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Original Article

Original Article

Sleep and circadian health in the UK Biobank: report on the 2023 sleep questionnaire enhancement

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Abstract

Study Objectives: Our study introduced the 2023 UK Biobank sleep questionnaire and described variation in sleep health dimensions and the prevalence of disordered sleep.

Methods: A questionnaire comprising validated measures and bespoke items was developed to capture key self-reported domains of sleep health and symptoms of sleep disorders. We quantified cohort prevalence of operationally defined sleep disorders and assessed the patterning of sleep health dimensions across key sociodemographic and clinically relevant variables.

Results: A total of 183 704 individuals completed at least one module of the questionnaire after email invitation (representing 56 per cent of those with an active email address), and an additional 1352 individuals completed via the participant website. In total 185 056 individuals were included in the analysis. Respondents were predominantly from a White ethnic background (96.8%), had a mean age of 69.9 (*SD*, 7.5) years, 57.9 per cent were female, and 25.5 per cent were in employment. Compared to non-respondents, respondents were more likely to be female, tended to be better educated, healthier, and exhibit lower levels of socioeconomic deprivation, although baseline sleep variables were similar between respondents and non-respondents. Around 40 per cent of respondents reported sleep duration less than 7 h, and 49 per cent reported poor sleep quality (Pittsburgh Sleep Quality Index >5). Approximately one-quarter (25.2%) met the criteria for at least one operationally defined sleep disorder, with insomnia being the most common (14.4%) followed by obstructive sleep apnea (8.0%), restless legs syndrome (4.1%), and frequent nightmares (3.7%). Sleep disorders were associated with higher levels of anxiety, depression, fatigue, and cognitive complaints.

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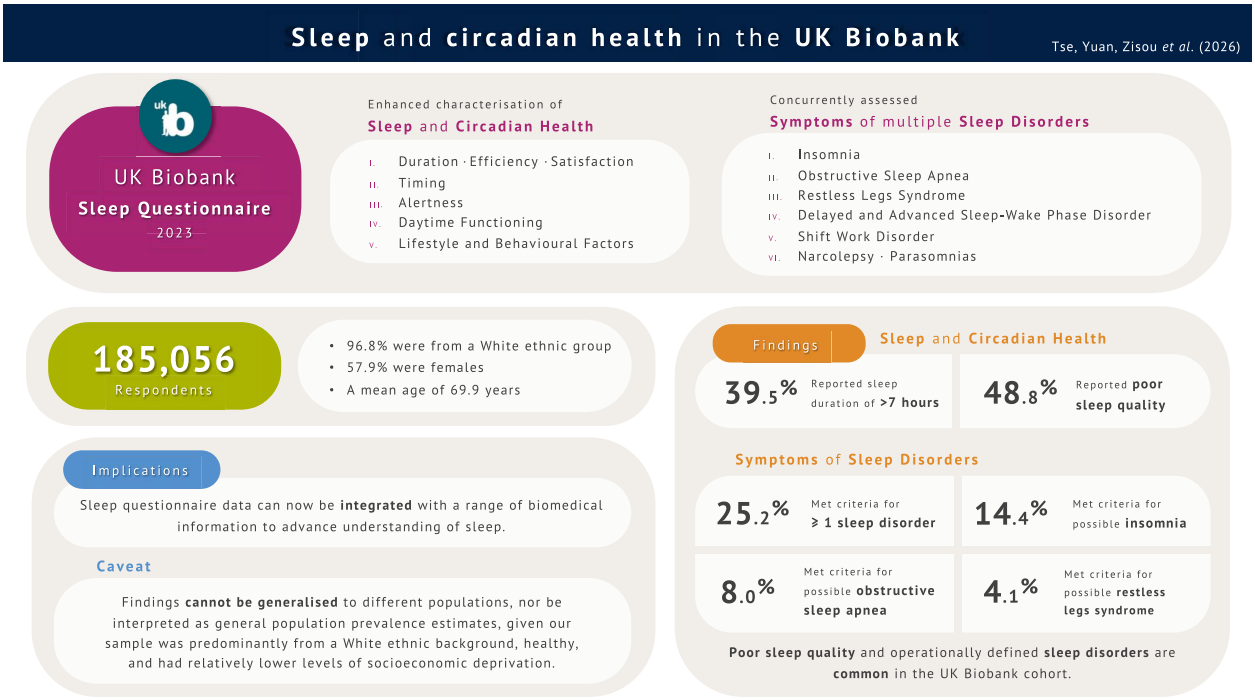
Conclusions: Poor sleep quality and operationally defined sleep disorders are common in the UK Biobank cohort. Sleep questionnaire data can now be integrated with a range of biomedical information to advance understanding of sleep.

Key words: sleep; circadian; UK Biobank; cohort study

Graphical Abstract



Statement of Significance

A comprehensive sleep questionnaire was introduced to the UK Biobank, with over 185 000 participants providing data. Overall, respondents reported relatively poor sleep quality; 40 per cent reported sleep duration less than 7 h, and 25 per cent met the criteria for at least one sleep disorder. Enhanced assessment of sleep in UK Biobank now enables integration with extensive biomedical data, including genetic, wearable, imaging, lifestyle, biomarker, and electronic health record data, offering opportunities to investigate the biological and environmental factors that influence sleep and circadian systems, and their impact on health.

Introduction

Sleep disorders are highly prevalent and burdensome [1, 2]. Despite major advances in understanding and classifying sleep disorders, sleep complaints often remain under-assessed, under-diagnosed, and by extension poorly managed in clinical practice [3, 4]. In addition to disordered sleep, population variation in sleep duration, timing, continuity, regularity, and quality are consistently associated with a range of adverse mental and physical health outcomes [5], while optimizing sleep dimensions in clinical and non-clinical populations delivers health benefit [6–8].

The emergence of large-scale biobank studies with embedded sleep measurement has facilitated novel discoveries; for example, on the genetic architecture of sleep and circadian traits [9–11], associations with morbidity and mortality [12, 13], and the potential causality between sleep-circadian parameters and disease through the application of Mendelian randomization [14, 15]. Indeed, to date[1], over 700 sleep and circadian-related studies have been published utilizing data from UK Biobank, a cohort study of ~500 000 people aged 40–69 years at enrolment, which integrates clinical, genetic, imaging, and other biomedical data with assessments of lifestyle and sociodemographic factors. However, a recurrent criticism leveled at such large-scale studies is the low-resolution measurement of sleep, typically reflecting just single-item questions [16], as well as limited consideration of the range and co-occurrence of sleep and circadian disorders [17].

Ideally, large-scale biobank studies would include both polysomnographic and clinical assessment of sleep and sleep disorders, but currently this is neither practical nor feasible at scale (although recent developments in measurement and analytics may change the future landscape [18]). Enhanced capture of probable sleep disorders at scale through comprehensive questionnaire measures would represent a key advance relative to previous work. For example, improved phenotyping would reduce misclassification between related sleep disorders in epidemiological analysis and more precisely characterize heterogeneity within disorder categories, paving the way for precision medicine approaches. Because sleep disorders often go undiagnosed, and are therefore under-reported in electronic health records, we need measures that capture probable cases to permit comparison with non-cases on genetics, biomarkers, structural and functional brain health, and other disease indices. Doing so will provide significant opportunity to define the

[1] PubMed search on September 12, 2025 ("uk biobank"[Title/Abstract] AND "circadian"[Title/Abstract]) OR ("uk biobank"[Title/Abstract] AND "sleep"[Title/Abstract])

patterning, underpinning biology, and putative consequences of a range of sleep and circadian disorders.

Recognizing the fundamental importance of sleep and circadian rhythms for health, UK Biobank introduced a dedicated web-based sleep questionnaire in 2023 (with data released in March 2025). The purpose of this article is to describe the instruments and items included in the questionnaire, introduce suggested phenotype coding for a range of sleep and circadian disorders, and present descriptive statistics on the patterning of sleep disorder cases and sleep/circadian traits.

Our objectives were thus:

1) to describe the characteristics of individuals who completed the sleep questionnaire;
2) to describe variation in sleep health dimensions and the association with sociodemographic factors and disordered sleep;
3) to describe the association between reporting sleep difficulties at the baseline assessment visit using single items (2006–2010) and meeting criteria for disordered sleep on the sleep questionnaire (2023);
4) to describe the cohort-wide prevalence of disordered sleep, the co-occurrence between different sleep disorders, and the sociodemographic, environmental, clinical, and lifestyle correlates of sleep disorders.

Materials and Methods

UK Biobank

UK Biobank is a prospective cohort study of over half a million adults aged 40–69 years when recruited from England, Scotland, and Wales between 2006 and 2010 (response rate 5.5%) (more information can be found in Sudlow et al. [19]). At the baseline assessment visit, participants gave informed consent, completed a touchscreen questionnaire, provided anthropometric measures and biological samples, and underwent an interview with a nurse. Sleep and sleep disruption were captured using single-item questions probing sleep duration, difficulties getting up in the morning, napping, dozing, snoring, insomnia, and chronotype.

The baseline assessment visit included consent to be recontacted to take part in further voluntary assessments. All the procedures were approved by the NHS Research Ethics Service (Ref. 11/NW/0382).

Development of the sleep questionnaire

Between 2017 and 2021, a group of sleep researchers and clinicians worked with the UK Biobank team to design a sleep questionnaire with the aim of capturing key domains of self-reported sleep health and sleep disorders. The online questionnaire comprised 138 items across 11 modules (see Figure 1). When developing the content of the questionnaire, we considered scientific value, the need to balance breadth and depth of assessment, participant acceptability (e.g. time to complete, ease of use, limited item duplication), and licensing considerations. At the time of planning, we judged that there was no existing single questionnaire with adequate psychometric properties to permit identification of all the main sleep and circadian disorder types. We selected published scales commonly used in research and clinical practice to assess common sleep disorders, supplemented by amended or additional questionnaire items (Supplementary Appendix 1). These comprised the Sleep Condition Indicator [20] (insomnia), Berlin Questionnaire [19] (obstructive sleep apnea [OSA]), Brief Screen for Sleep Disorders [21] (delayed sleep–wake phase disorder [DSWPD] and advanced sleep–wake phase disorder [ASWPD]), Shift Work Sleep Disorder Questionnaire [22] (shift work disorder [SWD]), Alliance Sleep Questionnaire [23] (narcolepsy, parasomnias), Rapid Eye Movement (REM) Sleep Behavior Disorder Single-Question Screen [24] (REM sleep behavior disorder [RBD]), and Cambridge-Hopkins Restless Legs Syndrome Questionnaire [25] (restless legs syndrome [RLS]).

We also assessed sleep and circadian health dimensions and selective potential correlates of sleep, including Pittsburgh Sleep Quality Index [26] (PSQI; global sleep quality), the reduced Morningness-Eveningness Questionnaire [27] (chronotype), the situational sleepiness scale and bespoke questionnaire items [28] (sleepiness), Flinders Fatigue Scale [29] (FFS; fatigue), British Columbia Cognitive Complaints Inventory [30] (BC-CCI; cognitive impairment), Patient Health Questionnaire-4 [31] (PHQ-4; depression and anxiety symptoms), and family history of sleep disorders [23]. A number of additional bespoke items were added to capture domains where there was no existing questionnaire, or to provide context to included questionnaire items (e.g. duration of early morning awakenings, napping, changes in sleep following the Coronavirus (COVID-19) pandemic, shift work pattern, timing of sleep periods on work and non-work days, and key lifestyle and behavioral factors, such as exercise, use of sleep tracking devices, alcohol, and caffeine).

Questionnaire administration

Participants with an active email address and had not withdrawn from further contact ($n = 327\,751$) received an invitation email containing a hyperlink to complete the online sleep questionnaire. Reminder emails were sent to non-respondents 2 weeks and 4 months after the initial invitation, and to partial respondents 2 weeks after they started the questionnaire. Participants for whom UK Biobank did not have an email address were encouraged via information on the UK Biobank website, and in the UK Biobank participant newsletter, to complete the online questionnaire by logging-on directly to the participant website.

The questionnaire was piloted in December 2022, administered initially to around 13 000 participants, and resultant data were incorporated into the final dataset. The aim was to ensure that the online platform and procedures were adequately robust and that the questionnaire was acceptable in terms of content and length. Based on pilot feedback, several questions in the "work and sleep" and "sleep consequences" modules were identified as needing revised wording to improve clarity, although the response options remained unchanged. Changes in wording (Supplementary Appendix 2) between item versions were judged to be sufficiently minor and, for the purposes of the present analysis, responses were grouped. The main phase of questionnaire administration began in late January 2023. Data were accessed in March 2025.

Defining outcomes/phenotypes from the sleep questionnaire

Using the available questionnaire items, we developed putative case definitions for insomnia disorder, OSA, RLS, DSWPD and ASWPD, SWD, and REM and NREM parasomnias. To do this, we drew upon diagnostic criteria (Diagnostic and Statistical Manual of Mental Disorders, 5th Edition [DSM-5] [32] or International Classification of Sleep Disorders, Third Edition, Text Revision [ICSD-3-TR] [33]), original scale scoring, and clinical expertise to arrive at consensus agreement. An initial coding framework was sent to a broader working group of sleep-circadian researchers, who provided comment and refinement, prior to finalizing definitions. Given that comprehensive clinical assessment (often involving

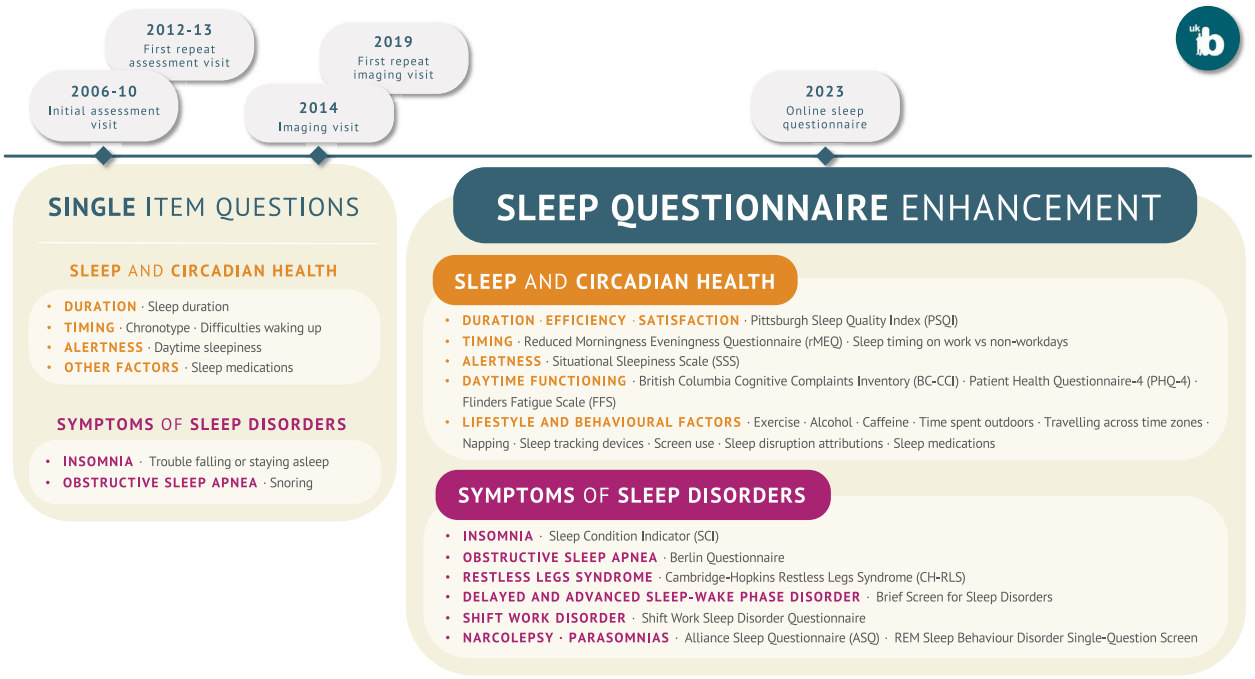


Figure 1. UK Biobank sleep questionnaire (2023).

polysomnography) is needed to appropriately diagnose sleep disorders, our case definitions should be considered suggestive of disorder rather than definitive.

Sleep disorder coding was applied based on overall case definitions. Respondents who met these definitions were classified as likely cases, even if responses to sub-fields were missing. Those who did not meet the case definitions were classified as likely non-case. Respondents with insufficient information to determine case or non-case status were assigned missing values for that phenotype. Changes made to phenotypes during the analysis phase are described in Supplementary Appendix 3.

Missing data were defined as those who responded "prefer not to answer". Responses including "do not know" and "not applicable" were considered as missing unless it was appropriate to assign a default value (see Supplementary Appendix 4 for framework). All "varies significantly" responses were considered as missing when the outcomes required precise clock timings (e.g. calculating sleep efficiency, mid-point of sleep period).

Analysis

Phenotype coding and descriptive analyses were independently conducted by two authors (H.Y. and C.Z.), with any discrepancies resolved through discussion. All operationally defined phenotypes were cross-checked at the respondent level, and resulting tabulations were compared by visual inspection.

Baseline characteristics and phenotypes were summarized using descriptive statistics (see Supplementary Appendix 6 for data fields for all single item variables). Continuous variables were approximately normally distributed and reported as mean (*SD*), while categorical variables were summarized as frequencies (percentages). Cross-tabulations were used to examine patterns in sleep health dimensions and operationally defined sleep disorders overall and across participant subgroups. Descriptive statistics involving sleep phenotypes were reported as row-wise or column-wise variables in tables. For the statistic in a row-wise or column-wise calculation, the denominator is the same across all columns or rows.

All analyses were performed on the UK Biobank Research Analysis Platform (https://www.ukbiobank.ac.uk/enable-your-research/research-analysis-platform) using Python (version 3.10) and R (version 4.4). To support transparency and reproducibility, all scripts used in the analysis are publicly available on GitHub (https://github.com/UK-Biobank-Sleep-consortium/ukb_sleep_enhancement). The operationally defined phenotypes will be returned to the UK Biobank Showcase for use by other researchers.

For composite timing phenotypes that required calculations from responses in the form of 24-h timestamps, a cut-point-based inclusion criterion was applied to filter out incorrect responses due to timestamp confusion. If computed habitual time in bed or sleep duration was less than 3 h or greater than 16 h, responses used for calculations were set to missing (Supplementary Appendix 5). Results were reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (Supplementary Appendix 7).

Results

Respondent characteristics

A total of 185 056 respondents completed at least one module of the sleep questionnaire and were included in the analysis, of whom 183 704 individuals completed after email invitation (representing 56 per cent of those with an active email address), and an additional 1352 individuals completed via the participant website (Figure 2). Respondents were predominately female (57.9%), from a White ethnic background (96.8%), and had a mean (*SD*) age of 69.9 (7.5) years (Table 1).

Compared to individuals who received an invitation but did not participate, sleep questionnaire respondents were more likely to be female (57.9% vs. 52.3%), from a White ethnic background (96.8% vs. 93.0%), and have a College or University degree (43.8% vs. 32.0%, Table 1), Moreover, sleep questionnaire respondents were more likely to be in the "healthy" body mass index (BMI) range (38.2% vs. 31.5%), have never smoked (58.6% vs. 55.1%) and report "excellent" overall health (21.6% vs. 15.6%) at the baseline assessment (Table 1). A similar pattern was also observed when

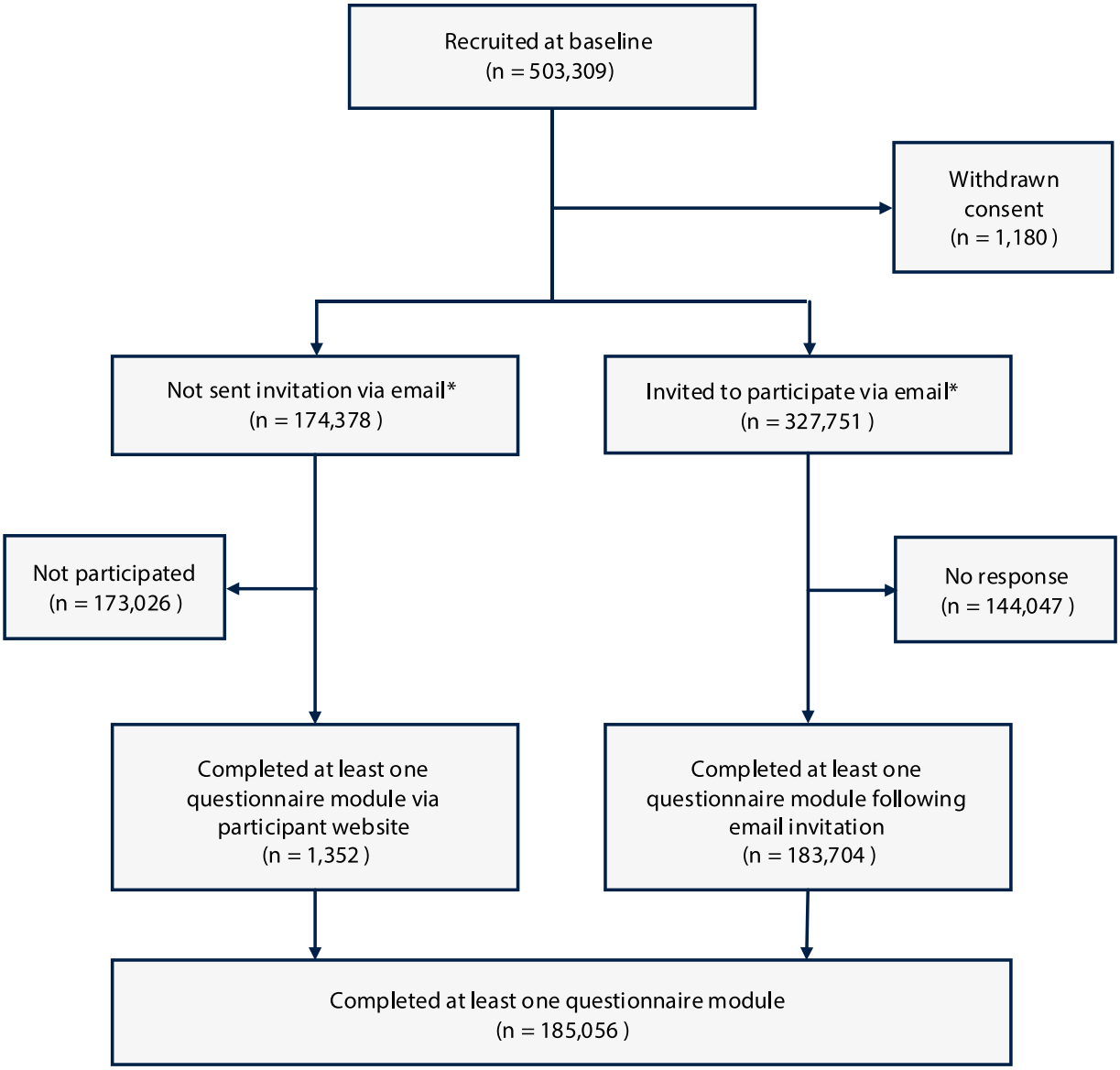


Figure 2. Flowchart of the UK Biobank sleep questionnaire.

comparing sleep questionnaire respondents to the broader UK Biobank cohort (Table 1). Sleep parameters collected at baseline were broadly similar between respondents and non-respondents (Supplementary eTable S1, Appendix 8). Respondents were more likely to have participated in the UK Biobank mental health questionnaire (63.5% vs. 20.9%), accelerometry (38.9% vs. 16.4%) and imaging assessment (38.8% vs. 11.1%).

For brevity, below we provide an illustrative summary of descriptive data patterns but see Tables 1–5 and Supplementary eTables S1–S7 for complete information on all examined variables and outcomes.

Sleep health dimensions

Mean sleep duration (*SD*) was 6.9 h (1.2 h) with 53.5 per cent of respondents reporting "optimal" sleep duration (7–9 h), while 39.5 per cent reported "short" (<7 h) and 4.6 per cent reported "long" (>9 h) sleep duration (Supplementary eTable S2); 74.6 per cent reported "fairly good" or "good" sleep quality in the past month. Mean [*SD*] global sleep quality score (total PSQI) was 6.65 [3.46], with 48.8 per cent scoring in the sleep disturbance range (>5), and mean sleep efficiency was 79.1 per cent (*SD*, 13.3 per cent; Supplementary eTable S2). The majority (73.6%) of respondents did not work, but those engaged in employment (and worked typical hours of 9 am–5 pm, $n = 35\,632$, 19.3%) woke 53 min later on free days compared to work days in the past month (Supplementary eTable S3). For shift-workers ($n = 10\,908$, 5.9%), sleep timing on work days in the past month followed a predictable pattern (e.g. morning shift workers had advanced sleep onset and offset times, while night-shift workers had markedly delayed sleep onset and offset times).

Sleep efficiency was lower in participants with advancing age, lower levels of education, and poorer self-rated health (Supplementary eTable S2). Short sleep duration was more common amongst individuals with Asian, Black, or a Mixed ethnic background; with lower levels of education; those living in the most deprived geographical areas; those in the "obese" BMI range; and those with "poor" or "fairly poor" health (Supplementary eTable S2). Global sleep quality score (PSQI) was also higher (indicating worse sleep quality) in participants with lower levels of educational qualification and less frequent alcohol consumption, higher levels of deprivation, BMI, smoking status, and poorer self-rated health status (Supplementary eTable S2).

Table 1. Population characteristics at baseline (2006–2010) for UK Biobank sleep cohort: participant count and proportions by subgroup

Characteristic	Baseline assessment (2006–2010) (*n* = 502 128)	Sleep questionnaire (2023) (*n* = 185 056)	Invited but did not participate in sleep questionnaire (*n* = 144 047)
Age at baseline (years)			
Mean (*SD*)	57.0 (8.1)	55.8 (7.6)	56.4 (8.3)
Age at sleep questionnaire completion (years)			
Mean (*SD*)	NA (NA)	69.9 (7.5)	NA (NA)
Sex			
Female	273 155 (54.4%)	107 071 (57.9%)	75 303 (52.3%)
Male	228 973 (45.6%)	77 985 (42.1%)	68 744 (47.7%)
Ethnicity			
Asian or Asian British	11 443 (2.3%)	2063 (1.1%)	4167 (2.9%)
Black or Black British	8048 (1.6%)	1294 (0.7%)	2804 (1.9%)
Mixed race or other	7502 (1.5%)	1996 (1.1%)	2476 (1.7%)
White	472 360 (94.1%)	179 047 (96.8%)	133 975 (93.0%)
Missing	2775 (0.6%)	656 (0.4%)	625 (0.4%)
Highest qualification			
College or University degree	161 001 (32.1%)	81 005 (43.8%)	46 088 (32.0%)
Vocational qualifications	135 324 (27.0%)	50 578 (27.3%)	40 855 (28.4%)
National exams at ages 16–18	110 453 (22.0%)	38 692 (20.9%)	34 325 (23.8%)
None of the above	85 228 (17.0%)	12 886 (7.0%)	20 471 (14.2%)
Missing	10 122 (2.0%)	1895 (1.0%)	2308 (1.6%)
Employment status			
Employed	286 640 (57.1%)	123 177 (66.6%)	85 899 (59.6%)
Not employed	212 641 (42.3%)	61 453 (33.2%)	57 398 (39.8%)
Missing	2847 (0.6%)	426 (0.2%)	750 (0.5%)
Townsend deprivation index			
Least deprived	186 226 (37.1%)	76 751 (41.5%)	56 263 (39.1%)
2nd Quintile	102 013 (20.3%)	39 309 (21.2%)	29 994 (20.8%)
3rd Quintile	74 880 (14.9%)	27 699 (15.0%)	21 327 (14.8%)
4th Quintile	67 107 (13.4%)	22 441 (12.1%)	18 669 (13.0%)
Most deprived	71 278 (14.2%)	18 637 (10.1%)	17 600 (12.2%)
Missing	624 (0.1%)	219 (0.1%)	194 (0.1%)
Body mass index			
Underweight (<18.5 kg/m^2)	2625 (0.5%)	1005 (0.5%)	600 (0.4%)
Normal weight (18.5–24.9 kg/m^2)	162 260 (32.3%)	70 668 (38.2%)	45 424 (31.5%)
Overweight (25–29.9 kg/m^2)	211 968 (42.2%)	76 487 (41.3%)	62 952 (43.7%)
Obese (≥30 kg/m^2)	122 172 (24.3%)	36 454 (19.7%)	34 339 (23.8%)
Missing	3103 (0.6%)	442 (0.2%)	732 (0.5%)
Smoking status			
Never	273 323 (54.4%)	108 409 (58.6%)	79 339 (55.1%)
Previous	172 920 (34.4%)	63 168 (34.1%)	50 360 (35.0%)
Current	52 937 (10.5%)	13 017 (7.0%)	13 686 (9.5%)
Missing	2948 (0.6%)	462 (0.2%)	662 (0.5%)
Alcohol consumption frequency			
<1 times/week	154 373 (30.7%)	47 328 (25.6%)	41 920 (29.1%)
1–2 times/week	129 184 (25.7%)	47 529 (25.7%)	37 632 (26.1%)
3–4 times/week	115 356 (23.0%)	48 711 (26.3%)	34 132 (23.7%)
Daily	101 715 (20.3%)	41 334 (22.3%)	30 076 (20.9%)
Missing	1500 (0.3%)	154 (0.1%)	287 (0.2%)
Self-reported overall health rating			
Excellent	81 787 (16.3%)	40 056 (21.6%)	22 482 (15.6%)
Good	288 816 (57.5%)	111 924 (60.5%)	85 562 (59.4%)
Fair	105 281 (21.0%)	28 549 (15.4%)	29 990 (20.8%)
Poor	22 759 (4.5%)	4092 (2.2%)	5269 (3.7%)
Missing	3485 (0.7%)	435 (0.2%)	744 (0.5%)
Self-reported prescribed sleep medication			
Yes	4829 (1.0%)	1167 (0.6%)	1204 (0.8%)
No	496 437 (98.9%)	183 814 (99.3%)	142 677 (99.0%)
Missing	862 (0.2%)	75 (0.0%)	166 (0.1%)
Participation in UK Biobank Mental Health Questionnaire (2016–2017)			
Yes	157 255 (31.3%)	117 550 (63.5%)	30 173 (20.9%)
No	344 873 (68.7%)	67 506 (36.5%)	113 874 (79.1%)

(continued)

Table 1. Continued.

Characteristic	Baseline assessment (2006–2010) (*n* = 502 128)	Sleep questionnaire (2023) (*n* = 185 056)	Invited but did not participate in sleep questionnaire (*n* = 144 047)
Participation in UK Biobank Accelerometry (2013–2015)			
Yes	103 610 (20.6%)	71 900 (38.9%)	23 643 (16.4%)
No	398 518 (79.4%)	113 156 (61.1%)	120 404 (83.6%)
Participation in UK Biobank Imaging (2014-ongoing)			
Yes	92 031 (18.3%)	71 801 (38.8%)	15 978 (11.1%)
No	410 097 (81.7%)	113 255 (61.2%)	128 069 (88.9%)

Table 2. Prevalence of operationally defined sleep disorders by sex and current age

	Overall		Age, *n* (%)		Sex, *n* (%)	
***n* (%)**	***n* (%)[a]**	**Age in years (*SD*)**	**<65 years**	**≥65 years**	**Female**	**Male**
Chronic insomnia disorder	26 729 (14.4%)	69.1 (7.7)	8823 (33.0)	17 906 (67.0)	18 342 (68.6)	8387 (31.4)
Obstructive sleep apnea	14 796 (8.0%)	67.7 (7.6)	5887 (39.8)	8909 (60.2)	8513 (57.5)	6283 (42.5)
Restless legs syndrome	7506 (4.1%)	69.7 (7.5)	2193 (29.2)	5313 (70.8)	5456 (72.7)	2050 (27.3)
Delayed sleep–wake phase disorder	1207 (0.7%)	67.9 (7.6)	452 (37.4)	755 (62.6)	765 (63.4)	442 (36.6)
Advanced sleep–wake phase disorder	903 (0.5%)	69.6 (7.5)	274 (30.3)	629 (69.7)	502 (55.6)	401 (44.4)
Shift work disorder	1717 (0.9%)	62.2 (5.9)	1289 (75.1)	428 (24.9)	968 (56.4)	749 (43.6)
Sleepwalking	1609 (0.9%)	70.3 (7.7)	448 (27.8)	1161 (72.2)	820 (51.0)	789 (49.0)
REM sleep behavior disorder	2157 (1.2%)	69.6 (7.5)	657 (30.5)	1500 (69.5)	604 (28.0)	1553 (72.0)
Nightmares	6805 (3.7%)	68.9 (7.6)	2272 (33.4)	4533 (66.6)	3721 (54.7)	3084 (45.3)
Summary						
None of the above	138 445 (74.8)	70.2 (7.5)	36 903 (26.7)	101 542 (73.3)	77 658 (56.1)	60 787 (43.9)
≥1 of above	46 611 (25.2)	69.1 (7.7)	15 341 (32.9)	31 270 (67.1)	29 413 (63.1)	17 198 (36.9)
≥2 of above	13 462 (7.3)	67.8 (7.6)	5327 (39.6)	8135 (60.4)	8371 (62.2)	5091 (37.8)
≥3 of above	2842 (1.5)	66.4 (7.4)	1344 (47.3)	1498 (52.7)	1643 (57.8)	1199 (42.2)

[a]The percentage (%) is calculated by dividing *n* by the total sleep questionnaire respondents (*n* = 185 056).

Females were more likely to have shorter sleep duration, lower sleep efficiency, and poorer global sleep quality than males. Individuals who were not employed or taking sleep medications at baseline (2006–2010) had poorer global PSQI sleep quality score (Supplementary eTable S2) compared to those who worked and did not take sleep medications.

Operationally defined sleep disorders – prevalence, baseline characteristics, and co-occurrence

Around one-quarter (25.2%) of respondents met criteria for at least one sleep disorder, while 7.3 per cent met criteria for at least two sleep disorders (Table 2). Chronic insomnia disorder was the most common sleep disorder (14.4%) followed by OSA (8.0%), RLS (4.1%), nightmare disorder (3.7%), RBD (1.2%), sleepwalking (0.9%), SWD (0.9 per cent of respondents/ 15.7 per cent of shift workers), and DSWPD and ASWPD (DSWPD, 0.7 per cent and ASWPD, 0.5%) (Table 2).

There was a particularly high proportion of female (vs. male) cases for insomnia (68.6%), RLS (72.7%), and DSWPD (63.4%) (Table 2), while conversely possible RBD was more frequently observed in males (72.0%) (Table 2).

In terms of co-occurrence of sleep disorders, around a quarter of insomnia cases (26.1%) met criteria for OSA (Table 3). Insomnia was also common in participants meeting criteria for OSA (47.2%), SWD (54.5%), RLS (30.2%), and nightmares (38.8%) (Table 3).

Across all possible sleep disorders, compared to the overall sample, there was a higher prevalence of individuals who, at baseline (2006–2010), were in the obese BMI range (21.4%–35.7% vs. 19.7%, Supplementary eTable S4), reported having frequent insomnia (29.8%–50.5% vs. 26.6%), reported frequent daytime sleepiness (2.7%–5.2% vs. 2.1%) and had sleep duration less than 7 h (24.1%–38.5% vs. 22.3%, Supplementary eTable S5). With the exception of ASWPD, individuals meeting criteria for any operationally defined sleep disorder, compared to the overall sample, were more likely to report baseline evening chronotype (8.6%–57.2% vs. 8.3%; ASWPD 0.4%) and difficulties getting up in the morning (not at all easy, 4.6%–25.5% vs. 3.4%; ASWPD 0.6%, Supplementary eTable S5).

Operationally defined sleep disorders –sleep health dimensions and lifestyle factors

Consistent with case criteria, those with operationally defined sleep disorders were characterized by poorer sleep quality and higher levels of daytime sleepiness relative to the overall sample (Table 4). Short sleep duration (<7 h) was most prominent in those with possible insomnia (76.4%) and SWD (70.5 per cent, Table 4). Sleep timing was earliest in those with possible ASWPD (midpoint of sleep period, 02:31 a.m.) and latest in those with DSWPD (midpoint of sleep period, 05:31 a.m., Table 4). Of all possible sleep disorders, insomnia had the lowest sleep efficiency (mean [*SD*], 67.2 per cent [13.8]), while DSWPD had the highest (mean [*SD*], 79.2 per cent [14.3]; Table 4). Respondents with insomnia also had the highest PSQI score (mean [*SD*], 11.1 [3.0]), while those with ASWPD had the lowest (6.9 [2.8]) (Table 4).

Table 3. Co-occurrence between operationally defined sleep disorders

		Comorbidity								
n **(%)**	**Overall prevalence[a]**	**Chronic insomnia disorder**	**Obstructive sleep apnea**	**Restless legs syndrome**	**Delayed sleep–wake phase disorder**	**Advanced sleep–wake phase disorder**	**Shift work disorder**	**Sleepwalking**	**REM sleep behavior disorder**	**Nightmares**
Chronic insomnia disorder	26 729 (14.4%)		6986 (26.1%)	2268 (8.5%)	310 (1.2%)	141 (0.5%)	935 (3.5%)	372 (1.4%)	574 (2.1%)	2638 (9.9%)
Obstructive sleep apnea	14 796 (8.0%)	6986 (47.2%)		1228 (8.3%)	333 (2.3%)	43 (0.3%)	546 (3.7%)	202 (1.4%)	474 (3.2%)	1480 (10.0%)
Restless legs syndrome	7506 (4.1%)	2268 (30.2%)	1228 (16.4%)		90 (1.2%)	27 (0.4%)	110 (1.5%)	72 (1.0%)	158 (2.1%)	451 (6.0%)
Delayed sleep–wake phase disorder	1207 (0.7%)	310 (25.7%)	333 (27.6%)	90 (7.5%)		0 (0.0%)	40 (3.3%)	14 (1.2%)	29 (2.4%)	106 (8.8%)
Advanced sleep–wake phase disorder	903 (0.5%)	141 (15.6%)	43 (4.8%)	27 (3.0%)	0 (0.0%)		11 (1.2%)	18 (2.0%)	7 (0.8%)	48 (5.3%)
Shift work disorder	1717 (0.9%)	935 (54.5%)	546 (31.8%)	110 (6.4%)	40 (2.3%)	11 (0.6%)		36 (2.1%)	50 (2.9%)	191 (11.1%)
Sleepwalking	1609 (0.9%)	372 (23.1%)	202 (12.6%)	72 (4.5%)	14 (0.9%)	18 (1.1%)	36 (2.2%)		92 (5.7%)	135 (8.4%)
REM sleep behavior disorder	2157 (1.2%)	574 (26.6%)	474 (22.0%)	158 (7.3%)	29 (1.3%)	7 (0.3%)	50 (2.3%)	92 (4.3%)		539 (25.0%)
Nightmares	6805 (3.7%)	2638 (38.8%)	1480 (21.7%)	451 (6.6%)	106 (1.6%)	48 (0.7%)	191 (2.8%)	135 (2.0%)	539 (7.9%)	

[a]Prevalence (%) is calculated by dividing the number of cases by the total sleep questionnaire respondents ($n = 185\,056$).

Table 4. Sleep health dimensions by operationally defined sleep disorders

	Overall (*n* = 185 056)	Chronic insomnia disorder (*n* = 26 729)	Obstructive sleep apnea (*n* = 14 796)	Restless legs syndrome (*n* = 7506)	Delayed sleep–wake phase disorder (*n* = 1207)	Advanced sleep–wake phase disorder (*n* = 903)	Shift work disorder (*n* = 1717)	Sleepwalking (*n* = 1609)	REM sleep behavior disorder (*n* = 2157)	Nightmares (*n* = 6805)
Sleep quality, mean (*SD*)										
PSQI. Range 0–21.	6.7 (3.5)	11.1 (3.0)	9.7 (3.6)	8.8 (3.7)	8.3 (3.3)	6.9 (2.8)	10.2 (3.5)	7.7 (3.8)	8.0 (4.0)	9.1 (3.8)
High = worse sleep quality										
Sleep satisfaction, *n* (%)										
Very good	36 216 (19.6%)	15 (0.1%)	550 (3.7%)	600 (8.0%)	102 (8.5%)	90 (10.0%)	32 (1.9%)	217 (13.5%)	280 (13.0%)	439 (6.5%)
Fairly good	101 744 (55.0%)	5029 (18.8%)	5139 (34.7%)	3591 (47.8%)	619 (51.3%)	635 (70.3%)	430 (25.0%)	855 (53.1%)	1065 (49.4%)	2828 (41.6%)
Fairly bad	37 390 (20.2%)	16 805 (62.9%)	6996 (47.3%)	2631 (35.1%)	420 (34.8%)	167 (18.5%)	892 (52.0%)	415 (25.8%)	608 (28.2%)	2647 (38.9%)
Very bad	6533 (3.5%)	4837 (18.1%)	2083 (14.1%)	678 (9.0%)	64 (5.3%)	11 (1.2%)	321 (18.7%)	116 (7.2%)	204 (9.5%)	883 (13.0%)
Missing	3173 (1.7%)	43 (0.2%)	28 (0.2%)	6 (0.1%)	2 (0.2%)	0 (0.0%)	42 (2.4%)	6 (0.4%)	0 (0.0%)	8 (0.1%)
Daytime sleepiness, *n* (%)										
No chance	72 703 (39.3%)	7805 (29.2%)	3789 (25.6%)	2672 (35.6%)	329 (27.3%)	232 (25.7%)	444 (25.9%)	565 (35.1%)	616 (28.6%)	2242 (32.9%)
Slight chance	69 103 (37.3%)	9039 (33.8%)	4904 (33.1%)	2746 (36.6%)	385 (31.9%)	296 (32.8%)	620 (36.1%)	575 (35.7%)	793 (36.8%)	2410 (35.4%)
Moderate chance	25 843 (14.0%)	5709 (21.4%)	3353 (22.7%)	1320 (17.6%)	291 (24.1%)	223 (24.7%)	327 (19.0%)	305 (19.0%)	434 (20.1%)	1232 (18.1%)
High chance	11 548 (6.2%)	3845 (14.4%)	2630 (17.8%)	753 (10.0%)	190 (15.7%)	142 (15.7%)	219 (12.8%)	148 (9.2%)	301 (14.0%)	860 (12.6%)
Missing	5859 (3.2%)	331 (1.2%)	120 (0.8%)	15 (0.2%)	12 (1.0%)	10 (1.1%)	107 (6.2%)	16 (1.0%)	13 (0.6%)	61 (0.9%)
Sleep timing, mean (*SD* min)										
Midpoint of sleep period	03:32 (75)	03:43 (84)	03:44 (84)	03:42 (81)	05:31 (89)	02:31 (71)	03:23 (95)	03:35 (88)	03:38 (75)	03:40 (84)
Sleep efficiency, mean (*SD*)										
Sleep efficiency (%)	79.1 (13.3)	67.2 (13.8)	73.0 (15.2)	73.6 (14.5)	79.2 (14.3)	78.7 (12.4)	74.1 (15.1)	76.3 (14.6)	77.3 (14.6)	74.4 (15.0)
Sleep duration, *n* (%)										
Mean duration (*SD*)	6.9 (1.2)	5.9 (1.2)	6.5 (1.4)	6.5 (1.3)	6.8 (1.3)	6.8 (1.0)	6.0 (1.3)	6.7 (1.3)	6.9 (1.4)	6.7 (1.4)
Short (<7 h)	73 147 (39.5%)	20 428 (76.4%)	8755 (59.2%)	4119 (54.9%)	595 (49.3%)	441 (48.8%)	1211 (70.5%)	758 (47.1%)	908 (42.1%)	3422 (50.3%)
Optimal (7–9 h)	99 086 (53.5%)	5622 (21.0%)	5064 (34.2%)	3077 (41.0%)	515 (42.7%)	429 (47.5%)	396 (23.1%)	761 (47.3%)	1055 (48.9%)	2908 (42.7%)
Long (>9 h)	8435 (4.6%)	375 (1.4%)	801 (5.4%)	255 (3.4%)	89 (7.4%)	28 (3.1%)	43 (2.5%)	70 (4.4%)	184 (8.5%)	394 (5.8%)
Missing	4388 (2.4%)	304 (1.1%)	176 (1.2%)	55 (0.7%)	8 (0.7%)	5 (0.6%)	67 (3.9%)	20 (1.2%)	10 (0.5%)	81 (1.2%)

Table 5. Chronotype and lifestyle related factors by operationally defined sleep disorders

	Overall (*n* = 185 056)	Chronic insomnia disorder (*n* = 26 729)	Obstructive sleep apnea (*n* = 14 796)	Restless legs syndrome (*n* = 7506)	Delayed sleep–wake phase disorder (*n* = 1207)	Advanced sleep–wake phase disorder (*n* = 903)	Shift work disorder (*n* = 1717)	Sleepwalking (*n* = 1609)	REM sleep behavior disorder (*n* = 2157)	Nightmare disorder (*n* = 6805)
Chronotype										
Definitely morning type	7193 (3.9%)	770 (2.9%)	235 (1.6%)	264 (3.5%)	0 (0.0%)	258 (28.6%)	65 (3.8%)	63 (3.9%)	56 (2.6%)	215 (3.2%)
Moderately morning type	57 340 (31.0%)	7297 (27.3%)	3169 (21.4%)	2197 (29.3%)	0 (0.0%)	645 (71.4%)	407 (23.7%)	513 (31.9%)	565 (26.2%)	1837 (27.0%)
Neither type	104 714 (56.6%)	14 823 (55.5%)	8586 (58.0%)	4199 (55.9%)	0 (0.0%)	0 (0.0%)	872 (50.8%)	847 (52.6%)	1229 (57.0%)	3699 (54.4%)
Moderately evening type	10 415 (5.6%)	2277 (8.5%)	1815 (12.3%)	574 (7.6%)	1026 (85.0%)	0 (0.0%)	223 (13.0%)	117 (7.3%)	182 (8.4%)	665 (9.8%)
Definitely evening type	566 (0.3%)	219 (0.8%)	168 (1.1%)	52 (0.7%)	181 (15.0%)	0 (0.0%)	32 (1.9%)	6 (0.4%)	20 (0.9%)	81 (1.2%)
Missing	4828 (2.6%)	1343 (5.0%)	823 (5.6%)	220 (2.9%)	0 (0.0%)	0 (0.0%)	118 (6.9%)	63 (3.9%)	105 (4.9%)	308 (4.5%)
Time spent outdoors per day in summer										
Less than 1 h	8239 (4.5%)	1971 (7.4%)	1379 (9.3%)	415 (5.5%)	178 (14.7%)	63 (7.0%)	176 (10.3%)	102 (6.3%)	137 (6.4%)	532 (7.8%)
1–<2 h	4971 (2.7%)	818 (3.1%)	520 (3.5%)	165 (2.2%)	60 (5.0%)	19 (2.1%)	81 (4.7%)	36 (2.2%)	55 (2.5%)	223 (3.3%)
2–<3 h	24 270 (13.1%)	3776 (14.1%)	2283 (15.4%)	975 (13.0%)	205 (17.0%)	92 (10.2%)	289 (16.8%)	208 (12.9%)	264 (12.2%)	913 (13.4%)
≥3 h	124 895 (67.5%)	17 012 (63.6%)	8861 (59.9%)	5322 (70.9%)	625 (51.8%)	662 (73.3%)	872 (50.8%)	1104 (68.6%)	1530 (70.9%)	4427 (65.1%)
Missing	22 681 (12.3%)	3152 (11.8%)	1753 (11.8%)	629 (8.4%)	139 (11.5%)	67 (7.4%)	299 (17.4%)	159 (9.9%)	171 (7.9%)	710 (10.4%)
Time spent outdoors per day in winter										
Less than 1 h	43 325 (23.4%)	8229 (30.8%)	5171 (34.9%)	2126 (28.3%)	577 (47.8%)	217 (24.0%)	501 (29.2%)	364 (22.6%)	573 (26.6%)	2004 (29.4%)
1–<2 h	41 181 (22.3%)	5781 (21.6%)	3081 (20.8%)	1728 (23.0%)	229 (19.0%)	165 (18.3%)	317 (18.5%)	345 (21.4%)	455 (21.1%)	1456 (21.4%)
2–<3 h	46 164 (24.9%)	6013 (22.5%)	3040 (20.5%)	1868 (24.9%)	189 (15.7%)	227 (25.1%)	317 (18.5%)	402 (25.0%)	536 (24.8%)	1557 (22.9%)
≥3 h	35 288 (19.1%)	4324 (16.2%)	2220 (15.0%)	1314 (17.5%)	122 (10.1%)	237 (26.2%)	320 (18.6%)	372 (23.1%)	465 (21.6%)	1256 (18.5%)
Missing	19 098 (10.3%)	2382 (8.9%)	1284 (8.7%)	470 (6.3%)	90 (7.5%)	57 (6.3%)	262 (15.3%)	126 (7.8%)	128 (5.9%)	532 (7.8%)
Use of electronic devices before bedtime										
I use them in bed	41 798 (22.6%)	7348 (27.5%)	4483 (30.3%)	1874 (25.0%)	425 (35.2%)	253 (28.0%)	546 (31.8%)	392 (24.4%)	518 (24.0%)	1805 (26.5%)
Less than 1 h	103 937 (56.2%)	13 961 (52.2%)	7678 (51.9%)	4222 (56.2%)	608 (50.4%)	436 (48.3%)	800 (46.6%)	796 (49.5%)	1214 (56.3%)	3664 (53.8%)
1–2 h	21 400 (11.6%)	3433 (12.8%)	1576 (10.7%)	969 (12.9%)	100 (8.3%)	108 (12.0%)	183 (10.7%)	232 (14.4%)	258 (12.0%)	831 (12.2%)
2–3 h	5217 (2.8%)	729 (2.7%)	399 (2.7%)	206 (2.7%)	28 (2.3%)	43 (4.8%)	38 (2.2%)	74 (4.6%)	76 (3.5%)	189 (2.8%)
3 h or longer	4848 (2.6%)	672 (2.5%)	360 (2.4%)	165 (2.2%)	24 (2.0%)	34 (3.8%)	26 (1.5%)	64 (4.0%)	48 (2.2%)	183 (2.7%)
Not applicable	1769 (1.0%)	212 (0.8%)	151 (1.0%)	49 (0.7%)	8 (0.7%)	19 (2.1%)	14 (0.8%)	27 (1.7%)	24 (1.1%)	62 (0.9%)
Missing	6087 (3.3%)	374 (1.4%)	149 (1.0%)	21 (0.3%)	14 (1.2%)	10 (1.1%)	110 (6.4%)	24 (1.5%)	19 (0.9%)	71 (1.0%)

(continued)

Table 5. Continued.

	Overall (*n* = 185 056)	Chronic insomnia disorder (*n* = 26 729)	Obstructive sleep apnea (*n* = 14 796)	Restless legs syndrome (*n* = 7506)	Delayed sleep–wake phase disorder (*n* = 1207)	Advanced sleep–wake phase disorder (*n* = 903)	Shift work disorder (*n* = 1717)	Sleepwalking (*n* = 1609)	REM sleep behavior disorder (*n* = 2157)	Nightmare disorder (*n* = 6805)
Exercise frequency in the past month										
Daily	35 980 (19.4%)	3984 (14.9%)	2066 (14.0%)	1328 (17.7%)	146 (12.1%)	224 (24.8%)	208 (12.1%)	313 (19.5%)	398 (18.5%)	1290 (19.0%)
More than once a week	44 552 (24.1%)	5411 (20.2%)	2724 (18.4%)	1631 (21.7%)	249 (20.6%)	168 (18.6%)	305 (17.8%)	349 (21.7%)	467 (21.7%)	1389 (20.4%)
3–4 times	39 386 (21.3%)	5878 (22.0%)	2982 (20.2%)	1639 (21.8%)	200 (16.6%)	193 (21.4%)	346 (20.2%)	339 (21.1%)	462 (21.4%)	1505 (22.1%)
1–2 times	27 683 (15.0%)	4760 (17.8%)	2613 (17.7%)	1343 (17.9%)	212 (17.6%)	124 (13.7%)	323 (18.8%)	258 (16.0%)	336 (15.6%)	1098 (16.1%)
Not at all	26 612 (14.4%)	4878 (18.2%)	3337 (22.6%)	1244 (16.6%)	302 (25.0%)	167 (18.5%)	368 (21.4%)	265 (16.5%)	364 (16.9%)	1136 (16.7%)
Unable to exercise	4383 (2.4%)	1383 (5.2%)	899 (6.1%)	292 (3.9%)	82 (6.8%)	15 (1.7%)	51 (3.0%)	58 (3.6%)	109 (5.1%)	294 (4.3%)
Missing	6460 (3.5%)	435 (1.6%)	175 (1.2%)	29 (0.4%)	16 (1.3%)	12 (1.3%)	116 (6.8%)	27 (1.7%)	21 (1.0%)	93 (1.4%)
Nap frequency in the past month										
Daily	12 317 (6.7%)	2932 (11.0%)	2220 (15.0%)	655 (8.7%)	164 (13.6%)	117 (13.0%)	122 (7.1%)	149 (9.3%)	259 (12.0%)	873 (12.8%)
More than once a week	25 368 (13.7%)	4268 (16.0%)	2685 (18.1%)	1095 (14.6%)	233 (19.3%)	176 (19.5%)	285 (16.6%)	240 (14.9%)	358 (16.6%)	1089 (16.0%)
3–4 times	23 506 (12.7%)	4927 (18.4%)	2979 (20.1%)	1138 (15.2%)	223 (18.5%)	168 (18.6%)	316 (18.4%)	251 (15.6%)	413 (19.1%)	1230 (18.1%)
1–2 times	56 108 (30.3%)	7577 (28.3%)	3845 (26.0%)	2301 (30.7%)	312 (25.8%)	240 (26.6%)	475 (27.7%)	478 (29.7%)	617 (28.6%)	1860 (27.3%)
Not at all	61 587 (33.3%)	6639 (24.8%)	2916 (19.7%)	2293 (30.5%)	260 (21.5%)	191 (21.2%)	405 (23.6%)	467 (29.0%)	495 (22.9%)	1684 (24.7%)
Missing	6170 (3.3%)	386 (1.4%)	151 (1.0%)	24 (0.3%)	15 (1.2%)	11 (1.2%)	114 (6.6%)	24 (1.5%)	15 (0.7%)	69 (1.0%)
Consumed alcohol to fall asleep in the past month										
Daily	2512 (1.4%)	620 (2.3%)	415 (2.8%)	108 (1.4%)	53 (4.4%)	16 (1.8%)	46 (2.7%)	33 (2.1%)	71 (3.3%)	245 (3.6%)
More than once a week	4323 (2.3%)	1143 (4.3%)	601 (4.1%)	222 (3.0%)	51 (4.2%)	24 (2.7%)	95 (5.5%)	51 (3.2%)	101 (4.7%)	325 (4.8%)
3–4 times	3385 (1.8%)	1171 (4.4%)	598 (4.0%)	177 (2.4%)	46 (3.8%)	32 (3.5%)	76 (4.4%)	36 (2.2%)	76 (3.5%)	315 (4.6%)
1–2 times	9884 (5.3%)	2787 (10.4%)	1346 (9.1%)	568 (7.6%)	129 (10.7%)	47 (5.2%)	214 (12.5%)	124 (7.7%)	183 (8.5%)	589 (8.7%)
Not at all	158 517 (85.7%)	20 583 (77.0%)	11 677 (78.9%)	6399 (85.3%)	911 (75.5%)	774 (85.7%)	1175 (68.4%)	1341 (83.3%)	1709 (79.2%)	5244 (77.1%)
Missing	6435 (3.5%)	425 (1.6%)	159 (1.1%)	32 (0.4%)	17 (1.4%)	10 (1.1%)	111 (6.5%)	24 (1.5%)	17 (0.8%)	87 (1.3%)
Caffeine consumption										
Non-drinker	26 423 (14.3%)	4815 (18.0%)	2572 (17.4%)	1331 (17.7%)	208 (17.2%)	169 (18.7%)	245 (14.3%)	291 (18.1%)	355 (16.5%)	1210 (17.8%)
1–3 servings/day	66 944 (36.2%)	10 095 (37.8%)	5217 (35.3%)	2626 (35.0%)	421 (34.9%)	319 (35.3%)	584 (34.0%)	564 (35.1%)	761 (35.3%)	2543 (37.4%)
≥4 servings/day	85 317 (46.1%)	11 384 (42.6%)	6830 (46.2%)	3513 (46.8%)	559 (46.3%)	403 (44.6%)	773 (45.0%)	727 (45.2%)	1021 (47.3%)	2966 (43.6%)
Missing	6372 (3.4%)	435 (1.6%)	177 (1.2%)	36 (0.5%)	19 (1.6%)	12 (1.3%)	115 (6.7%)	27 (1.7%)	20 (0.9%)	86 (1.3%)

In terms of lifestyle factors, compared to overall respondents, a greater proportion of individuals with sleep disorders napped daily (7.1%–15.0% vs. 6.7%), did not exercise in the past month (16.5%–25.0% vs. 14.4%), and used electronic devices in bed (24.0%–35.2% vs. 22.6%, Table 5). Those with DSWPD, compared to overall respondents and other sleep disorders, were more likely to spend less than 1 h per day outdoors in summer (14.7% vs. 4.5% vs. 5.5%–10.3%) and in winter (47.8% vs. 23.4% vs. 22.6%–34.9%, Table 5). Individuals with operationally defined sleep disorders tended to report greater cognitive difficulties (range of mean BC-CCI values: 4.5–7.0 vs. 3.8), fatigue (range of mean FFS values: 6.3–14.0 vs. 5.8), depression (range of mean PHQ-2 values: 0.8–2.3 vs. 0.7), and anxiety (range of mean Generalized Anxiety Disorder 2-item [GAD-2] values: 1.2–2.5 vs. 1.0, Supplementary eTable S6). Individuals with SWD were more likely to report being involved in more than 1 accident or near-miss due to sleepiness in the past year compared to people with other operationally defined sleep disorders (10.0% vs. 4.0%–7.0%, Supplementary eTable S6).

Family history of sleep disorders

There was an over-representation of family history of sleep disorders in cases versus non-cases. For example, 34.1 per cent of those with RLS reported positive family history of RLS compared to 11.2 per cent of those without RLS; 31.5 per cent of insomnia cases reported positive family history of insomnia compared to 18.8 per cent of those without; 13.5 per cent of OSA cases reported positive family history of OSA compared to 6.9 per cent of those without; and 11.9 per cent of those with nightmare disorder reported positive family history of nightmare disorder compared to 5.4 per cent of those without (see Supplementary eTable S7).

Discussion

We introduce a data resource for sleep and circadian research, which is now accessible for integrative and longitudinal data analyses. The main strength of this descriptive study lies in its enhanced characterization of sleep and circadian health—and their disruption—within the UK Biobank, offering insights that were previously inaccessible due to low-resolution measurement. Very few cohort or population-based studies concurrently assess multiple sleep and circadian disorders. Importantly, these data can now be directly linked to a wide range of additional biomedical data, including genetic, lifestyle, and health information, as well as biological samples, to provide deeper insight into the etiology of disordered sleep and relationships with disease. For example, the questionnaire data could be used to perform Genome-Wide Association Study (GWAS) on well-defined sleep disorders and to assess potential causality between sleep-circadian traits and various health outcomes using Mendelian randomization (MR) [16].

Sleep questionnaire respondents tended to be better educated, healthier, and from a higher socioeconomic background than those who did not participate, suggesting a possible "healthy volunteer" selection bias within the UK Biobank cohort (which is known to be somewhat healthier than the general population) [34, 35]. Patterning of sleep health by sociodemographic factors was broadly consistent with previous work [36, 37]. Overall, the sample reported poorer global sleep quality scores relative to population-based studies in other European countries (e.g. [38, 39]). It is, of course, possible that those experiencing poor sleep were more motivated to complete the questionnaire. However, rates of possible sleep disorder, such as insomnia [40] and RLS [41], were broadly consistent with the general population literature, supporting the face validity of our case criteria. Nonetheless, findings cannot be generalized to different populations and settings, nor be interpreted as general population prevalence estimates, given our sample was predominantly from a White ethnic background, healthy, and had relatively lower levels of socioeconomic deprivation. Sex differences were apparent for several disorders, and consistent with contemporary literature, but we observed an unexpected preponderance of females versus males in possible OSA cases, which deserves further investigation. Reinforcing previous work [42, 43], disordered sleep appeared to be associated with cognitive impairment, fatigue, anxiety, and depression.

Findings reported here should be interpreted with caution due to the descriptive nature of the study; no statistical analyses or covariate adjustments were performed. Operationally defined sleep disorders were derived from self-report measures and there was no confirmation from clinical interviews, polysomnography, or prospective sleep–wake monitoring. This raises the possibility that some disorders are underestimated, while others may be overestimated. Questions mainly focused on current symptoms, or symptoms within the past year, and thus we did not capture lifetime episodes, diagnoses, or treatment history. While we deployed validated questionnaires, it was necessary in some instances to create alternative scoring criteria or include additional items to index possible disorder. Some disorders were defined based on limited descriptive features (e.g. DSWPD), indexed by just single questionnaire items focused on frequency of specific symptoms (e.g. sleepwalking, nightmares), or comprised a combination of items with uncertain predictive validity (e.g. using two defined categories from the Berlin questionnaire for OSA). This notwithstanding, sleep health profiles patterned in the expected direction across cases (e.g. extreme sleep timing for circadian sleep–wake phase disorders, excessive daytime sleepiness for OSA) and there was clear evidence of disrupted sleep at the baseline assessment (approximately 14 years earlier) in those who subsequently met case criteria on the 2023 sleep questionnaire. Future data linkage, including formal diagnosis by a healthcare professional, may be needed to confidently capture rare sleep disorders, like narcolepsy.

To retain as much data as possible, we created case/non-case definitions that accounted for ambiguous responses such as "prefer not to answer," "varies significantly," "do not know," and "not applicable," as well as missing responses from nested questions. These responses were typically not part of the original validated questionnaires and required additional consideration during data processing. When handling atypical sleep-timing responses—likely reflecting confusion between 12-h versus 24-h format—we cross-checked with other questionnaire items and corrected responses where appropriate. Researchers planning to analyse UK Biobank sleep data are encouraged to review our criteria, including cleaning pipeline (see Supplementary Appendix 4), and employ scoring approaches consistent with their study-specific objectives.

Disordered sleep and poor sleep quality were common within UK Biobank participants who completed the detailed sleep questionnaire. These data, including proposed phenotype definitions, can now be integrated with a range of biomedical information to advance understanding of sleep.

Supplementary material

Supplementary material is available at *SLEEP* online.

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Data availability

The access to the UK Biobank can be requested on the UK Biobank website. The suggested phenotypes will be returned to the UK Biobank showcase after the acceptance of this manuscript. Researchers interested in obtaining early access to the phenotypes can do so using our codebase directly on the UK Biobank Research Analysis Platform.

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