] which can promote late chronotype.

Together, these lines of evidence provide a basis to hypothesize that sleep may be central to multiple cardiovascular risk behaviors. To advance this work, population studies are needed to indicate the magnitude of association between different sleep metrics (i..e, duration and chronotype) with a range of leading behavioral risk factors (i.e., physical activity, screen-based sedentary behavior, dietary intake, and tobacco use), to determine if there is a common phenotype of behavioral cardiovascular risk across a range of risk behaviors (i.e., short sleepers and late chronotypes associated with poor levels in all risk behaviors). To this end, the purpose of this study is to evaluate the main association between sleep duration (short, adequate, and long) and chronotype (early, intermediate, late) with physical activity, screen-based sedentary behavior (television viewing, computer use), dietary intake (daily fruit and vegetable intake), and current smoking, in a population sample of 439,933 adults. Consistent with the smaller, single-outcome studies conducted in this area to date [25, 36, 40], we hypothesize that short sleep and late chronotype will be associated with poor cardiovascular health behaviors. A positive signal from this descriptive study would propel this area of work by identifying a sleep phenotype for cardiovascular behavioral risk.

# Methods

## Study Design and Participants

To examine the relationship between sleep duration and chronotype with physical activity, sedentary behavior, dietary intake, and tobacco use, population data from the United Kingdom (UK) Biobank (application # 3474) were analyzed. The UK Biobank is a prospective cohort study that began in 2005. Using patient registers from the UK National Health Service (NHS), adults aged 40–69 years who live within a 10-mile radius of one of the UK Biobank's 35 assessment centers are invited to participate. At a baseline visit, participants provided written informed consent and completed a touch screen questionnaire that assessed sociodemographic, lifestyle, and health behavior variables. Between 2006 and 2010, 502,656 eligible and consenting adults provided baseline data and these data were used in the current analysis. More expansive details about the rationale, design, and survey methods for UK Biobank have been described elsewhere [41, 42] and information on data availability and access procedures are given on the study website [43].

## Measures

### Independent Variables: Sleep Duration and Chronotype

**Sleep Duration:** Sleep duration was assessed with the survey item "About how many hours sleep do you get in every 24 h? (Please include naps.)" Responses were coded in integers and categorized into the following categories for analysis: very short (≤4 h), short (5–6 h), adequate (7–8 h), and long (≥9 h) based on previous data linking sleep duration to cardiometabolic disease risk in a US population sample [44].

**Chronotype:** Chronotype assessed using the question "Do you consider yourself to be…?" (definitely a morning person, more a morning than an evening person, more an evening than a morning person, definitely an evening person) [45]. For analysis, chronotype was categorized as early ("definitely morning person"), intermediate-early ("more a morning than an evening person"), intermediate-late ("more an evening than a morning person"), and late ("definitely evening"). Self-reported chronotype has been validated with self-reported sleep-wake times [46].

### Dependent Variables: Health Behaviors

**Physical Activity:** Participants estimated how many days in a typical week they engaged in walking, moderate, and vigorous activity for ten or more minutes [47]. Minutes per week spent in each activity (walking, moderate, vigorous) were calculated and used in the analysis.

**Screen-Based Sedentary Behavior:** Participants estimated how many hours per day they spend using a computer and watching TV on a typical day [47].

**Diet Variables: Fruit Consumption:** To evaluate fruit intake, participants were asked to consider their dietary intake in the last year and to answer: "About how many pieces of FRESH fruit would you eat per DAY?" Each piece of fruit counted as one portion and median daily fruit intake was calculated and used in the current analysis.

**Vegetable Consumption:** To evaluate vegetable intake, participants were asked to consider their dietary intake in the last year and to answer: "On average how many heaped tablespoons of COOKED vegetables would you eat per DAY?" "On average how many heaped tablespoons of SALAD or RAW vegetables would you eat per DAY?" Based on the UK guidelines [48] that a portion of vegetables is three heaped tablespoons, median vegetable consumption on the average day was calculated and used in the current analysis.

**Tobacco Use:** Self-reported current smoking status was evaluated using a single item: "About how many cigarettes did you smoke on average each day?" Participants who reported smoking any cigarettes (including less than one per day) were categorized as being smokers while the remainder of the sample were considered non-smokers.

**Control Variables: Sociodemographic characteristics—**Sociodemographic variables included in the analysis were age, sex (male/female), ethnicity (coded as White, Asian/ Asian British/Chinese, Black/Black British, and mixed/other), attended college (coded as yes/no), and employment (coded as employed, not-employed, or retired).

### Analysis

Cross-sectional data from 501,766 participants were obtained. Participants with responses coded "don't know", "prefer not to answer", or missing data for sleep duration or chronotype were excluded leaving 439,933 participants in the final sample. Participants included in the final analysis were significantly more likely to be female, white, college attendees, and employed; thus, all multivariate analyses were adjusted for these variables.

To examine variation in sleep duration and chronotype with health behavior variables, descriptive statistics and regression models were estimated. For the descriptive analysis, prevalence of very short (<4 h), short (5-6 h), adequate (7-8 h) and long (nine or more hours) sleep [44] and chronotype (early, intermediate-early, intermediate-late, and late) were computed for all sociodemographic and health behavior characteristics. Normally distributed continuous variables were described using means and standard deviations, while non-normally distributed variables were described using medians and interquartile ranges. Categorical variables were described using frequencies and percentages.

To quantify the association between sleep duration and chronotype with health behavior outcomes, a regression model for each health behavior that included both sleep variables (duration and chronotype) and adjusted for sex, race, college attendance, and employment was generated. A three level sleep duration variable was used that collapsed the very short and short sleep categories allowing differences in short versus adequate sleep and long versus adequate sleep for each of the health behaviors to be described. A three level chronotype variable that collapsed more intermediate-early and intermediate-late into an "intermediate" category was used to examine differences in early versus intermediate chronotype, late versus intermediate chronotype, and early versus late chronotype for each of the health behaviors. General linear and binary logistic regression models were generated for continuous and dichotomous outcomes, respectively. Parameter estimates, along with their standard errors and 95 % confidence intervals, are provided for measures of effect in general linear models, while odds ratios are provided for logistic regression models. Statistical significance is taken at the 0.05 level. All statistical analyses were accomplished using SAS V9.3 (SAS Institute, Cary, NC).

## Results

### Participant Sociodemographic, Sleep, and Health Behavior Characteristics

The sample was comprised of 439,933 adults (Table 1). The mean age of the sample was 56.5 (SD = 8.1) years, 56 % were female, 95 % were White, 58 % were employed, and 39.5 % had attended college. On average, the sample was overweight with a mean body mass index of 27.4 kg/m$^2$ (SD=4.8). In terms of sleep duration, 68 % of the sample reported 7–8 h for sleep in a 24-h period (adequate sleep), 1 % reported getting four or fewer hours (very short sleep), 24.5 % reported 5–6 h (short sleep), and 8 % reported nine or more hours of sleep (long sleep). Twenty-seven percent of the sample were early chronotype, 36 % intermediate-early chronotype, 28 % were intermediate-late chronotype, and 9 % were late chronotype.

Participants reported engaging in a mean of 328.5 min (SD =377.0 min) or 6.3 h of walking activity each week. Mean minutes of moderate activity per week was 286.4 min (SD=369.4 min) or 4.8 h, and mean vigorous activity per week was 140.7 min (SD=188.7 min) or 2.3 h. Screen time was reported for a median of 1 (computer; IQR=1) to 3 (television; IQR=2) hours per day. Median daily servings of fruit was 2.0 (IQR=2) and vegetables was 1.3 (IQR=1.0). Eight percent of the sample reported current smoking (Table 1).

## Association Between Sleep and Physical Activity

Physical activity levels varied by sleep duration. Short sleepers accrued more mean minutes of walking, moderate, and vigorous activity than adequate sleepers (Table 1). Across the different chronotype categories, early chronotypes reported accruing more mean minutes of walking, moderate, and vigorous activity than intermediate or late chronotypes (Table 2).

Linear regression models of walking, moderate, and vigorous physical activity that adjusted for age, sex, ethnicity, employment, and college attendance showed that overall, short sleepers reported more minutes of physical activity per week than adequate sleepers. Long sleepers reported more minutes of moderate and vigorous activity than did adequate sleepers, although the differences, while statistically significant, were trivial (Table 3). The largest point estimate was noted for vigorous activity whereby short sleepers accrued on average, 0.10 more minutes per week of vigorous activity a week than adequate sleepers.

Multivariate examination of the association between chronotype and physical activity (Table 3) showed that early chronotype was associated with more physical activity. The largest effect size for this was seen with vigorous activity: on average, early chronotypes accrued 0.13 more minutes of vigorous activity per week than intermediate types (independent of sleep duration). Similarly, early chronotypes accrued, on average, 0.18 more minutes per week of walking and 0.17 more minutes of moderate activity, and 0.17 more minutes of vigorous activity per week than late chronotypes (Table 4).

## Association Between Screen-Based Sedentary Behavior and Sleep

Little variation was found in screen-based sedentary behaviors (computer use and television viewing) across the sleep duration categories. Median computer use was 1 h/day and median television use was 3 h/day for short, adequate, and long sleepers. Examination of variation in screen-based sedentary behavior by chronotype category showed that early chronotypes had lower median hours of computer use per day (0.5) than intermediate or late chronotypes (median=1.0). All chronotype groups reported a median of 3.0 h of television viewing per day (Table 2).

In the multivariate analysis of the association between sedentary behavior and sleep, data showed that television viewing varied considerably across sleep duration categories: on average, short sleepers reported 0.20 more hours of television viewing per day than adequate sleepers while long sleepers reported on average 0.61 more hours of television per day than adequate sleepers. Late chronotypes reported more screen-based sedentary behavior than early chronotypes. For example, early chronotypes had 0.31 fewer hours of computer use and 0.14 fewer hours of television viewing per day than late chronotypes (Table 4).

## Association Between Dietary Intake, Body Mass Index, and Sleep

Little variation in fruit and vegetable consumption across the sleep duration and chronotype categories was seen. Specifically, median fruit consumption was 2.0 (IQR=2.0), and median vegetable consumption was 1.3 (IQR=1.0) across all sleep duration categories (Table 1). Fruit intake did not vary across chronotype categories (Median=2.0, IQR=2.0) while early chronotypes reported a slightly higher median daily vegetable intake of 1.5 servings per day as compared to 1.3 median servings reported by intermediate and late groups (Table 2).

The multivariate associations between sleep duration and chronotype with the dietary intake variables of fruit and vegetable consumption did not follow a consistent pattern (Tables 3 and 4). Longer sleep duration was negatively associated with daily fruit intake, but positively associated with vegetable intake (Table 3). Short sleepers consumed, on average, 0.02 more servings of fruit per day than adequate sleepers. In terms of variation in fruit and vegetable consumption across chronotype, early chronotypes consumed, on average, 0.14 more servings of fruit and 0.11 more servings of vegetables, per day than intermediate chronotypes. Late chronotypes consumed, on average, 0.10 fewer daily servings of fruit and 0.02 fewer daily servings of vegetables than intermediate chronotypes.

## Tobacco Use and Sleep

Considerable variation in tobacco use across the sleep duration and chronotype categories was seen. Specifically, 9.8 % of short sleepers, 6.9 % of adequate sleepers, and 9.4 % of long sleepers reported current smoking (Table 1). The percentage of respondents who smoked cigarettes progressively increased across the early/late chronotype range: 6.4 % of early chronotypes and 14.9 % of late chronotypes reported current smoking (Table 2).

Logistic regression models of current smoking show that individuals with short and long sleep duration (versus adequate) and late chronotypes (versus intermediate) had an increased odds of being current smokers (Tables 3 and 4). As compared to adequate sleepers, short sleepers had a 45 % increased odds of being smokers (OR =1.450, SE= 0.018) while compared to adequate sleepers, long sleepers had a 36 % greater odds of being smokers (OR = 1.359, SE = 0.027) (Table 3). When chronotype was considered, early chronotype had a 17 % reduced odds of being a current smoker as compared to intermediate types (OR = 0.833, SE=0.012) while late chronotype had a more than twofold increased odds of being a smoker than intermediate types (OR=2.126, SE=0.034) (Table 4), independent of sleep duration. Late chronotypes had a 60 % increased odds of being a smoker than morning types (OR=0.407, SE=0.11) (Table 4).

## Discussion

The purpose of this population analysis was to explore the association between sleep duration, chronotype, and the behavioral risk factors for cardiovascular disease (physical activity, dietary intake, tobacco use) in a large population sample. Consistent with the study hypothesis, these population-level data clearly suggest that short and long sleepers and late chronotypes are groups at increased risk for poor cardiovascular health behaviors. Notably, short (versus adequate) sleepers had a 45 % increased odds of being current smokers and late (versus early) chronotypes had a 60 % increased odds of being a smoker. Long sleepers accrued 0.61 more hours of television per day than adequate sleepers. Early chronotypes on average had 0.31 fewer daily hours of computer use and 0.14 fewer hours of television and 0.25 more servings of fruit and 0.13 more servings of vegetables than late chronotypes. These data converge with previous work demonstrating that adequate sleep is associated with beneficial heart health behaviors and extend what is known by suggesting that sleep timing, in particular, late chronotype patterns are associated with poor heart health behaviors.

Our findings that the odds of current smoking was lower in adequate sleepers and higher in short and long sleepers both support and extend previous work. As a stimulant, nicotine use has been widely associated with short sleep duration [32, 49], extended sleep latency [39], increased perceptions of insufficient sleep [50], and increased risk for insomnia [51]. Night-time smoking, a frequent cause of disrupted and shortened sleep, occurs in approximately 41 % of smokers [52]. These findings directly converge with our data showing that short sleepers had a 45 % increased odds of being smokers (versus adequate sleepers). Not previously shown is our finding that long sleepers had a 36 % increased odds of current smoking as compared to adequate sleepers. One possible reason for this association is the co-occurrence of depression with long sleep. Clinical and sub-clinical depression occur in up to 50 % of current smokers [53, 54] while extended sleep periods, daytime sleepiness, and fragmented night-time sleep are all characteristic of individuals with depression [55]. Smokers with elevated depressive symptoms may be apt to sleeping for longer periods and/or experience more daytime sleeping.

Our result that late chronotype had a 60 % increased odds of being a current smoker as compared to early chronotypes is congruent with the few previous studies to have examined this relationship in adults [34, 36, 56]. The association between late chronotype and current smoking could be at least partially explained by evidence showing that several affective and emotional traits are common to both smokers and late chronotypes. For example, sensation seeking, impulsivity attention deficit, anger, and negative mood have been reported as more common in late versus early chronotypes [57–59] and in smokers versus non-smokers [60, 61]. Nicotine administration has been shown to ameliorate these negative affective states [62, 63]; thus, it could be argued that affect and mood regulation is promoted by continued tobacco use in late chronotypes. Relatedly, increases in affective states such as anger [64] and impulsivity [65] following smoking cessation predict relapse while cessation has been reported by early chronotypes as “easier” [66]. Promoting adequate sleep and earlier sleep preference and timing may be a viable smoking cessation intervention component.

The association between longer sleep duration and late chronotype with lower levels of physical activity found in this study was marginal, but did converge with a small number of other studies examining this question [40, 67, 68]. More noteworthy was the finding that long sleepers accrued on average 0.61 more television viewing hours per day than adequate sleepers. Previous work has been mixed in this area. One other study also found long sleep duration to be associated with more television viewing than adequate sleep [69], while data from the American Time Use Survey showed an inverse relationship between sleep duration and amount of time spent watching television [70]. The importance of long sleepers reporting significantly more television viewing time lies in the fact that sedentary behavior is an independent risk factor for cardiovascular disease [71, 72]. For example, ten or more hours of sitting per day increased cardiovascular diseases risk by 18 % (Hazard ratio = 1.18; 95% CI = 1.09–1.29) as compared to five or fewer hours [73], while four or more hours (versus ≤1) of screen-based sedentary behavior per day (TV and recreational computer use) was associated with an adjusted twofold greater prevalence (Prevalence Ratio = 2.09; 95 % CI = 1.16, 3.75) of insulin levels indicative of hyperinsulinemia (N20 μU/mL) [74]. Sedentary behavior is also highly associated with higher body mass index and lower activity levels [75, 76]. This potential clustering of negative behaviors (television viewing, higher body mass index, low physical activity) represents a group at high risk for cardiovascular disease.

Longer sleep duration and late chronotype were associated with lower daily fruit and vegetable intake, in fact, early chronotypes consumed 0.25 more servings of fruit and 0.133 more servings of vegetables daily than late chronotypes. Consistent with these data, previous studies have also shown late chronotypes to have less healthful dietary habits and a tendency for a higher body mass index (BMI) [27, 77]. In terms of relating fruit and vegetable intake to risk for cardiovascular disease, a recent meta-analysis showed that adults consuming five daily servings of fruit and vegetables (~400 g) had a 15 % reduced risk of CVDs, while those consuming 2.5 daily servings (~200 g) had a 8 % reduced risk of CVDs compared to adults who did not eat any fruit and vegetables over a 10.5-year follow-up period [78]. Thus, even incremental differences in daily fruit and vegetable consumption could impact disease risk across time.

Our findings that more healthful cardiovascular health behaviors (i.e., more physical activity, less screen-based sedentary behavior, higher fruit and vegetable intake, non-tobacco use) was associated with early chronotype could also be at least partially explained by personality factors. Conscientiousness has been identified as the strongest personality predictor of diurnal preference [79], with early chronotype and conscientiousness being highly correlated [80]. Early chronotype is also associated with traits related to conscientiousness including lower levels of procrastination [81] and higher levels of self-control and emotional stability [81, 82]. Given that conscientiousness has been positively associated with habitual physical activity [83] and negatively associated with body mass index [84] and current tobacco use [85], it could be argued that personality characteristics are an integral part of explaining the variance in chronotype and positive health behaviors.

Collectively, our data show that short and long sleepers (i.e., non-adequate sleepers) and late chronotypes may benefit from clinical and population level approaches to encourage adequate sleep duration and earlier sleep/wake timing. From a health behavior perspective, the multiple health behavior change (MHBC) framework has been gathering momentum in the last decade [86, 87]. One of the central themes of the MHBC framework is the consideration of the sequencing of behaviors to change. For example, does change in one behavior incite behavior change in another [88], or is a concurrent approach more effective? [89]. Sleep is associated with cardiovascular morbidity and mortality [90] and this population analysis has shown that sleep is significantly associated with all three of the main risk behaviors for poor heart health. Together, this presents the hypothesis that sleep duration and timing may both directly and *indirectly* affect cardiovascular morbidity and mortality. Indirectly, sleep may influence the incidence and severity of tobacco use, inactivity, and poor dietary intake. On this basis, it could be argued that promoting adequate sleep and earlier wake/sleep timing may be a necessary precursor in the MHBC sequence of achieving optimal change in tobacco, activity, and dietary behaviors.

Reshaping of environmental features to adjust sleep timing and promote adequate sleep represents plausible intervention approaches to improving sleep. For example, increasing light exposure in the natural environment shifts sleep timing earlier [91], while exposure to ambient light at night either from ereaders [92] or urban lighting [93] promotes “lateness.” Noise from air conditioning and fans [94] and street noise relate to poorer sleep quality [94, 95] while improvements in urban housing quality [96] also improve sleep. Given the current data showing the vulnerability of long sleepers and late chronotypes to poor heart health behaviors, consideration of how environment structures can be manipulated to promote better sleep may be important for better cardiovascular health.

The current study is one of the first large-scale population studies to concurrently evaluate the association between the sleep metrics of duration and chronotype with physical activity, screen-based sedentary behavior, tobacco use, and dietary intake. Main limitations include the use of self-report behavioral data and a cross-sectional design that prevents consideration of the temporal relationship between these variables. These data should also be interpreted with consideration of the fact that the sleep duration variable did not distinguish between work days and free days [13] and that portion size for fruit and vegetable intake used UK (not USA) guidelines. Moreover, choronotype was estimated using self-categorization and not clock times that would have allowed the identification of the sleep mid-point [97]. Nevertheless, these results showing that long sleepers and late chronotypes are more vulnerable to negative heart health behaviors represent a novel and important contribution to this literature. Further work in this area is needed to determine whether objective measures of these (and other) sleep metrics are predictive of heart health behaviors in a diverse sample across time and subsequently whether improving sleep (i.e., achieving adequate sleep duration, earlier timing) effectively promotes heart health. The interactive effects of sleep duration and timing on cardiovascular risk behaviors and outcomes also warrant consideration. The elucidation of sleep as a novel behavioral target for heart health promotion may be a key to reaching the American Heart Association's goal of a 20 % improvement in cardiovascular health before the year 2020.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## Table 1

**Prevalence of short, adequate, and long sleep duration for participant sociodemographic and health behavior characteristics**

| Sleep duration category | Total sample | Short ≤6 h | Adequate 7–8 h | Long ≥9 h |
|---|---|---|---|---|
| Total sample | 439, 933 | 107,718 (24.6) | 297,914 (67.7) | 33, 893 (7.7) |
| Sociodemographic characteristics | | | | |
| Age in years [mean (SD)] | 56.5 (8.1) | 56.4 (7.9) | 56.4 (8.1) | 58.5 (8.0) |
| Sex [*N* (%)] | | | | |
| Female | 245, 079 (55.7) | 59,176 (54.7) | 166,452 (55.9) | 19,451 (57.4) |
| Male | 194,854 (44.3) | 48,950 (45.3) | 131,462 (44.1) | 14,442 (42.6) |
| Ethnic group [*N* (%)] | | | | |
| Mixed/other | 6298 (1.4) | 2117 (2.0) | 3718 (1.3) | 463 (1.3) |
| Asian/Asian/British/Chinese | 9597 (2.2) | 2867 (2.7) | 5992 (2.0) | 738 (2.2) |
| Black/Black British | 6601 (1.5) | 3004 (2.8) | 3172 (1.1) | 425 (1.3) |
| White | 416,106 (94.9) | 99,730 (92.6) | 284,224 (95.6) | 32,152 (95.2) |
| Employment [*N* (%)] | | | | |
| Unemployed | 35,829 (8.2) | 10,330 (9.6) | 20,507 (6.9) | 4992 (14.9) |
| Retired | 146,531 (33.6) | 31,668 (29.6) | 97,787 (33.1) | 17,076 (50.9) |
| Employed | 253,835 (58.2) | 65,123 (60.8) | 177,240 (60.0) | 11,472 (34.2) |
| Attended college [*N* (%)] | | | | |
| Yes | 142, 955 (39.5) | 30,704 (35.9) | 103,936 (41.3) | 8315 (33.5) |
| No | 218,815 (60.5) | 54,745 (54.1) | 147,599 (58.7) | 16,471 (66.5) |
| Chronotype [*N* (%)] | | | | |
| Early | 119,110 (27.1) | 33,670 (31.1) | 77,126 (25.9) | 8314 (24.5) |
| Intermediate | 281,266 (63.9) | 63,137 (58.4) | 196,437 (65.9) | 21,692 (64.0) |
| Late | 39,557 (9.0) | 11,319 (10.5) | 24,351 (8.2) | 3887 (11.5) |
| Health behavior characteristics | | | | |
| Physical activity (minutes/week) [Mean (SD)] | | | | |
| Walking | 328.5 (377.0) | 347.1 (399.8) | 323.4 (370.1) | 316.0 (360.5) |
| Range for walking 0–2100 min/week | | | | |
| Moderate | 286.4 (369.4) | 299.6 (386.1) | 280.2 (362.9) | 301.8 (373.6) |
| Range for moderate 0–2100 min/week | | | | |
| Vigorous | 140.7 (188.7) | 154.7 (215.3) | 136.0 (178.0) | 142.9 (197.4) |
| Range for vigorous 0 – 2100 min/week | | | | |
| Screen-based sedentary behavior (hours/day) [median (interquartile range; IQR)] | | | | |
| Computer use | 1.0 (1.0) | 1.0 (1.0) | 1.0 (1.0) | 0.5 (1.0) |
| Television viewing | 3.0 (2.0) | 3.0 (2.0) | 3.0 (2.0) | 3.0 (2.0) |
| Dietary habits [median servings/day (interquartile range; IQR)] | | | | |
| Fruits | 2.0 (2.0) | 2.0 (2.0) | 2.0 (2.0) | 2.0 (2.0) |
| Vegetables | 1.3 (1.0) | 1.3 (1.0) | 1.3 (1.0) | 1.3 (1.0) |
| Current smoking [*N* (%)] | | | | |
| Yes | 34,401 (7.8) | 10,615 (9.8) | 20,589 (6.9) | 3197 (9.4) |

| Sleep duration category | Total sample | Short<br>≤6 h | Adequate<br>7–8 h | Long<br>≥9 h |
|---|---|---|---|---|
| No | 405,212 (92.2) | 97,410 (90.2) | 277,140 (93.1) | 30,662 (90.6) |

## Table 2

**Prevalence of chronotype categories (early, intermediate, late) for participant sociodemographic and health behavior characteristics (*N* = 439, 933)**

| | Chronotype category | | |
|---|---|---|---|
| | **Early** | **Intermediate** | **Late** |
| Total sample | 119,110 (27.1) | 281,266 (63.9) | 39,557 (9.0) |
| Sociodemographic characteristics | | | |
| Age [mean (SD)] | 57.4 (7.8) | 56.4 (8.1) | 55.1 (8.3) |
| Sex [*N* (%)] | | | |
| Female | 67,296 (56.5) | 156,682 (55.7) | 21,101 (53.3) |
| Male | 51,814 (43.5) | 124,584 (44.2) | 18,456 (46.7) |
| Ethnic group [*N* (%)] | | | |
| Mixed/other | 1946 (1.7) | 3599 (1.3) | 753 (1.9) |
| Asian/Asian/British/Chinese | 3564 (3.0) | 5418 (1.8) | 885 (2.2) |
| Black/Black British | 2287 (1.9) | 3651 (1.3) | 663 (1.7) |
| White | 110,941 (93.4) | 268,090 (95.6) | 37,075 (94.2) |
| Employment [*N* (%)] | | | |
| Unemployed | 9227 (7.8) | 22,023 (7.9) | 4579 (11.7) |
| Retired | 42,586 (36.1) | 92,969 (33.3) | 10,976 (28.0) |
| Employed | 66,161 (56.1) | 164,090 (58.8) | 23,584 (60.3) |
| Attended college [*N* (%)] | | | |
| Yes | 35,203 (38.2) | 51,653 (39.6) | 15,591 (45.4) |
| No | 56,956 (60.8) | 78,733 (60.4) | 18,741 (54.6) |
| Health behavior characteristics | | | |
| Physical activity (minutes/week) [mean (SD)] | | | |
| Walking | 357.5 (393.9) | 322.1 (372.4) | 285.8 (349.0) |
| Range for walking 0–2100 min/week | | | |
| Moderate | 316.3 (390.0) | 278.5 (362.9) | 250.5 (342.9) |
| Range for moderate 0–2100 min/week | | | |
| Vigorous | 159.8 (214.2) | 134.3 (177.9) | 128.0 (175.5) |
| Range for vigorous 0–2100 min/week | | | |
| Screen-based sedentary behavior (hours/day) [median (interquartile range; IQR)] | | | |
| Computer use | 0.5 (1.0) | 1.0 (1.0) | 1.0 (1.5) |
| Television viewing | 3.0 (2.0) | 3.0 (2.0) | 3.0 (2.0) |
| Diet intake [median servings/day (interquartile range; IQR)] | | | |
| Fruits | 2.0 (2.0) | 2.0 (2.0) | 2.0 (2.0) |
| Vegetables | 1.5 (1.0) | 1.3 (1.0) | 1.3 (1.0) |
| Current smoking [*N* (%)] | | | |
| Yes | 7609 (6.4) | 20,890 (7.4) | 5902 (14.9) |
| No | 111,419 (93.6) | 260,177 (92.6) | 34,047 (85.1) |

**Table 3**

**Regression models of physical activity, screen-based sedentary behavior, and diet variables on sleep duration and chronotype ($N$ = 439,933)**

| Dependent variable | Physical activity (minutes/week) | | | Screen-based sedentary behavior (hours/day) | | Diet variables | | Tobacco use |
|---|---|---|---|---|---|---|---|---|
| | Walking | Moderate | Vigorous | Computer use | Television viewing | Fruit Servings/day | Vegetables Servings/day | |
| Comparison[a] | β (SE)<br>95 % CI | β (SE)<br>95 % CI | β (SE)<br>95 % CI | β (SE)<br>95 % CI | β (SE)<br>95 % CI | β (SE)<br>95 % CI | β (SE)<br>95 % CI | OR (SE)<br>95 % CI |
| Short sleep duration | 0.060 (0.004)<br>0.052–0.068 | 0.049 (0.004)<br>0.041–0.057 | 0.093 (0.005)<br>0.083–0.102 | 0.049 (0.004)<br>0.042–0.056 | 0.201 (0.006)<br>0.190–0.213 | 0.017 (0.004)<br>0.010–0.024 | 0.008 (0.004)<br>0.001–0.015 | 1.450 (0.018)<br>1.415–1.486 |
| Long sleep duration | −0.016 (0.006)<br>−0.028 to −0.004 | 0.062 (0.007)<br>0.048–0.075 | 0.039 (0.008)<br>0.023–0.056 | −0.067 (0.006)<br>−0.078 to −0.056 | 0.614 (0.010)<br>0.595–0.633 | −0.042 (0.006)<br>–0.053 to −0.031 | 0.020 (0.006)<br>0.008–0.031 | 1.359 (0.027)<br>1.306–1.413 |
| Early chronotype | 0.090 (0.004)<br>0.083–0.098 | 0.100 (0.004)<br>0.092–0.108 | 0.130 (0.005)<br>0.121–0.139 | −0.020 (0.004)<br>−0.027 to −0.013 | −0.006 (0.006)<br>−0.018–0.005 (NS) | 0.144 (0.004)<br>0.137–0.150 | 0.106 (0.004)<br>0.099–0.113 | 0.833 (0.012)<br>0.811–0.856 |
| Late chronotype | −0.099 (0.006)<br>−0.111 to −0.088 | −0.080 (0.006)<br>−0.092 to −0.067 | −0.040 (0.008)<br>−0.054 to −0.025 | 0.242 (0.005)<br>0.232–0.253 | 0.059 (0.009)<br>0.041–0.076 | −0.103 (0.005)<br>−0.113 to −0.092 | −0.023 (0.005)<br>−0.034 to −0.013 | 2.126 (0.034)<br>2.061–2.193 |

Regression models of the health behaviors include the sleep duration and chronotype variables as well as the controlling variables of sex, race, college attendance, and employment. General linear regression models were used for continuous outcomes (physical activity, screen-based sedentary behavior, fruit intake, and vegetable intake) while logistic regression was used for the binary outcome of tobacco use

*NS* non-signficant at the 0.05 level

[a]The reference category for sleep duration is adequate sleep duration (7–8 h). The reference category for chronotype is intermediate chronotype

**Table 4**

**Regression models of physical activity, screen-based sedentary behavior, and diet variables to show contrasts for short versus long sleep and early versus late chronotype (*N*= 439,933)**

| Dependent variable | Physical activity (minutes/week) | | | Screen-based sedentary behavior (hours/day) | | Diet variables | | Tobacco use |
|---|---|---|---|---|---|---|---|---|
| | Walking | Moderate | Vigorous | Computer use | Television viewing | Fruit Servings/day | Vegetables Servings/day | |
| **Comparison[a]** | **β (SE)<br>95 % CI** | **β (SE)<br>95 % CI** | **β (SE)<br>95 % CI** | **β (SE)<br>95 % CI** | **β (SE)<br>95 % CI** | **β (SE)<br>95 % CI** | **β (SE)<br>95 % CI** | **OR (SE)<br>95 % CI** |
| Short sleep duration | 0.077 (0.012)<br>0.054–0.010 | 0.007 (0.013)<br>−0.019–0.032 (NS) | 0.061 (0.018)<br>0.026–0.096 | 0.129(0.012)<br>0.107–0.152 | −0.374 (0.020)<br>−0.412 to −0.336 | 0.051 (0.012)<br>0.028–0.073 | 0.001 (0.012)<br>−0.022–0.024 (NS) | 1.082 (0.034)<br>0.013–0.145 |
| Early chronotype | 0.178(0.011)<br>0.157–0.200 | 0.172 (0.012)<br>0.148–0.196 | 0.172 (0.017)<br>0.139–0.204 | −0.313(0.011)<br>−0.334 to −0.291 | −0.141 (0.018)<br>−0.176 to −0.105 | 0.246(0.011)<br>0.225–0.267 | 0.133 (0.011)<br>0.112–0.155 | 0.407(0.11)<br>0.385–0.430 |

Regression models of the health behaviors include the sleep duration and chronotype variables as well as the controlling variables of sex, race, college attendance, and employment. General linear regression models were used for continuous outcomes (physical activity, screen-based sedentary behavior, fruit intake, and vegetable intake) while logistic regression was used for the outcome of tobacco use)

*NS* non-signficant at the 0.05 level

[a]The reference category for sleep duration is long sleep duration (nine or more hours). The reference category for chronotype is late chronotype