ESC European Society of Cardiology

European Heart Journal (2023) **00**, 1–11
https://doi.org/10.1093/eurheartj/ehad657

CLINICAL RESEARCH
Epidemiology, prevention, and health care policies

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Healthy sleep score changes and incident cardiovascular disease in European prospective community-based cohorts

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Received 27 May 2023; revised 20 June 2023; accepted 25 July 2023

See the editorial comment for this article "Tracking changes in 'healthy sleep' for cardiovascular risk assessment," by D. Linz, https://doi.org10.1093/eurheartj/ehad509.

Abstract

Background and Aims Evidence on the link between sleep patterns and cardiovascular diseases (CVDs) in the community essentially relies on studies that investigated one single sleep pattern at one point in time. This study examined the joint effect of five sleep patterns at two time points with incident CVD events.

Methods By combining the data from two prospective studies, the Paris Prospective Study III (Paris, France) and the CoLaus|PsyCoLaus study (Lausanne, Switzerland), a healthy sleep score (HSS, range 0–5) combining five sleep patterns (early chronotype, sleep duration of 7–8 h/day, never/rarely insomnia, no sleep apnoea, and no excessive daytime sleepiness) was calculated at baseline and follow-up.

Results The study sample included 11 347 CVD-free participants aged 53–64 years (44.6% women). During a median follow-up of 8.9 years [interquartile range (IQR): 8.0–10.0], 499 first CVD events occurred (339 coronary heart disease (CHD) and 175 stroke). In multivariate Cox analysis, the risk of CVD decreased by 18% [hazard ratio (HR) 0.82, 95% confidence interval (CI) 0.76–0.89] per one-point increment in the HSS. After a median follow-up of 6.0 years (IQR: 4.0–8.0) after the second follow-up, 262 first CVD events occurred including 194 CHD and 72 stroke. After adjusting for baseline HSS and covariates, the risk of CVD decreased by 16% (HR 0.84, 95% CI 0.73–0.97) per unit higher in the follow-up HSS over 2–5 years.

Conclusions Higher HSS and HSS improvement over time are associated with a lower risk of CHD and stroke in the community.

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Structured Graphical Abstract

Key Question

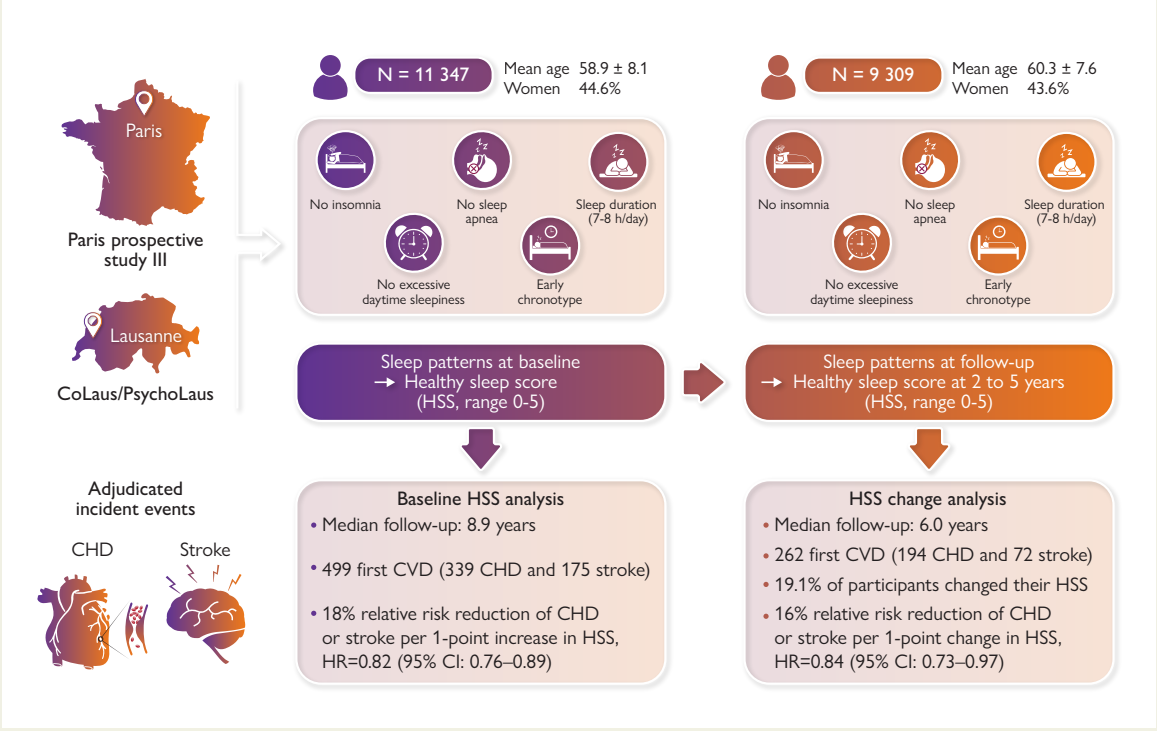
The effect of sleep patterns on cardiovascular disease (CVD) risk has not been fully investigated. In particular, do sleep patterns change over time and is this change related to CVD risk?

Key Finding

In this study 19.1% of subjects changed their sleep patterns over time. The risk of CVD decreased by 18% per one-point increment in the baseline healthy sleep score (HSS, range 0-5), and by 16% per one-point increment of HSS during follow-up.

Take Home Message

Higher HSS and improvement in the HSS over time are associated with a lower risk of coronary heart disease and stroke in the community.



In a combined dataset from two large and independent European prospective cohort studies including 11 347 CVD-free participants, there were 499 first CVD events during a median follow-up of 8.9 years and 262 first CVD events during a median follow-up of 6.0 years after the second follow-up. Analysis of the joint effect of five sleep patterns showed that the risk of CVD decreased by 18% per one-point increment in the baseline HSS score and by 16% per unit higher in the follow-up HSS score over a 2- to 5-year period. HSS, healthy sleep score; CHD, coronary heart disease; CVD, cardiovascular disease; HR, hazard ratio; CI, confidence interval.

Keywords Cardiovascular disease • Prevention • Sleep patterns • Healthy sleep score • Pooled cohort study

Introduction

A growing body of scientific evidence suggests that sleep patterns are risk markers for cardiovascular disease (CVD).[1–4] The recent 'Life's Essential 8'[5] by the American Heart Association that includes sleep duration as a component of the cardiovascular health score further supports the importance of studying the sleep–CVD axis. Given the burden of impaired sleep patterns and CVD worldwide,[6–8] exploring the interplay between sleep and CVD carries important public health implications. While a 'good sleep' or 'healthy sleep' encompasses several dimensions, most evidence on the link between sleep patterns and CVD is based on studies that examined one single sleep pattern [mainly sleep duration,[4,9] sleep apnoea,[2] insomnia,[1] snoring,[10,11] excessive daytime sleepiness (EDS),[3] or chronotype].[12] A few studies investigated the combined effect of two sleep patterns, mainly sleep duration and insomnia, on CVD risk.[13–17] Furthermore, all these prior studies considered sleep patterns measured at one point in time ('baseline' measurement), so that it is currently unknown whether or not a change in sleep patterns is related to CVD.

To the best of our knowledge, the joint effect of several sleep patterns on CVD risk has been investigated in two studies only, the UK Biobank[18] and the Swedish 'Screening Across the Lifespan Twin' (SALT).[19] In both studies, the authors developed a healthy sleep score (HSS) based on five sleep patterns (sleep duration between 7 and 8 h, no insomnia, early chronotype, absence of snoring, and no EDS) and reported an inverse association between a higher HSS and incident CVD

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events. However, how the HSS changes over time and whether this change is related to CVD were not examined in these two studies.

Therefore, the main objective of this study was to examine the joint effect of those five sleep patterns at baseline and over time with incident CVD events. The secondary objective was to assess the possible public health implications of achieving an optimal HSS towards CVD risk by estimating the proportion of CVD events that could be potentially avoided if the population achieved an optimal HSS (i.e. population attributable fraction). These questions were addressed using pooled and harmonized data from two large independent community-based cohorts.

Methods

Study populations

The Paris Prospective Study III

The Paris Prospective Study III (PPS3, Paris, France) is an ongoing prospective observational community-based cohort study on novel determinants of the main phenotypes of CVD.[20] Between 2008 and 2012, 10 157 men and women aged 50–75 years were recruited in a preventive medical centre in Paris. At baseline, they underwent a standard physical examination coupled with standard biological tests after an overnight fasting and provided information related to lifestyle (tobacco and alcohol consumption, physical activity, diet), personal and family medical history, current health status, and medication use on questionnaires.

The CoLaus|PsyCoLaus study

The CoLaus|PsyCoLaus study (Lausanne, Switzerland) is a Swiss population-based observational prospective study investigating determinants of CVD.[21,22] Between 2003 and 2006, 6733 men and women aged 35–75 years were included from a simple, non-stratified random sample of the Lausanne population, Switzerland. At baseline, information related to lifestyle (tobacco and alcohol consumption, physical activity, diet), personal and family medical history, current health status, and medication were collected using questionnaires. During follow-up periods, subjects underwent a physical examination after an overnight fasting and responded to a questionnaire covering demographic and medical history and health behaviours.

Main exposure: healthy sleep score—definition and construction

Healthy sleep score definition

In both PPS3 and CoLaus|PsyCoLaus, subjective sleep-related complaints and habits were self-reported on validated questionnaires at two time points 2 years apart in PPS3 and 5 years apart in CoLaus|PsyCoLaus, respectively. Those questionnaires assess sleep duration and insomnia complaints (modified Pittsburgh sleep quality index),[23] obstructive sleep apnoea (OSA; Berlin questionnaire),[24,25] and EDS [Epworth Sleepiness Scale (ESS)].[26] The properties of these sleep questionnaires have been reported and are summarized in the Supplementary data online.[23,27–29] Sleep duration was assessed in terms of number of reported hours by the question 'How many hours of effective sleep do you get each night?' Information on chronotype was assessed using the following question in PPS3: It is sometimes said that someone is a 'morning person' or an 'evening person'. How do you consider yourself? (i) definitely a 'morning' person, (ii) more a 'morning' person, (iii) more an 'evening' person, or (iv) definitely an 'evening' person. In CoLaus|PsyCoLaus, information on chronotype was assessed by the validated French translation[30] of the Horne–Ostberg Morningness-Eveningness Score.[31]

The HSS combines five sleep patterns including early chronotype ('morning' or 'more a morning'), sleep duration of 7–8 h/day, reported never/rarely insomnia symptoms, no sleep apnoea (defined as <2 positive categories on the Berlin questionnaire), and no EDS (defined as an ESS score <11). Each sleep pattern was scored 1 point if it was optimal and 0 point otherwise. The score ranged from 0 to 5 (the higher the better), reflecting the number of optimal sleep patterns.

Baseline healthy sleep score

The baseline score was analysed as an ordinal scale (0–5, the higher the better) and as a categorical scale (0–1, 2, 3, 4, and 5).

Healthy sleep score at follow-up

First, we considered change in HSS score as a discrete variable and computed the absolute difference (change) between the baseline and follow-up score among those who completed sleep questionnaires at both time points. Second and for clinical interpretation, the score at baseline and at follow-up was dichotomized according to the median (HSS = 3), so that four categories of change were considered: stable low (<3 at both time points), stable high (≥3 at both time points), 'increase' (<3 at baseline and ≥3 at the second evaluation), and 'decrease' (≥3 at baseline and <3 at the second evaluation), respectively. These categories of change were defined *a priori*, and the dichotomization of the HSS at baseline and at follow-up was chosen to maximize the number of participants in each category of change.

Polysomnography healthy sleep score

An in-home overnight full polysomnography (PSG) was performed in a subsample of 2162 participants from the CoLaus|PsyCoLaus study, the HypnoLaus study.[32] The protocol of the PSG has been previously detailed[32] and is summarized in the Supplementary data online. We calculated a PSG healthy sleep score (PSG HSS) ranging from 0 to 3 (the higher the better) considering optimal sleep duration (Total sleep time of 7–8 h), no objective maintenance insomnia [wake after sleep onset (WASO) ≤99.5 min: third quartile or sleep efficiency (SE) ≥85%], and no sleep apnoea (apnoea–hypopnoea index <15 events/h of sleep). We also considered a PHSS ranging from 0 to 2 that only included optimal sleep duration and no sleep apnoea, since the accuracy of WASO or SE to measure insomnia has been debated.

Covariates common to both cohorts

In both cohorts, smoking status was defined as non-smoker, current smoker, former smoker, or in the process of stopping smoking—1 year; alcohol consumption was defined as at least one drink a day of alcohol; regular physical activity was defined by at least 1 h of walking per day. In the PPS3 study, the practice of a sport or exercises during leisure time at least once a week was also considered. Socio-professional categories were defined in both cohorts based on current occupational status as follows: not working [inactive (except retired) or unemployed], low (manual and clerical workers), middle (intermediate occupations), and high (managers or higher intellectual professions). Prevalent CVD was defined as self-reported history of angina pectoris, coronary heart disease (CHD), stroke, heart failure, myocardial infarction, or arrhythmia in both studies. In the PPS3 study, pulmonary embolism, aneurysm, and peripheral arterial disease were also considered as prevalent CVD. In both cohorts, family history of CVD was defined as a self-reported history of myocardial infarction or stroke (or sudden cardiac death in PPS3) in parents and/or siblings.

Blood pressure (BP) and heart rate were recorded over 10 min in the supine position during the echotracking measurements in PPS3. In CoLaus|PsyCoLaus study, BP and heart rate were measured thrice on the left arm, with an appropriately sized cuff, after at least 10 min rest in the seated position, and the average values were used in the study. In both cohorts, hypertension was defined as systolic BP ≥140/90 mmHg and/or a diastolic BP ≥90 mmHg during the visit and/or use of antihypertensive drug treatment.

Total, HDL, and LDL cholesterol and glucose were measured after an overnight fast. Diabetes mellitus was defined as a fasting glucose level ≥7 mmol/L and/or use of antidiabetic drug treatment.

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Incident cardiovascular disease outcomes

Examined outcomes included incident CHD, stroke, and the combination of the two referred as CVD in the present study. In PPS3, CVD events reported every 2 years by the participants were clinically validated after the review of the medical records up to September 2020.[33] In CoLaus|PsyCoLaus, CVD events are prospectively collected and adjudicated by independent cardiologists and neurologists based on the review of the medical records up to 2019.[34] Standardized and similar criteria have been used to define CHD and stroke events in both cohorts. Non-fatal CHD events included acute coronary syndrome (i.e. unstable angina, non-ST, and ST-elevation myocardial infarction), hospitalized angina pectoris requiring coronary revascularization procedures, revascularization procedures including coronary artery bypass graft (CABG), or percutaneous coronary interventions or surgical CABG. Hospitalized stroke included ischaemic, haemorrhagic, transient ischaemic attack (TIA), and undetermined stroke. All stroke events had brain imaging data available (magnetic resonance imaging and cerebral tomodensitometry). Stroke diagnosis was based on the hospital discharge diagnosis describing the occurrence of new neurological deficits lasting >24 h, except for TIA.

Statistical analysis

Data from the two cohort cohorts were combined (pooled data analysis) in the main analysis.

Continuous and categorical variables were described as mean ± standard deviation (SD) and column percentages, respectively. Tetrachoric correlation coefficients[35] suited for binary variables were calculated to describe the inter-relationship between the sleep patterns at baseline. The baseline characteristics of the participants according to the categories of the HSS were made using Pearson χ^2 test, Student's *t*-test, or analysis of variance (ANOVA), where appropriate.

Main analyses

The associations of baseline HSS and change in the HSS with incident CVD events were examined using Cox proportional hazards regression with a random effect on the study country[36] and using time in study as the time scale. Hazards ratios (HRs) and their 95% confidence intervals (CIs) were estimated. For both the baseline and change analysis, the log linearity assumption was verified by comparing the likelihood ratio of models with the HSS as a continuous variable and models with the HSS as a categorical variable. The comparison of the likelihood ratio confirmed that there was no departure from linearity. The proportional hazard assumption was assessed by including in the multivariate models a multiplicative interaction term between baseline and change in HSS with time in study.

Association between baseline healthy sleep score and incident cardiovascular disease events

This analysis was conducted among participants who reported at least one sleep pattern in order to maximize the study sample size and who had no prior CVD at baseline and without missing covariates at baseline. Hazard ratios per one point increment in the HSS (range 0–5) and per categories of HSS using a score of 0–1 as the reference were adjusted for age, sex, family history of CVD, socio-professional categories, smoking status, alcohol consumption, diabetes mellitus, LDL, and HDL cholesterol. No adjustment was made for BP, antihypertensive treatment, or body mass index (BMI) as hypertension diagnosis and BMI are already included in the definition of OSA according to the Berlin questionnaire.[25]

Association of change in healthy sleep score with incident cardiovascular disease events

This analysis was conducted among the participants who did not suffer from any CVD events between the two follow-ups, who reported at least one sleep pattern at both follow-ups and who had no missing covariates at both follow-ups. In this analysis, follow-up starts after the second evaluation of the sleep patterns. Firstly, HRs per unit of change in the HSS (i.e. absolute difference in the HSS between the two time points, range −4 to +4) were quantified. Secondly, HRs per category of change in the HSS (decrease, stable low, stable high, and increase) were estimated using the decrease group as the reference category. These two analyses were adjusted for the baseline HSS and the same covariates as in the analysis of baseline HSS.

Population-attributable fraction estimate

To quantify the proportion of incident cases of CVD that could potentially be avoided if the population distribution of the HSS were changed (all other factors remaining unchanged), we estimated the population-attributable fraction (PAF) associated with the presence of several optimal sleep patterns, under the hypothetical assumption of a causal relationship. Point estimates and 95% CIs of the PAF were calculated using the method described by Spiegelman *et al.*[37] The PAF estimate accounted for the prevalence of the exposure and HR of CVD risk associated with that exposure.

Sensitivity analyses

To assess the robustness of the study results, the following sensitivity analyses were performed. First, a weighted HSS (also ranging from 0 to 5) was constructed to account for the number of available sleep patterns per participant (from 1 to 5). Weights were calculated as follows:

$$\text{weighted HSS} = \frac{5 \times \text{HSS}}{\text{total number of items completed out of the 5}}$$

Next, the association between the weighted HSS and CVD risk was assessed. Second, to evaluate competing risk by death, cause-specific HRs were estimated.[38] Third, to evaluate the effect of sample attrition, inverse probability of attrition weighting (IPAW) analysis was employed.[39] For this analysis, the probability of answering the sleep health questionnaire at baseline (baseline HSS analysis) and at follow-up (change in HSS analysis) was estimated in multivariate-adjusted binary logistic regressions, and the inverse of these probabilities was used as weights in the corresponding Cox analysis. Fourth, as an alternative method to examine change in HSS over time, we computed the averaged HSS among those who completed the HSS at baseline and at follow-up and then estimated the HR per one point increment in the averaged HSS. Fifth, analysis was restricted to those who reported information on the five items of the HSS at baseline (baseline HSS analysis) and at both baseline and follow-up (HSS change analysis), respectively. Sixth, to evaluate to which extent the associations were driven by one item or another of the HSS, the baseline and the change analysis were repeated after removing one item of the HSS at a time. The association of each individual item of the HSS (baseline and change analysis) with incident CVD was also provided. Seventh, sex stratified and age-stratified (by quartile of age calculated in the pooled sample) analyses were conducted, and product interaction terms between baseline and change in HSS score with sex and age were added to the Cox models in separate analysis. To further explore sex disparities in the association of HSS with CVD, the baseline characteristics were explored by sex and sex-stratified Cox analyses conducted for each individual item of the HSS. Eighth, Cox analysis using age as the time scale was performed to ensure that the association observed was not due to an age effect. Nineth, Cox analyses were further adjusted for BMI and hypertension status. Tenth, cohort-specific analyses were conducted. Last, association between the PSG HSS and incident CVD was evaluated.

All statistical analyses were performed using the SAS software, version 9.4 TS Level 1M5.

Results

Study sample characteristics

After excluding participants with previous CVD ($n = 648$), missing covariates ($n = 1447$), missing sleep data ($n = 3158$), and no follow-up ($n = 290$) (*Figure 1*; see also Supplementary data online, *Figure S1* for the study-specific flowcharts), the study sample included 11347

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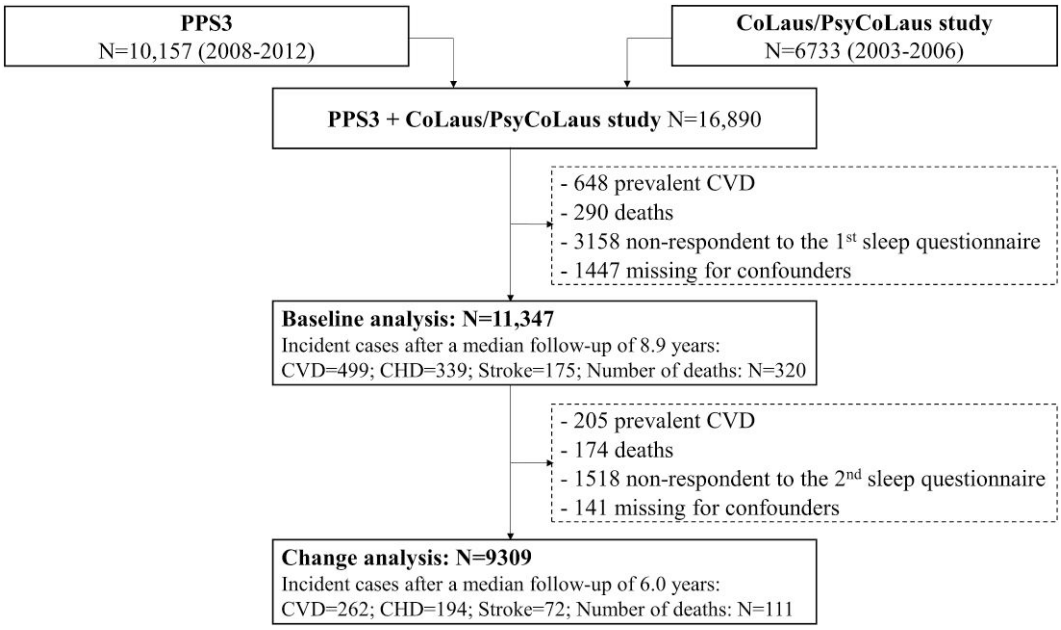

Figure 1 Flowchart of the study population

participants (mean age: 58.9 ± 8.1; 44.6% women). The characteristics of the eligible and excluded participants are compared in the Supplementary data online, *Table S1*.

The baseline characteristics according to the sleep score categories are reported in *Table 1*. Nine per cent of participants had a poor HSS (score = 0 or 1), while 10% had an optimal HSS (score = 5). Participants with a higher sleep score were more likely to be non-smokers, physically active, non-diabetic, to have lower BMI, lower BP, and were more likely to have a higher HDL cholesterol level. There was a low to moderate correlation between the sleep items (correlation range: −0.122 to 0.305; see Supplementary data online, *Table S2*), which supports their combination into a score.

Baseline healthy sleep score and incident cardiovascular disease events

During a median follow-up of 8.9 years [interquartile range (IQR): 8.0–10.0], a total of 499 first CVD events occurred including 339 CHD and 175 stroke (96 ischaemic, 22 haemorrhagic, 56 TIA, 1 of unknown cause). The HRs and 95% CIs for incident CVD, CHD, and stroke according to the number of optimal sleep patterns are reported in *Table 2*. There was a 18% risk reduction [HR 0.82 (95% CI: 0.76–0.89)] of CVD per one-point increment of the HSS, including a 16% risk reduction for CHD and a 21% risk reduction for stroke, respectively. When compared with those with a score of 0–1, participants with a score of 2, 3, 4, and 5 had a 10%, 19%, 38%, and 63% lower risk of CVD, respectively (*P* for linear trend <.0001).

Proportion of incident cardiovascular disease events attributable to sleep patterns

As shown in *Table 2*, 29.2% (95% CI: 13.6%–43.3%) and 59.6% (40.6%–73.7%) of CVD events could be potentially prevented if all the participants had four or five optimal sleep patterns at baseline, respectively. These estimates were higher for stroke than for CHD.

Change in healthy sleep score and incident cardiovascular disease events

This analysis was conducted in 9309 participants free of CVD between the 2 time points of HSS evaluation and who had provided information on at least one sleep pattern at both time points. As shown in *Figure 2*, 17.2% of the participants had a stable low HSS (<3 at both time points), 63.7% had a stable high HSS (≥3 at both time points), 11.0% decreased their HSS (from ≥3 at baseline to <3 at follow-up), while 8.1% improved their HSS (from <3 at baseline to ≥3 at follow-up), respectively. A more detailed analysis of the patterns of change in HSS is reported in Supplementary data online, *Table S3*. Analysis by sleep pattern (see Supplementary data online, *Table S4*) indicates that sleep duration of 7–8 h/night showed both the greatest improvement (13.0% changed from short or long sleep duration to optimal sleep duration) and the greatest worsening (12.6% changed from optimal sleep duration to short or long sleep duration).

The baseline characteristics of the participants according to the categories of change in the HSS are reported in Supplementary data online, *Table S5*. After a median follow-up of 6.0 (IQR: 4.0–8.0) years after the second follow-up, 262 first CVD events occurred including 194 CHD and 72 stroke. As presented in the *Table 3*, after adjustment for baseline covariates and HSS, there was a 16% risk reduction [HR 0.84 (95% CI: 0.73–0.97)] of CVD per unit higher in the follow-up HSS. The risk reduction was 21% for CHD and was less clear for stroke due to the small number of events. In this model, baseline HSS was also associated with the outcomes with HRs of 0.77 (0.69–0.87), 0.79 (0.69–0.91), and 0.74 (0.59–0.93) for CVD, CHD, and stroke, respectively. In addition, compared with individuals who had a decrease in their HSS between follow-ups, the risk reduction of CVD was 39% [HR 0.61 (0.35–1.08)], 30% [HR 0.70 (0.42–1.17)], and 45% [HR 0.55

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Table 1 Baseline characteristics of participants according to healthy sleep score (*N* = 11 347)—pooled analysis

	Overall cohort	Healthy sleep score				
		0–1	2	3	4	5
Number of participants	11 347 (100.0)	1065 (9.4)	2401 (21.1)	3653 (32.2)	3075 (27.1)	1153 (10.2)
Female sex	44.6	44.1	49.1	44.6	41.4	44.1
Age (years)	58.9 ± 8.1	58.9 ± 8.6	59.2 ± 8.2	59.3 ± 8.1	58.4 ± 7.8	58.3 ± 7.7
Smoking status						
Never	46.4	39.7	43.4	46.6	49.1	50.9
Ex-smoker	36.1	38.3	37.2	36.2	34.6	35.4
Current	17.5	22.0	19.4	17.2	16.3	13.7
Alcohol consumption	73.9	68.2	72.3	75.5	76.1	71.5
Physical activity[a]	60.6	56.7	57.3	61.2	62.3	64.2
Body mass index (kg/m^2)	25.4 ± 4.0	27.3 ± 4.7	25.8 ± 4.2	25.3 ± 3.9	24.9 ± 3.6	24.6 ± 3.4
Socio-professional categories						
Not working	19.5	22.5	20.7	19.8	17.3	19.4
Low	14.3	19.2	15.9	13.3	13.0	12.9
Medium	33.3	34.0	33.1	33.4	33.4	32.7
High	32.9	24.2	30.4	33.4	36.3	35.0
Diabetes mellitus	5.6	10.8	6.6	4.9	4.4	4.0
Hypertension	36.3	53.3	43.8	35.5	29.6	25.1
Family history of heart disease	36.7	41.1	38.4	36.5	34.9	34.3
LDL cholesterol (mg/dL)	140 ± 33	138 ± 35	139 ± 34	140 ± 33	142 ± 33	141 ± 33
HDL cholesterol (mg/dL)	61 ± 16	58 ± 16	60 ± 16	61 ± 16	62 ± 16	62 ± 17
Total cholesterol (mg/dL)	222 ± 37	219 ± 38	221 ± 38	222 ± 36	223 ± 36	224 ± 36
Sleep patterns						
Early chronotype	55.6	16.0	33.4	49.9	62.4	100.0
Sleep 7–8 h/day	59.4	13.0	30.0	55.5	85.3	100.0
Never/rarely insomnia	50.8	7.8	19.0	40.4	71.9	100.0
No sleep apnoea	80.8	32.4	67.9	84.4	93.9	100.0
No excessive daytime sleepiness	87.6	37.8	77.3	93.2	98.0	100.0

The results are presented as mean ± SD for continuous variables or percentages for categorical variables.
SD, standard deviation.
[a]Defined as 'at least 1 h of walking per day' in the CoLaus|PsyCoLaus study, and as 'at least 1 h of walking per day or regular practice of sports during leisure time at least once per week' in the Paris Prospective Study 3.

(0.39–0.79)] for the improvement, stable low, and stable high categories of change in HSS, respectively.

Sensitivity analyses

The association between baseline HSS and change in HSS with incident CVD events remained consistent in the following analyses: when using weighted HSS, competing risk analyses, IPAW analyses, and averaged HSS (see Supplementary data online, *Table S6*); when restricting the sample to those reporting the five items of the HSS at baseline and at follow-up (see Supplementary data online, *Table S7*); when excluding one metric at a time from the HSS, suggesting that these associations were unlikely to be driven by a specific sleep pattern (see Supplementary data online, *Table S8*); the results of the analyses by individual sleep pattern are reported in Supplementary data online, *Table S9*. Results were also consistent in analyses stratified by sex and age groups (see Supplementary data online, *Table S10*). Of note, stronger effect size was observed in women compared with men, especially for CHD, although sex interaction was not statistically significant. This is supported by sex differences in the baseline characteristics (see Supplementary data online, *Table S11*) and in the association of the individual sleep pattern with CVD (see Supplementary data online, *Tables*

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Table 2 Multivariate-adjusted hazard ratios (95% confidence intervals) of baseline healthy sleep score for cardiovascular diseases among 11 347 participants—pooled analysis

	Participants; *n* (%)	CVD (CHD or stroke)			CHD			Stroke		
		Cases	HR (95% CI)	PAF (95% CI)	Cases	HR (95% CI)	PAF (95% CI)	Cases	HR (95% CI)	PAF (95% CI)
Continuous HSS[a]	11 347 (100.0)	499	0.82 (0.76–0.89)		339	0.84 (0.77–0.93)		175	0.79 (0.70–0.90)	
Categorical HSS										
0–1	1065 (9.4)	66	1.00	1.00	42	1.00	1.00	26	1.00	1.00
2	2401 (21.2)	124	0.90 (0.66–1.21)	7.9 (−12.4; 27.6)	86	1.00 (0.69–1.45)	0.1 (−26.9; 27.1)	42	0.75 (0.46–1.22)	19.3 (−9.6; 45.2)
3	3653 (32.2)	171	0.81 (0.61–1.08)	12.6 (−2.8; 27.4)	115	0.88 (0.62–1.26)	7.6 (−13.2; 27.8)	61	0.69 (0.44–1.10)	19.9 (−1.6; 39.6)
4	3075 (27.1)	113	0.62 (0.46–0.85)	29.2 (13.6; 43.3)	79	0.70 (0.48–1.02)	22.9 (1.7; 42.2)	36	0.49 (0.29–0.81)	40.6 (18.8; 58.7)
5	1153 (10.2)	25	0.37 (0.23–0.59)	59.6 (40.6; 73.7)	17	0.42 (0.24–0.73)	55.5 (29.0; 74.1)	10	0.35 (0.17–0.74)	61.0 (30.3; 80.2)
P for linear trend			<0.0001			0.0003			0.0006	

All models adjusted for sex, age, total alcohol consumption, physical activity, smoking status, socio-professional categories, diabetes mellitus, family history of heart diseases, LDL cholesterol, and HDL cholesterol. The analysis is not adjusted for BP and BMI since hypertension and BMI are already included in the definition of the OSA.
HSS, healthy sleep score; CVD, cardiovascular disease; CHD, coronary heart disease; HR, hazard ratio; CI, confidence interval; PAF, population attributable fraction.
[a]Hazard ratio are given per one point increment in HSS.

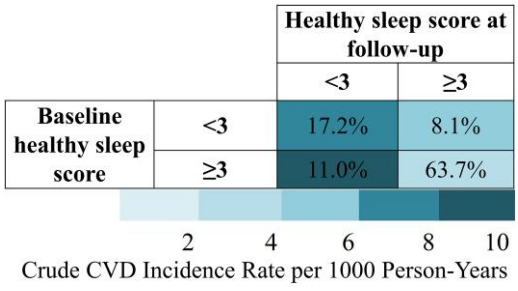

Figure 2 Heatmap of the categories of change in the healthy sleep score and the corresponding unadjusted incidence rates of cardiovascular disease. The healthy sleep score was dichotomized according to the median calculated on the baseline healthy sleep score

S12 and *S13*). Results remained unchanged when using Cox analysis with age as the time scale (see Supplementary data online, *Table S14*), after further adjusting for BMI and hypertension (see Supplementary data online, *Table S15*), in cohort-specific analyses (see Supplementary data online, *Tables S16* and *S17*). Lastly, the association between PSG HSS and CVD followed the same trend as in the main analysis (see Supplementary data online, *Table S18*).

Discussion

By combining the data from two large and independent European prospective cohort studies, we examined the joint effect of five sleep patterns including early chronotype, no sleep apnoea, no insomnia, sleep duration of 7–8 h, and no EDS at baseline and at follow-up, with incident CVD events. Three main findings were reported. First, the risk of CVD decreased by 18% per one-point increment in the baseline HSS. Second, the risk of CVD decreased by 16% per unit higher in the follow-up HSS over a 2- to 5-year period (*Structured Graphical Abstract*). Third, based on the current findings, between 30% and 60% of new CVD events could be potentially prevented if all the study participants had four or five sleep patterns at the optimal level.

The few prior studies examining several sleep patterns in the same individuals and their association with CVD events have mostly studied dyads of sleep patterns, mainly insomnia and short[13,14,17] or long sleep duration[15] as well as snoring with EDS.[40] Only two studies, the UK Biobank[18] and the SALT,[19] have examined the joint effect of five sleep patterns at baseline with incident CVD events. In the UK Biobank study,[18] there was a 35% reduction in CVD risk between participants with a high (HSS of 5) and those with a poor score (0–1). A stronger effect size was observed in the present study, possibly due in part to the inclusion of OSA (based on the Berlin questionnaire) in the HSS definition rather than snoring in the UK Biobank study. In the SALT study,[19] there was a 75% increased risk of CVD between participants with poor sleep patterns (HSS of 0–1) and those with a healthy sleep pattern (HSS of 4–5). It is noteworthy that this was a secondary analysis performed in 45% of the initial cohort.

To the best of our knowledge, this is the first prospective study examining the sleep patterns over time and their association with subsequent CVD events. The primary limitations of prior epidemiologic studies on sleep and CVD outcomes are single timepoint measures.

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Table 3 Multivariate-adjusted hazard ratios (95% confidence intervals) of change in healthy sleep score for cardiovascular diseases among 9309 participants—pooled analysis

	Participants; *n* (%)	CVD (CHD or stroke)		CHD		Stroke	
		Cases	HR (95% CI)	Cases	HR (95% CI)	Cases	HR (95% CI)
Continuous change in HSS (per unit higher compared with baseline HSS)[a]	9309 (100.0)	262	0.84 (0.73–0.97)	194	0.78 (0.66–0.92)	72	1.07 (0.81–1.41)
Baseline HSS			0.77 (0.69–0.87)		0.79 (0.69–0.91)		0.74 (0.59–0.93)
Categories of change in HSS							
Decrease[b]	1026 (11.0)	45	1.00	36	1.00	9	1.00
Stable low[c]	1601 (17.2)	64	0.70 (0.42–1.17)	43	0.61 (0.34–1.10)	21	1.06 (0.38–2.90)
Stable high[d]	5932 (63.7)	128	0.55 (0.39–0.79)	96	0.51 (0.34–0.77)	34	0.76 (0.35–1.64)
Increase[e]	750 (8.1)	25	0.61 (0.35–1.08)	19	0.61 (0.32–1.17)	8	0.86 (0.28–2.57)
Baseline HSS			0.86 (0.70–1.06)		0.89 (0.70–1.13)		0.79 (0.54–1.18)

The study sample size is lower than in *Table 2* as it includes those who answered the sleep questionnaires at both time points and were free of CVD in the interval. All models adjusted for sex, age, total alcohol consumption, physical activity, smoking status, socio-professional categories, diabetes mellitus, family history of heart diseases, LDL cholesterol, HDL cholesterol, and baseline HSS. The analysis is not adjusted for BP and BMI since hypertension and BMI are already included in the definition of the OSA according to the Berlin questionnaire.
HSS, healthy sleep score; CVD, cardiovascular disease; CHD, coronary heart disease; HR, hazard ratio; CI, confidence interval.
[a]Hazard ratio are given per unit higher compared with baseline HSS.
[b]Healthy sleep score ≥3 at baseline and HSS <3 at follow-up.
[c]Healthy sleep score <3 at both time points.
[d]Healthy sleep score ≥3 at both time points.
[e]Healthy sleep score <3 at baseline and HSS ≥3 at follow-up.

Evidence indicates that sleep is a dynamic process that changes at critical periods of ageing but also as a function of exposure to a variety of stressors and medications.[41] In addition, although no causal conclusion can be drawn, both baseline HSS and change in HSS related to CVD reinforce the robustness and the biological plausibility of the reported associations. The fact that 63.7% of the participants had a stable high HSS (equal or above the median level at both timepoints) is an encouraging finding. Only 8.1% of the participants increased their HSS above the median value, a figure that is consistent with the pattern of change found with other composite scores, such as the cardiovascular health score.[42,43] The group of participants that decreased their score below the median value (11.0%) and the even larger group that remained below the median value (17.2%) over time represent targets for investigations. In particular, the (modifiable) determinants of these trends should be identified and controlled for. These include socio-economic factors, environmental exposome (such as exposure to build and noise environment), or psychological factors.[44–46] Furthermore, the greatest risk reduction of CVD was among those who had a high HSS and remained high overtime. Similarly, when considering the continuous change in HSS, effect size was stronger for the baseline HSS than for the change in HSS. These results emphasize the prominence of achieving as early as possible in life a high level of HSS and the importance of maintaining a healthy sleep over time. Accumulating evidence suggests that exposure to risk factors early in life is associated with premature CVD events and mortality in adulthood and that early years of life play a significant part in influencing behaviours in adulthood.[47] Given child's brain plasticity, childhood may therefore represent an opportune time frame to establish life-long health promoting habits, attitudes, and knowledge, including sleep habits.[48,49] The lower risk of CVD associated with improvement in HSS among those with an initial low HSS also suggests that it is never too late to start improving the HSS, no matter how low it was. In the present study, stronger effect size in women compared with men was suggested, especially for CHD, even though sex interaction was not statically significant. Women had on average a healthier lifestyle, were less often diabetic and hypertensive, and had higher levels of HDL-cholesterol, but the analysis was adjusted for these risk factors. On the other hand, no clear sex difference has been reported regarding the association between sleep health and CVD.[4,50] Intriguingly, crude CVD incidence rate was higher among those who decreased their HSS relative to those who remained low. There were no major differences in the baseline characteristics across the categories of change in HSS. Therefore, this finding might reflect survival bias, so that we only see those who survived despite having a low HSS trajectory. Also speculative, the decreasing HSS trajectory might be symptomatic of a more systemic health decline.

There are common mechanisms supporting the reported association between sleep patterns and CVD risk including increased BP, sympathetic activation,[51,52] chronic inflammation,[52] and oxidative stress.[53] More specific mechanisms include repeated hypoxaemia episodes or arterial stiffness in the case of OSA;[25,54] chronic misalignment between internal physiological timing and externally imposed schedules,[55] which induces sleep curtailment and also metabolic disorders[56] in the case of shifted chronotype. Insomnia may also be associated with an increased activity of the hypothalamic-pituitary-adrenocortical (HPA) system, especially when associated with short objective sleep duration, which increases HPA axis activity.[57]

Achieving four or five optimal sleep patterns could potentially prevent 30% and 60% of incident CVD events in adults, which underlines the strong public health implications of the present findings. Care providers, health policy-makers, and also citizens should be aware of the primordial importance of preserving/improving their sleep patterns with regard to CVD risk. A challenging strategy might be to start increasing awareness and health literacy of the population on sleep quality and quantity early in life when (health) behaviours are not yet fixed.

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Health care systems should also provide better access to screening and treatment for conditions such as chronic insomnia, circadian rhythm sleep–wake disorders, and sleep apnoea. Cognitive behavioural therapy is effective in treating insomnia,[58] and several lines of efficient therapies exist for OSA according to its phenotype and severity.[59] Morningness-eveningness is thought to be highly influenced by genetics and expressed as a preference rather than a modifiable behaviour,[60,61] even though behavioural measures combined with chronotherapy (luminotherapy, use of melatonin) can be used in people with a misalignment of their biological clock and their environment in circadian rhythm sleep–wake disorders.[62] The analysis of the individual sleep patterns suggests the importance of preventing and treating insomnia and OSA and maintaining a chronotype synchronized with their environment with regard to the risk of CVD. Solutions may also come from the training of the health care professionals and/or the digitalization of some therapies.[63]

The present study has some limitations. As an observational study, the reported associations between sleep patterns and CVD events cannot be interpreted as being causal. In particular, the stepwise decreases in diabetes, hypertension, family history of heart disease, and higher HDL cholesterol with a healthier sleep score in the present study could partly explain the lower risk of CVD associated with a healthier sleep score (residual confounding). Similarly, PAF supposes a causal relationship between HSS and CVD,[64] and estimates should therefore be interpreted with caution. Misclassification of sleep patterns may have occurred given that sleep patterns were self-reported. However, such misclassification would likely reduce the results to the null and thus underestimate the effect size. Furthermore, the sleep score assigned the same weight to each metric, whereas some may have stronger associations with CVD. On the other hand, this equal scoring system makes the HSS easy to understand and more likely to be used by the health professionals and the population. Two points in time may lack precision to reliably estimate change in the HSS over time. Also, the HSS change analysis was conditional on those surviving and agreeing to attend the second follow-up, which might have led to some degree of selection bias. Finally, the vast majority of the study participants were White, and this might affect the generalizability of the results to other populations. However, this does not alter the internal validity of the study results.

Conclusions

Higher HSS, maintenance of high HSS, and improvement in HSS are associated with lower risk of CHD and stroke. This study paves the way for promoting a healthy sleep and further supports strong collaboration between sleep and CVD medicine.

Acknowledgements

We thank the PPS3 assistant research team, the medical, and technical staff of the IPC Center, for the study recruitment of PPS3, and the Platform for Biological Resources (PRB) of the Hôpital Européen Georges Pompidou for the management of the PPS3 biobank. We also thank the PPS3 assistant research team for performing the follow-up of the participants. PPS3 is organized under an agreement between INSERM and the IPC Center and between INSERM and the Resources Biologiques de l'Hôpital European Georges Pompidou, Paris, France. We also thank the Caisse Nationale d'Assurance Maladie des Travailleurs Salariés (CNAM-TS, France) and the Caisse Primaire d'Assurance Maladie de Paris (CPAM-P, France) for helping make this study possible. The CoLaus|PsyCoLaus team would like to thank all the people who participated in the recruitment of the participants, data collection, and validation, particularly Peter Vollenweider, Martin Preisig, Eva Pochon, Nicole Bonvin, Yolande Barreau, Mathieu Firmann, François Bastardot, Panagiotis Antiochos, Cédric Gubelmann, Marylène Bay, Benoît Delabays, and Guillaume Jordan.

Supplementary data

Supplementary data are available at *European Heart Journal* online.

Declarations

Disclosure of Interest

All authors declare no disclosure of interest for this contribution.

Data Availability

The data that support the findings of this study cannot be shared publicly due to the privacy of individuals who participated in the study. However, pseudo-anonymized data can be made available from the corresponding author upon reasonable request, pending evaluation by the Paris Prospective Study III scientific committee of the research application. The data of CoLaus|PsyCoLaus study used in this article cannot be fully shared as they contain potentially sensitive personal information on participants. According to the Ethics Committee for Research of the Canton of Vaud, sharing these data would be a violation of the Swiss legislation with respect to privacy protection. However, coded individual-level data that do not allow researchers to identify participants are available upon request to researchers who meet the criteria for data sharing of the CoLaus|PsyCoLaus Datacenter (CHUV, Lausanne, Switzerland). Any researcher affiliated to a public or private research institution who complies with the CoLaus|PsyCoLaus standards can submit a research application to research.colaus@chuv.ch or research.psycolaus@chuv.ch. Proposals requiring baseline data only will be evaluated by the baseline (local) Scientific Committee (SC) of the CoLaus and PsyCoLaus studies. Proposals requiring follow-up data will be evaluated by the follow-up (multicentric) SC of the CoLaus|PsyCoLaus cohort study. Detailed instructions for gaining access to the CoLaus|PsyCoLaus data used in this study are available at www.colaus-psycolaus.ch/professionals/how-to-collaborate/.

Funding

A.N. is supported by a postdoctoral grant from the Lefoulon-Delalande Foundation. The PPS3 was and is supported by grants from the National Research Agency (ANR); the Region Ile de France (Domaine d'Intérêt Majeur); the Research Foundation for Hypertension (RFHTA); the Research Institute in Public Health (IRESP); Horizon 2020 ESCAPE-NET; the INSERM International Research Project; and 'Fondation pour la Recherche Médicale' (FRM) Team grant. The CoLaus|PsyCoLaus study was and is supported by research grants from GlaxoSmithKline, the Faculty of Biology and Medicine of Lausanne, the Swiss National Science Foundation (grants 33CSCO-122661, 33CS30-139468, 33CS30-148401, 33CS30_177535, and 3247730_204523), and the Swiss Personalized Health Network (grant 2018DRI01). None of the mentioned sources of funding had any role in the study design, data collection and analysis, decision in preparing or to publish the manuscript.

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Ethical Approval

The PPS3 protocol was approved by the Ethics Committee of the Cochin Hospital (Paris), and all volunteers provided written informed consent. The CoLaus|PsyCoLaus study was approved by the local Ethics Commission (www.cer-vd.ch; project number PB_2018-00038, reference 239/09), and all participants provided written informed consent.

Pre-registered Clinical Trial Number

The international pre-registered trial number of the PPS3 is NCT00741728.

References

1. He Q, Zhang P, Li G, Dai H, Shi J. The association between insomnia symptoms and risk of cardio-cerebral vascular events: a meta-analysis of prospective cohort studies. *Eur J Prev Cardiol* 2017;**24**:1071–82. https://doi.org/10.1177/2047487317702043
2. Salari N, Khazaie H, Abolfathi M, Ghasemi H, Shabani S, Rasoulpoor S, *et al.* The effect of obstructive sleep apnea on the increased risk of cardiovascular disease: a systematic review and meta-analysis. *Neurol Sci* 2022;**43**:219–31. https://doi.org/10.1007/s10072-021-05765-3
3. Wang L, Liu Q, Heizhati M, Yao X, Luo Q, Li N. Association between excessive daytime sleepiness and risk of cardiovascular disease and all-cause mortality: a systematic review and meta-analysis of longitudinal cohort studies. *J Am Med Dir Assoc* 2020;**21**:1979–85. https://doi.org/10.1016/j.jamda.2020.05.023
4. Yin J, Jin X, Shan Z, Li S, Huang H, Li P, *et al.* Relationship of sleep duration with all-cause mortality and cardiovascular events: a systematic review and dose-response meta-analysis of prospective cohort studies. *J Am Heart Assoc* 2017;**6**:e005947. https://doi.org/10.1161/JAHA.117.005947
5. Lloyd-Jones DM, Allen NB, Anderson CAM, Black T, Brewer LC, Foraker RE, *et al.* Life's essential 8: updating and enhancing the American Heart Association's construct of cardiovascular health: a presidential advisory from the American Heart Association. *Circulation* 2022;**146**:e18–43. https://doi.org/10.1161/CIR.0000000000001078
6. Benjafield AV, Ayas NT, Eastwood PR, Heinzer R, Ip MSM, Morrell MJ, *et al.* Estimation of the global prevalence and burden of obstructive sleep apnoea: a literature-based analysis. *Lancet Respir Med* 2019;**7**:687–98. https://doi.org/10.1016/S2213-2600(19)30198-5
7. Chattu VK, Manzar MD, Kumary S, Burman D, Spence DW, Pandi-Perumal SR. The global problem of insufficient sleep and its serious public health implications. *Healthcare* 2019;**7**:1. https://doi.org/10.3390/healthcare7010001
8. Roth GA, Mensah GA, Johnson CO, Addolorato G, Ammirati E, Baddour LM, *et al.* Global burden of cardiovascular diseases and risk factors, 1990–2019: update from the GBD 2019 study. *J Am Coll Cardiol* 2020;**76**:2982–3021. https://doi.org/10.1016/j.jacc.2020.11.010
9. Wang D, Li W, Cui X, Meng Y, Zhou M, Xiao L, *et al.* Sleep duration and risk of coronary heart disease: a systematic review and meta-analysis of prospective cohort studies. *Int J Cardiol* 2016;**219**:231–9. https://doi.org/10.1016/j.ijcard.2016.06.027
10. Liu J, Shao Y, Bai J, Shen Y, Chen Y, Liu D, *et al.* Snoring increases the development of coronary artery disease: a systematic review with meta-analysis of observational studies. *Sleep Breath* 2021;**25**:2073–81. https://doi.org/10.1007/s11325-021-02345-9
11. Bai J, He B, Wang N, Chen Y, Liu J, Wang H, *et al.* Snoring is associated with increased risk of stroke: a cumulative meta-analysis. *Front Neurol* 2021;**12**:574649. https://doi.org/10.3389/fneur.2021.574649
12. Bhar D, Bagepally BS, Rakesh B. Association between chronotype and cardio-vascular disease risk factors: a systematic review and meta-analysis. *Clin Epidemiol Glob Health* 2022;**16**:101108. https://doi.org/10.1016/j.cegh.2022.101108
13. Bertisch SM, Pollock BD, Mittleman MA, Buysse DJ, Bazzano LA, Gottlieb DJ, *et al.* Insomnia with objective short sleep duration and risk of incident cardiovascular disease and all-cause mortality: Sleep Heart Health Study. *Sleep* 2018;**41**:zsy047. https://doi.org/10.1093/sleep/zsy047
14. Chandola T, Ferrie JE, Perski A, Akbaraly T, Marmot MG. The effect of short sleep duration on coronary heart disease risk is greatest among those with sleep disturbance: a prospective study from the Whitehall II cohort. *Sleep* 2010;**33**:739–44. https://doi.org/10.1093/sleep/33.6.739
15. Chien KL, Chen PC, Hsu HC, Su TC, Sung FC, Chen MF, *et al.* Habitual sleep duration and insomnia and the risk of cardiovascular events and all-cause death: report from a community-based cohort. *Sleep* 2010;**33**:177–84. https://doi.org/10.1093/sleep/33.2.177
16. Sands-Lincoln M, Loucks EB, Lu B, Carskadon MA, Sharkey K, Stefanick ML, *et al.* Sleep duration, insomnia, and coronary heart disease among postmenopausal women in the Women's Health Initiative. *J Womens Health (Larchmt)* 2013;**22**:477–86. https://doi.org/10.1089/jwh.2012.3918
17. Westerlund A, Bellocco R, Sundström J, Adami HO, Åkerstedt T, Lagerros YT. Sleep characteristics and cardiovascular events in a large Swedish cohort. *Eur J Epidemiol* 2013;**28**:463–73. https://doi.org/10.1007/s10654-013-9802-2
18. Fan M, Sun D, Zhou T, Heianza Y, Lv J, Li L, *et al.* Sleep patterns, genetic susceptibility, and incident cardiovascular disease: a prospective study of 385 292 UK biobank participants. *Eur Heart J* 2020;**41**:1182–9. https://doi.org/10.1093/eurheartj/ehz849
19. Wang Z, Yang W, Li X, Qi X, Pan K, Xu W. Association of sleep duration, napping, and sleep patterns with risk of cardiovascular diseases: a Nationwide Twin Study. *J Am Heart Assoc* 2022;**11**:e025969. https://doi.org/10.1161/JAHA.122.025969
20. Empana JP, Bean K, Guibout C, Thomas F, Bingham A, Pannier B, *et al.* Paris Prospective Study III: a study of novel heart rate parameters, baroreflex sensitivity and risk of sudden death. *Eur J Epidemiol* 2011;**26**:887–92. https://doi.org/10.1007/s10654-011-9618-x
21. Firmann M, Mayor V, Vidal P, Bochud M, Pécoud A, Hayoz D, *et al.* The CoLaus study: a population-based study to investigate the epidemiology and genetic determinants of cardiovascular risk factors and metabolic syndrome. *BMC Cardiovasc Disord* 2008;**8**:6. https://doi.org/10.1186/1471-2261-8-6
22. Preisig M, Waeber G, Vollenweider P, Bovet P, Rothen S, Vandeleur C, *et al.* The PsyCoLaus study: methodology and characteristics of the sample of a population-based survey on psychiatric disorders and their association with genetic and cardiovascular risk factors. *BMC Psychiatry* 2009;**9**:9. https://doi.org/10.1186/1471-244X-9-9
23. Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res* 1989;**28**:193–213. https://doi.org/10.1016/0165-1781(89)90047-4
24. Netzer NC, Stoohs RA, Netzer CM, Clark K, Strohl KP. Using the Berlin Questionnaire to identify patients at risk for the sleep apnea syndrome. *Ann Intern Med* 1999;**131**:485. https://doi.org/10.7326/0003-4819-131-7-199910050-00002
25. Lisan Q, van Sloten T, Boutouyrie P, Laurent S, Danchin N, Thomas F, *et al.* Sleep apnea is associated with accelerated vascular aging: results from 2 European community-based cohort studies. *J Am Heart Assoc* 2021;**10**:e021318. https://doi.org/10.1161/JAHA.120.021318
26. Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *Sleep* 1991;**14**:540–5. https://doi.org/10.1093/sleep/14.6.540
27. Backhaus J, Junghanns K, Broocks A, Riemann D, Hohagen F. Test–retest reliability and validity of the Pittsburgh Sleep Quality Index in primary insomnia. *J Psychosom Res* 2002;**53**:737–40. https://doi.org/10.1016/S0022-3999(02)00330-6
28. Senaratna CV, Perret JL, Matheson MC, Lodge CJ, Lowe AJ, Cassim R, *et al.* Validity of the Berlin questionnaire in detecting obstructive sleep apnea: a systematic review and meta-analysis. *Sleep Med Rev* 2017;**36**:116–24. https://doi.org/10.1016/j.smrv.2017.04.001
29. Chervin RD, Aldrich MS, Pickett R, Guilleminault C. Comparison of the results of the Epworth sleepiness scale and the multiple sleep latency test. *J Psychosom Res* 1997;**42**:145–55. https://doi.org/10.1016/S0022-3999(96)00239-5
30. Taillard J, Philip P, Chastang JF, Bioulac B. Validation of Horne and Ostberg morningness-eveningness questionnaire in a middle-aged population of French workers. *J Biol Rhythms* 2004;**19**:76–86. https://doi.org/10.1177/0748730403259849
31. Horne JA, Ostberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int J Chronobiol* 1976;**4**:97–110. PMID : 1027738.
32. Heinzer R, Vat S, Marques-Vidal P, Marti-Soler H, Andries D, Tobback N, *et al.* Prevalence of sleep-disordered breathing in the general population: the HypnoLaus study. *Lancet Respir Med* 2015;**3**:310–8. https://doi.org/10.1016/S2213-2600(15)00043-0
33. Empana JP, Lerner I, Perier MC, Guibout C, Jabre P, Bailly K, *et al.* Ultrasensitive troponin I and incident cardiovascular disease. *Arterioscler Thromb Vasc Biol* 2022;**42**:1471–81. https://doi.org/10.1161/ATVBAHA.122.317961
34. Beuret H, Hausler N, Nanchen D, Méan M, Marques-Vidal P, Vaucher J. Comparison of Swiss and European risk algorithms for cardiovascular prevention in Switzerland. *Eur J Prev Cardiol* 2021;**28**:204–10. https://doi.org/10.1177/2047487320906305
35. Bonett DG, Price RM. Inferential methods for the tetrachoric correlation coefficient. *J Educ Behav Stat* 2005;**30**:213–25. https://doi.org/10.3102/10769986030002213
36. Vaida F, Xu R. Proportional hazards model with random effects. *Stat Med* 2000;**19**:3309–24. https://doi.org/10.1002/1097-0258(20001230)19:24<3309::AID-SIM825>3.0.CO;2-9
37. Spiegelman D, Hertzmark E, Wand HC. Point and interval estimates of partial population attributable risks in cohort studies: examples and software. *Cancer Causes Control* 2007;**18**:571–9. https://doi.org/10.1007/s10552-006-0090-y
38. Austin PC, Fine JP. Practical recommendations for reporting Fine-Gray model analyses for competing risk data. *Stat Med* 2017;**36**:4391–400. https://doi.org/10.1002/sim.7501
39. Metten MA, Costet N, Multigner L, Viel JF, Chauvet G. Inverse probability weighting to handle attrition in cohort studies: some guidance and a call for caution. *BMC Med Res Methodol* 2022;**22**:45. https://doi.org/10.1186/s12874-022-01533-9
40. Endeshaw Y, Rice TB, Schwartz AV, Stone KL, Manini TM, Satterfield S, *et al.* Snoring, daytime sleepiness, and incident cardiovascular disease in the health, aging, and body composition study. *Sleep* 2013;**36**:1737–45. https://doi.org/10.5665/sleep.3140
41. Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative

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sleep values across the human lifespan. *Sleep* 2004;**27**:1255–73. https://doi.org/10.1093/sleep/27.7.1255
42. Gaye B, Tajeu GS, Vasan RS, Lassale C, Allen NB, Singh-Manoux A, *et al.* Association of changes in cardiovascular health metrics and risk of subsequent cardiovascular disease and mortality. *J Am Heart Assoc* 2020;**9**:e017458. https://doi.org/10.1161/JAHA.120.017458
43. van Sloten TT, Tafflet M, Périer MC, Dugravot A, Climie RED, Singh-Manoux A, *et al.* Association of change in cardiovascular risk factors with incident cardiovascular events. *JAMA* 2018;**320**:1793. https://doi.org/10.1001/jama.2018.16975
44. Patel SR, Malhotra A, Gottlieb DJ, White DP, Hu FB. Correlates of long sleep duration. *Sleep* 2006;**29**:881–9. https://doi.org/10.1093/sleep/29.7.881
45. Billings ME, Hale L, Johnson DA. Physical and social environment relationship with sleep health and disorders. *Chest* 2020;**157**:1304–12. https://doi.org/10.1016/j.chest.2019.12.002
46. Joost S, Haba-Rubio J, Himsl R, Vollenweider P, Preisig M, Waeber G, *et al.* Spatial clusters of daytime sleepiness and association with nighttime noise levels in a Swiss general population (GeoHypnoLaus). *Int J Hyg Environ Health* 2018;**221**:951–7. https://doi.org/10.1016/j.ijheh.2018.05.004
47. Jacobs DR, Woo JG, Sinaiko AR, Daniels SR, Ikonen J, Juonala M, *et al.* Childhood cardiovascular risk factors and adult cardiovascular events. *N Engl J Med* 2022;**386**:1877–88. https://doi.org/10.1056/NEJMoa2109191
48. Climie R, Fuster V, Empana JP. Health literacy and primordial prevention in childhood-an opportunity to reduce the burden of cardiovascular disease. *JAMA Cardiol* 2020;**5**:1323–4. https://doi.org/10.1001/jamacardio.2020.2864
49. Fernandez-Jimenez R, Al-Kazaz M, Jaslow R, Carvajal I, Fuster V. Children present a window of opportunity for promoting health: JACC review topic of the week. *J Am Coll Cardiol* 2018;**72**:3310–9. https://doi.org/10.1016/j.jacc.2018.10.031
50. Itani O, Jike M, Watanabe N, Kaneita Y. Short sleep duration and health outcomes: a systematic review, meta-analysis, and meta-regression. *Sleep Med* 2017;**32**:246–56. https://doi.org/10.1016/j.sleep.2016.08.006
51. Labarca G, Gower J, Lamperti L, Dreyse J, Jorquera J. Chronic intermittent hypoxia in obstructive sleep apnea: a narrative review from pathophysiological pathways to a precision clinical approach. *Sleep Breath* 2020;**24**:751–60. https://doi.org/10.1007/s11325-019-01967-4
52. Yeghiazarians Y, Jneid H, Tietjens JR, Redline S, Brown DL, El-Sherif N, *et al.* Obstructive sleep apnea and cardiovascular disease: a scientific statement from the American Heart Association. *Circulation* 2021;**144**:e56–67. https://doi.org/10.1161/CIR.0000000000000988
53. Lavie L. Obstructive sleep apnoea syndrome–an oxidative stress disorder. *Sleep Med Rev* 2003;**7**:35–51. https://doi.org/10.1053/smrv.2002.0261
54. Ulasli S S, Sariaydin M, Ozkececi G, Gunay E, Halici B, Unlu M. Arterial stiffness in obstructive sleep apnoea: is there a difference between daytime and night-time? *Respirology* 2016;**21**:1480–5. https://doi.org/10.1111/resp.12845
55. Knutson KL, von Schantz M. Associations between chronotype, morbidity and mortality in the UK Biobank cohort. *Chronobiol Int* 2018;**35**:1045–53. https://doi.org/10.1080/07420528.2018.1454458
56. Scheer FA, Hilton MF, Mantzoros CS, Shea SA. Adverse metabolic and cardiovascular consequences of circadian misalignment. *Proc Natl Acad Sci U S A* 2009;**106**:4453–8. https://doi.org/10.1073/pnas.0808180106
57. Dressle RJ, Feige B, Spiegelhalder K, Schmucker C, Benz F, Mey NC, *et al.* HPA axis activity in patients with chronic insomnia: a systematic review and meta-analysis of case-control studies. *Sleep Med Rev* 2022;**62**:101588. https://doi.org/10.1016/j.smrv.2022.101588
58. Riemann D, Baglioni C, Bassetti C, Bjorvatn B, Dolenc Groselj L, Ellis JG, *et al.* European guideline for the diagnosis and treatment of insomnia. *J Sleep Res* 2017;**26**:675–700. https://doi.org/10.1111/jsr.12594
59. Randerath W, de Lange J, Hedner J, Ho JPTF, Marklund M, Schiza S, *et al.* Current and novel treatment options for obstructive sleep apnoea. *ERJ Open Res* 2022;**8**:00126-2022. https://doi.org/10.1183/23120541.00126-2022
60. Hida A, Kitamura S, Katayose Y, Kato M, Ono H, Kadotani H, *et al.* Screening of clock gene polymorphisms demonstrates association of a PER3 polymorphism with morningness-eveningness preference and circadian rhythm sleep disorder. *Sci Rep* 2014;**4**:6309. https://doi.org/10.1038/srep06309
61. Hur YM. Stability of genetic influence on morningness-eveningness: a cross-sectional examination of South Korean twins from preadolescence to young adulthood. *J Sleep Res* 2007;**16**:17–23. https://doi.org/10.1111/j.1365-2869.2007.00562.x
62. Leger D, Duforez F, Gronfier C; et le Groupe consensus chronobiologie et sommeil de la Société française de recherche et médecine du sommeil (SFRMS). [Treating circadian sleep-wake disorders by light]. *Presse Med* 2018;**47**:1003–9. https://doi.org/10.1016/j.lpm.2018.10.013
63. Soh HL, Ho RC, Ho CS, Tam WW. Efficacy of digital cognitive behavioural therapy for insomnia: a meta-analysis of randomised controlled trials. *Sleep Med* 2020;**75**:315–25. https://doi.org/10.1016/j.sleep.2020.08.020
64. Rockhill B, Newman B, Weinberg C. Use and misuse of population attributable fractions. *Am J Public Health* 1998;**88**:15–9. https://doi.org/10.2105/AJPH.88.1.15

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