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Tobacco exposure and sleep disturbance in 498 208 UK Biobank participants

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ABSTRACT

Background The prevalence of sleep disturbance is high and increasing. The study investigated whether active, former and passive smoking were associated with sleep disturbance.

Methods This cross-sectional study used data from the UK Biobank: a cohort study of 502 655 participants, of whom 498 208 provided self-reported data on smoking and sleep characteristics. Multivariable multinomial and logistic regression models were used to examine the associations between smoking and sleep disturbance.

Results Long-sleep duration (>9 h) was more common among current smokers [odds ratio (OR): 1.47; 95% confidence interval (CI): 1.17–1.85; probability value (P) = 0.001] than never smokers, especially heavy (>20/day) smokers (OR: 2.85; 95% CI: 1.66–4.89; $P < 0.001$). Former heavy (>20/day) smokers were also more likely to report short (<6 h) sleep duration (OR: 1.41; 95% CI: 1.25–1.60; $P < 0.001$), long-sleep duration (OR: 1.99; 95% CI: 1.47–2.71; $P < 0.001$) and sleeplessness (OR: 1.47; 95% CI: 1.38–1.57; $P < 0.001$) than never smokers. Among never smokers, those who lived with more than one smoker had higher odds of long-sleep duration than those not cohabitating with a smoker (OR: 2.71; 95% CI: 1.26–5.82; $P = 0.011$).

Conclusions Active and passive exposure to high levels of tobacco smoke are associated with sleep disturbance. Existing global tobacco control interventions need to be enforced.

Keywords passive smoking, sleep disorders, smoking cessation, tobacco

Introduction

Worldwide, sleep disturbance affects more than one-third of the adult general population,[1] and the prevalence is rising partly due to the ageing population and increasing urbanisation.[2,3] The proportion of the English population taking sleep medication has doubled since 1983.[4] Symptoms of sleep disturbance include sleeplessness or insomnia, short- and long-sleep duration, difficulty awakening in the morning and signs of daytime dysfunction, such as daytime sleepiness.[5]

Sleep disturbance predisposes to poor health, including cardiovascular diseases and mental health problems.[6,7] Short (<6 h/day) and long (>9 h/day) sleep duration are particularly associated with increased risk of diabetes,[8]

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cardiovascular diseases[9] and memory impairment.[10] Meta-analyses of cohort studies[11,12] have consistently shown an increased mortality risk in persons reporting short- or long-sleep duration. Economic implications of sleep disturbance cannot be overlooked and include increased absenteeism and lost productivity,[13] more accidents[14] and increased healthcare utilisation and costs.[13] In the USA, the annual economic burden of sleep disturbance has been estimated at $100 billion,[13] and the National Health Service (NHS) in England spends around £50 million on sleep medication each year.[15]

It is evident that nicotine can stimulate the release of neurotransmitters, such as acetylcholine and norepinephrine[16] which, in turn, may inhibit gamma-aminobutyric acid (GABA) and sleep-promoting neurons located in the ventrolateral preoptic area (VLPO), causing excessive arousal of the body.[17] Electroencephalography (EEG) reports have also revealed marked differences in sleep waves between smokers and non-smokers, with smokers having frequent arousals.[18] There is strong evidence that smoking cessation is associated with poor sleep;[19] however, previous studies on active smoking and sleep characteristics have produced conflicting results. For instance, while some studies have reported positive associations between active smoking and sleep disturbance,[20–25] others have reported no association[26–32] or even negative associations.[33–35] Furthermore, research is lacking into whether exposure to passive smoking is associated with sleep disturbance.

With the increasing geriatric population and increasing prevalence of sleep disturbance, understanding how exposure to tobacco smoke is associated with sleep behaviour may help strengthen the existing tobacco control interventions, which may subsequently reduce the impact of smoking on a wide range of health parameters, including sleep disturbance. We used the baseline data of a large population-based cohort study to examine the associations of active, former and passive smoking with various self-reported sleep characteristics including total sleep duration, sleeplessness, difficulty awakening in the morning and daytime dozing (DD).

Methods

Study population and procedures

UK Biobank[36] recruited 502 655 men and women aged 40–69 years from the general population between 2006 and 2010. Participants attended one of 22 assessment centres across the UK where they completed a touch-screen questionnaire.[37] A validated questionnaire was used to obtain information on a number of variables such as socio-demographic characteristics (age, sex and ethnicity), lifestyle factors (smoking behaviour), occupational information (frequency of shift work) and self-reported health (stress, depression and health rating) from the participants.[36] Our study was cross-sectional and we used the baseline data in the UK Biobank.

In our study, we grouped the participants into 'never smokers', 'former smokers' and 'current smokers' based on their response to the questions: 'Do you smoke now?' and subsequent ones. Those who responded 'Yes' were considered as 'current smokers.' Participants who responded 'No' were further asked whether they had previously smoked. Those who had previously smoked were grouped as 'former smokers', and those who were neither current smokers nor had previously smoked were grouped as 'never smokers.' In addition, data on daily number of cigarettes consumed by current and former smokers, and whether never smokers lived with one or more current smoker were obtained from the participants.[37]

Sleep duration was defined as the total number of hours a respondent reported to be sleeping in a day. The participants were asked: 'About how many hours of sleep do you get in every 24 h?' We categorised the numerical responses into short-sleep duration (<6 h per day), normal (6–9 h per day) and long-sleep duration (>9 h per day) using the National Sleep Foundation definition of short-, long- and normal-sleep duration.[38] The questions: 'Do you have trouble falling asleep at night or do you wake up in the middle of the night?' and 'How likely are you to doze off or fall asleep during the daytime when you don't mean to?' were used to evaluate sleeplessness and DD, respectively.[37]

The participants' health state was evaluated with a question that asked the participants to rate their health on a scale of 1–4: '1' equated to 'excellent health' and '4' equated to 'poor health.' They were also asked whether they felt 'stressed' or 'depressed' and their responses were used to ascertain stress and depression separately.[37] Shift work was evaluated with a question that asked the participants to describe their current shift pattern, whether it involved a shift schedule. The responses were: 'Not', 'Sometimes', 'Usually' and 'Always' in shift work. Participants were further asked whether they considered themselves to be 'Definitely a morning person', 'More of a morning person', 'More of an evening person' and 'Definitely an evening person' based on the time they were most active. This was used to assess chronotype.[37]

Postcode of residence was used to allocate the participants to general population quintiles of socioeconomic status (proxy for household status), using the Townsend index which is derived from area-based information on

unemployment, car ownership, ownership of house and overcrowding. The design of the UK Biobank has been published elsewhere.[36,39]

Statistical analyses

In order to identify confounding factors, the Pearson Chi-square (χ^2), Chi-square test for trend and Kruskal–Wallis rank tests were used to examine whether there were significant differences in sleep characteristics and smoking status according to socio-demographic characteristics, lifestyle, occupational and health factors. A series of logistic regression models were used to investigate the associations between tobacco exposure and sleep characteristics: sleeplessness, difficulty awakening in the morning and DD. We used a multinomial logistic regression model to examine the association between tobacco exposure and total sleep duration (long-, short- and normal-sleep duration). The models were initially run univariately, then multivariably. The multivariable models adjusted for covariates—age, sex, ethnicity, socioeconomic deprivation, self-reported stress and depression, alcohol and coffee consumption, physical activity level, engagement in shift work and self-identified chronotype—that were significantly associated with both the exposure and the outcome. Interaction tests were conducted and the associations were further stratified by covariates that had statistically significant interactions with smoking on the association with sleep disturbance, as appropriate.

Two-tailed test was used in all the analyses. Our study comprised a very large sample and might therefore be prone to Type I error. We therefore set statistically significant level at $P \leq 0.01$, instead of the conventional $P < 0.05$. The assumptions underlying the validity of χ^2 and Kruskal–Wallis tests were examined, and the Hosmer–Lemeshow test was further used to assess the goodness-of-fit of the multivariable regression models. All analyses were undertaken using Stata version 14.0. This study was conducted under the generic approval for UK Biobank from the NHS National Research Ethics Service (approval letter dated 17 June 2011, ref 11/NW/0382).

Results

Characteristics of the participants

Of the 502 655 UK Biobank participants, 498 208 (99.1%) were eligible for inclusion in the study. Of these, 54.4% were women and the mean age was 56.5 years. Overall, 27 383 (5.5%) reported short total sleep duration (<6 h), 9234 (1.9%) long-sleep duration (>9 h), 359 722 (28.2%) sleeplessness, 378 828 (24.1%) DD and 407 251 (18.1%) difficulty awakening in the morning (Table 1).

Participants who reported short- or long-sleep duration, sleeplessness and DD were older, more likely to be socioeconomically deprived, more likely to report feeling stressed or depressed, more likely to report poor overall health, less physically active, consumed more coffee and were more likely to work shifts (Table 1). In addition, women were more likely than men to report short- or long-sleep duration (Table 1) and sleeplessness (31.9% versus 23.8%), but were less likely to report DD (22.4% versus 26.0%).

Current smokers were more likely to report short- or long-sleep duration (10.9%) than either never (7.1%) or former (6.7%) smokers (Table 2). The prevalence of short- or long-sleep duration increased with the amount currently and previously smoked among current and former smokers, respectively (Table 2). Compared with never smokers who did not live with a smoker (6.9%), the prevalence of short- or long-sleep duration was higher among those who lived with one smoker (9.1%) and highest among those who lived with more than one smoker in the house (11.8%).

Smoking and sleep disturbance

On univariate analysis (Table 3), current smokers were more likely than never smokers to have short- or long-sleep duration. However, following adjustment for potential confounders, only the association with long-sleep duration remained statistically significant (adjusted odds ratio (OR): 1.47; 95% confidence interval (CI): 1.17–1.85; $P = 0.001$). When we adjusted for health status, we found that 8.8% of the observed association could be explained by poor health. The odds of long-sleep duration was particularly highest among those who smoked more than 20 cigarettes per day (adjusted OR: 2.85; 95% CI: 1.66–4.89; $P < 0.001$). Current smokers were, however, less likely to report DD than never smokers (adjusted OR: 0.91; 95% CI: 0.86–0.96; $P = 0.001$), with evidence of a dose-relationship whereby the likelihood of DD decreased with the amount smoked per day (Table 4).

Overall, there was no statistically significant association between former smokers and short- or long-sleep duration: (adjusted OR: 0.96; 95% CI: 0.90–1.02) and (adjusted OR: 1.13; 95% CI: 0.97–1.33), respectively. However, on subgroup analysis, former smokers who had previously smoked more than 20 cigarettes per day had statistically significantly higher odds of short (adjusted OR: 1.41; 95% CI: 1.25–1.60; $P < 0.001$) and long-sleep duration (adjusted OR: 1.99; 95% CI: 1.47–2.71; $P < 0.001$) than never smokers (Table 3). Former smokers were also more likely to report sleeplessness (adjusted OR: 1.10; 95% CI: 1.07–1.14;

Table 1 Participants' characteristics by sleep characteristics

	<6 h, n = *27 383* *(%)*	*6–9 h*, n = *461 591* *(%)*	*>9 h*, n = *9234* *(%)*	*Sleeplessness*, n = *141 427* *(%)*	*DMA*, n = *89 723* *(%)*	*DD*, n = *120 047* *(%)*
Sex						
Male	43.6	45.8	44.5	61.6	45.6	49.2
Female	56.4	54.2	55.5	38.4	54.4	50.8
Age (years)						
<47	13.1	15.5	12.7	11.3	15.3	10.8
47–56	32.0	30.1	24.8	29.5	30.2	26.0
57–66	43.9	43.8	46.5	47.4	43.8	48.4
>66	10.7	10.6	16.0	11.8	10.7	14.9
Ethnicity						
White	89.6	95.0	92.0	95.7	94.5	91.6
Black	4.7	1.4	2.6	1.2	1.7	2.8
Asian	2.8	1.9	2.8	1.6	2.0	3.1
Chinese	0.3	0.3	0.4	0.2	0.3	0.5
Other	1.6	0.9	1.5	0.8	0.9	1.4
Mixed	1.0	0.7	0.8	0.6	0.6	0.6
Deprivation quintile						
1 (least deprived)	14.4	20.6	13.8	19.0	20.7	17.8
2	15.5	20.4	16.3	19.2	20.0	18.4
3	17.6	20.3	17.7	19.6	19.9	19.2
4	21.1	19.9	21.5	20.2	20.0	20.3
5 (most deprived)	31.4	18.9	30.7	21.9	20.1	24.3
Alcohol consumption (glasses/day)						
0	43.4	32.9	46.1	24.1	33.4	35.0
1–4	30.9	36.8	28.4	22.1	36.4	37.1
5–9	15.0	18.5	13.9	11.5	18.3	17.2
>9	10.7	11.9	11.7	8.0	11.9	10.7
Physical activity (min/day)						
0	0.1	0.1	0.3	0.1	0.1	0.2
1–30	45.3	48.2	48.2	47.5	47.5	48.1
31–60	27.1	28.4	27.3	27.9	28.3	27.9
61–90	4.5	4.2	4.3	4.4	4.4	4.3
>90	23.0	19.1	19.9	20.1	19.6	19.7
Engagement in shift work						
Never	72.6	83.4	73.0	82.4	82.6	77.9
Sometimes	10.3	7.3	8.8	7.4	7.5	8.6
Usually	3.3	2.1	3.1	2.1	2.1	2.8
Always	13.8	7.3	15.1	8.0	7.9	10.6
Self-identified chronotype						
Definitely morning	34.8	26.7	24.7	27.7	27.2	28.9
More morning	29.3	36.0	27.0	34.3	35.4	34.1
More evening	24.5	28.6	32.5	27.8	28.5	27.4
Definitely evening	11.3	8.7	15.8	10.2	8.9	9.6

Continued

Table 1 Continued

	<6 h, n = *27 383* (%)	*6–9 h*, n = *461 591* (%)	*>9 h*, n = *9234* (%)	*Sleeplessness*, n = *141 427* (%)	*DMA*, n = *89 723* (%)	*DD*, n = *120 047* (%)
Self-reported stress						
No	69.5	77.1	66.4	69.3	76.5	71.1
Yes	30.5	22.9	33.6	30.7	23.5	28.9
Self-reported depression						
No	43.0	60.8	43.6	46.9	59.5	50.9
Yes	57.0	39.2	56.4	53.1	40.5	49.1
Self-reported health state						
Excellent	8.9	17.1	8.0	11.2	16.4	12.0
Good	45.6	59.2	37.7	52.1	57.9	53.0
Fair	31.8	20.2	32.4	27.7	21.2	26.7
Poor	13.7	3.6	21.9	9.0	4.6	8.3

n, Number of participants; DMA, Self-reported Difficulty in morning awakening; DD, Self-reported daytime dozing

Table 2 Prevalence of sleep characteristics

	<6 h, n = *27 383* (%)	*6–9 h*, n = *461 591* (%)	*>9 h*, n = *9234* (%)	*Sleeplessness*, n = *141 427* (%)	*DMA* n = *89 723* (%)	*DD*, n = *120 047* (%)
Smoking status						
Never	39.6	40.1	36.7	37.5	39.9	39.2
Former	44.5	49.4	46.6	50.7	48.9	49.7
Current	15.9	10.5	16.7	11.8	11.1	11.1
Live with a smoker (never smokers)						
No	88.5	91.6	89.4	91.7	91.3	90.8
Yes (1)	9.9	7.5	9.4	7.4	7.8	8.2
Yes (>1)	1.6	0.9	9.4	0.9	1.0	1.1

n, Number of participants; DMA, Difficulty in morning awakening.

$P < 0.001$) and DD (adjusted OR: 1.05; 95% CI: 1.02–1.08; $P = 0.004$) than never smokers, with the highest risk of sleeplessness apparent among those who previous smoked more than 20 cigarettes per day (Table 4). Similarly, never smokers who lived with one or more smoker had an increased odds of long-sleep duration (adjusted OR: 2.71; 95% CI: 1.26–5.82; $P = 0.011$). However, neither active nor passive exposure to tobacco smoke was significantly associated with difficulty in awakening in the morning in this study.

Sub-group analyses revealed that most of the statistically significant associations were stronger in men, white participants, those aged 47–66 years and participants who were not in any shift work. In addition, 'evening type' current smokers were more likely to report long-sleep duration but were less likely to doze off at daytime, while sleeplessness was stronger among 'morning type' former smokers. However, there was no substantial difference in the effect size of the association between smoking and sleep disturbance in the deprivation quintiles.

In the sensitivity analysis (Supplementary Tables 2 and 3), current smokers still had statistically significantly higher odds of long-sleep duration (adjusted OR: 1.29; 95% CI: 1.04–1.60) and lower odds of DD (adjusted OR: 0.87; 95% CI: 0.83–0.92) than former smokers. Additionally, compared to former smokers, current smokers had lower odds of sleeplessness (adjusted OR: 0.95; 95% CI: 0.91–1.00).

Discussion

Main findings

Active, former and passive smoking were all associated with sleep disturbance. Consistent with previous studies, we demonstrated that former heavy smokers were more likely to report short- or long-sleep duration and sleeplessness.

Table 3 Multinomial logistic regression analyses of smoking and sleep duration

	Univariate					*Multivariable*				
	<6 h		*6–9 h*	*>9 h*		*<6 h*		*6–9 h*	*>9 h*	
	OR (95% CI)	*P-value*	*OR*	*OR (95% CI)*	*P-value*	*OR (95% CI)*	*P-value*	*OR*	*OR (95% CI)*	*P-value*
Smoking status										
Never	1.00		1.00	1.00		1.00		1.00	1.00	
Former	0.91 (0.89–0.94)	<0.001	1.00	1.03 (0.98–1.08)	0.197	0.96 (0.90–1.02)	0.154	1.00	1.13 (0.97–1.33)	0.122
Current	1.54 (1.49–1.60)	<0.001	1.00	1.74 (1.64–1.85)	<0.001	1.03 (0.94–1.13)	0.534	1.00	**1.47 (1.17–1.85)**	**0.001***
Cigarettes/day (current smokers)										
0	1.00		1.00	1.00		1.00		1.00	1.00	
1–10	1.43 (1.34–1.53)	<0.001	1.00	1.60 (1.43–1.80)	<0.001	1.08 (0.91–1.29)	0.351	1.00	1.47 (1.00–2.18)	0.052
11–20	1.77 (1.67–1.87)	<0.001	1.00	1.96 (1.79–2.15)	<0.001	0.99 (0.85–1.17)	0.947	1.00	1.11 (0.73–1.69)	0.626
>20	2.55 (2.34–2.77)	<0.001	1.00	2.78 (2.41–3.19)	<0.001	**1.46 (1.15–1.87)**	**0.002***	1.00	**2.85 (1.66–4.89)**	**<0.001***
Cigarettes/day (former smokers)										
0	1.00		1.00	1.00		1.00		1.00	1.00	
1–10	0.85 (0.80–0.90)	<0.001	1.00	0.85 (0.77–0.94)	0.002	0.88 (0.77–1.01)	0.062	1.00	0.98 (0.71–1.37)	0.917
11–20	0.96 (0.92–1.00)	0.070	1.00	1.24 (1.16–1.33)	<0.001	0.96 (0.87–1.06)	0.395	1.00	1.23 (0.97–1.56)	0.085
>20	1.44 (1.37–1.52)	<0.001	1.00	1.90 (1.75–2.06)	<0.001	**1.41 (1.25–1.60)**	**<0.001***	1.00	**1.99 (1.47–2.71)**	**<0.001***
Live with a smoker (never smokers)										
No	1.00		1.00	1.00		1.00		1.00	1.00	
Yes (1)	1.37 (1.28–1.46)	<0.001	1.00	1.28 (1.14–1.44)	<0.001	1.02 (0.87–1.20)	0.792	1.00	0.86 (0.54–1.38)	0.402
Yes (>1)	1.91 (1.63–2.24)	<0.001	1.00	1.46 (1.07–1.99)	0.018	1.47 (0.99–2.15)	0.051	1.00	**2.71 (1.26–5.82)**	**0.011***

Multivariable adjusted for age, sex, ethnicity, social deprivation quintile, self-reported stress, self-reported depression, alcohol and coffee consumption, physical activity level, shift work and self-identified chronotype.

*Statistically significant results (*P*-value ≤0.01).

Furthermore, current and never smokers exposed to high levels of passive smoke were also more likely to report long-sleep duration. These associations were independent of socio-demographic, lifestyle, occupational and health confounding factors.

What is already known about the topic

Whilst previous studies have consistently shown an association between smoking cessation and sleep disturbance,[19,40,41] the existing evidence in relation to current smoking is inconsistent.[29–31,33–35] Some of the previous studies have been much smaller in size (range 88–498) and have varied in their definition of sleep disturbance.[25,28,31] In addition, most previous studies have focused on sleeplessness; in comparison, sleep duration and daytime dysfunction have been relatively neglected. Some studies have also combined current and former smokers in a single group in the analyses,[42–44] and many did not adjust for potential confounders such as engagement in shift work, chronotype and mental health.[23,30,42,43,45]

There is some evidence to suggest that sleep disturbance may vary by ethnicity;[46] hence, it may be difficult to generalise findings from one country to another. Only one previous study has been conducted in the UK; a cross-sectional study of 1484 men and women living in rural Oxfordshire.[47] The investigators reported that cigarette smoking was associated with shorter self-reported sleep duration in both sexes, but smoking was not associated with self-reported sleep quality.[47] The investigators stratified the analyses by sex and adjusted for age but could not control for other potential confounders.

What this study adds

Our study comprised a very large sample of the general population. We were able to examine three types of tobacco exposure (current, former and passive smoking) and five measures of sleep disturbance (short-sleep duration, long-sleep duration, sleeplessness, difficulty awakening in the morning and DD) in the same study population. There is strong evidence of increased morbidity and mortality risk in persons reporting long-sleep duration.[11,12] We showed that current smokers might be at increased risk of long-sleep duration and this might mediate the established harmful health effects of cigarette smoking. Importantly, short-, long- and normal-sleep durations

Table 4 Logistic regression analysis of smoking and sleeplessness, DMA and DD

	Sleeplessness				*DMA*				*DD*			
	Univariate		*Multivariable*		*Univariate*		*Multivariable*		*Univariate*		*Multivariable*	
	OR (95% CI)	P-*value*	*OR (95% CI)*	P-*value*	*OR (95% CI)*	P-*value*	*OR (95% CI)*	P-*value*	*OR (95% CI)*	P-*value*	*OR (95% CI)*	P-*value*
Smoking status												
Never	1.00		1.00		1.00		1.00		1.00		1.00	
Former	1.14 (1.13–1.16)	<0.001	**1.10 (1.07–1.14)**	**<0.001***	1.00 (0.99–1.02)	0.745	1.01 (0.98–1.05)	0.392	1.04 (1.03–1.06)	<0.001	**1.05 (1.02–1.08)**	**0.004***
Current	1.22 (1.19–1.24)	<0.001	1.05 (1.00–1.10)	0.041	1.00 (0.98–1.03)	0.641	1.03 (0.98–1.08)	0.269	1.05 (1.03–1.07)	<0.001	**0.91 (0.86–0.96)**	**0.001***
Cigarettes/day (current smokers)												
0	1.00		1.00		1.00		1.00		1.00		1.00	
1–10	1.20 (1.15–1.24)	<0.001	1.07 (0.98–1.16)	0.728	0.97 (0.93–1.02)	0.273	0.92 (0.84–1.02)	0.109	0.96 (0.92–1.00)	0.036	**0.87 (0.79–0.96)**	**0.007***
11–20	1.34 (1.29–1.38)	<0.001	1.01 (0.93–1.10)	0.783	1.01 (0.97–1.05)	0.542	1.11 (1.01–1.21)	0.023	1.05 (1.02–1.09)	0.003	**0.83 (0.75–0.91)**	**<0.001***
>20	1.70 (1.60–1.80)	<0.001	1.15 (0.99–1.36)	0.072	0.99 (0.92–1.06)	0.694	1.04 (0.88–1.23)	0.664	1.17 (1.10–1.25)	<0.001	**0.74 (0.62–0.89)**	**0.001***
Cigarettes/day (former smokers)												
0	1.00		1.00		1.00		1.00		1.00		1.0.00	
1–10	1.23 (1.20–1.27)	<0.001	**1.14 (1.08–1.21)**	**<0.001***	1.00 (0.96–1.03)	0.768	0.98 (0.92–1.04)	0.440	1.03 (1.00–1.06)	0.053	**1.08 (1.01–1.15)**	**0.016***
11–20	1.25 (1.23–1.28)	<0.001	**1.18 (1.13–1.23)**	**<0.001***	1.02 (0.99–1.04)	0.201	1.02 (0.97–1.07)	0.358	1.04 (1.02–1.07)	<0.001	0.97 (0.92–1.02)	0.215
>20	1.50 (1.46–1.55)	<0.001	**1.47 (1.38–1.57)**	**<0.001***	1.02 (0.99–1.06)	0.210	1.03 (0.95–1.11)	0.479	1.32 (1.28–1.36)	<0.001	1.05 (0.97–1.13)	0.230
Live with a smoker (never smokers)												
No	1.00		1.00		1.00		1.00		1.00		1.00	
Yes (1)	1.15 (1.11–1.20)	<0.001	1.05 (0.97–1.13)	0.261	1.01 (0.97–1.06)	0.507	1.10 (1.01–1.20)	0.025	1.09 (1.05–1.14)	<0.001	1.08 (0.99–1.17)	0.104
Yes (>1)	1.21 (1.10–1.34)	<0.001	1.03 (0.83–1.29)	0.785	1.10 (0.98–1.24)	0.113	1.17 (0.93–1.47)	0.186	1.30 (1.17–1.44)	<0.001	1.23 (0.97–1.55)	0.153

Multivariable adjusted for age, sex, ethnicity, social deprivation quintile, self-reported stress, self-reported depression, alcohol and coffee consumption, physical activity level, shift work and self-identified chronotype.

*Statistically significant results (*P*-value ≤0.01).

were defined using a standard definition.[38] To the best of our knowledge, this is the first population-based study to investigate how passive smoking is associated with both long-sleep duration and DD. Additionally, we were able to examine whether there was evidence of a dose-response relationship with the level of tobacco exposure in all the three groups: daily number of cigarettes smoked for current and former smokers and number of cohabitants who smoked for never smokers. A number of other factors are known to be associated with sleep disturbance and smoking including age, sex, physical illnesses,[48] socioeconomic deprivation,[4] alcohol consumption[49] and we were able to adjust for these, and other potential confounders, in the analyses. Moreover, we stratified the associations by age, sex, ethnicity, chronotype and social deprivation. Furthermore, we conducted a sensitivity analysis to examine whether the sleep characteristics in current smokers differed from former smokers. These, in particular, have not been considered in the majority of the previous studies.

The mechanism underlying the association between cigarette smoking and sleep disturbance has been widely explored. Nicotine is known to stimulate the release of neurotransmitters, such as acetylcholine, dopamine and norepinephrine.[16] It is believed that these neurotransmitters inhibit GABA and sleep-promoting neurons located in the VLPO, causing excessive arousal of the body, which may consequently lead to sleep disturbance.[17] This has also been observed in EEG reports, where marked differences in the sleep waves were observed between smokers and non-smokers, with smokers having frequent arousals.[18] Nicotine can entrain circadian timing mechanisms which strongly regulate the timing of the sleep wake cycle,[50] and these might explain the increased risk of sleep disturbance and nicotine withdrawal effects such as sleeplessness and DD observed in our study.

Limitations of the study

The UK Biobank is representative of the UK general population, within the age range recruited, in terms of age, sex, ethnic and socioeconomic breakdown. However, participants are not necessarily representative in terms of lifestyle. Therefore, it would be inappropriate to generalise summary statistics, such as prevalence, to the general population. However, estimates of the magnitude of associations, such as between tobacco and sleep, should be generalisable. In common with most epidemiological studies of sleep, sleep characteristics were self-reported; objective measurement of parameters such as sleep duration would, however, not be feasible within such a large study. It is also important to mention that the questions used to evaluate sleep disturbance were not from a validated scale such as the General Sleep Disturbance Scale. Smoking characteristics were also self-reported; reports of smoking status and level of exposure could not be corroborated by objective measures such as cotinine assay. Whilst we adjusted for a wide range of potential confounders, residual confounding is always possible within any observational study. For instance, we used self-reported depression and stress as a proxy for mental health and it is possible that these do not completely measure overall mental health. Anxiety disorders are the most common mental disorders and are also associated with sleep disturbance and probably initiation of cigarette smoking, but we could not adjust for anxiety in our analysis. Additionally, since this was a cross-sectional study, it was not possible to determine the temporal relationship between smoking and sleep; therefore, reverse causation cannot be excluded. For example, sleep disturbance might lead to mental disorders such as anxiety and depression.[51] There is some evidence to suggest that poor stress control and anxiety disorders are among the factors that predict initiation of cigarette smoking.[52,53]

Conclusions

Tobacco exposure is known to directly increase the risk of many diseases including respiratory and cardiovascular diseases and many cancers.[54] Our study suggests that there is also an association between tobacco exposure and a number of sleep characteristics. If this association is causal, tobacco exposure may also be impacting on health partly via an effect on sleep. Smoking prevalence and exposure to passive smoking are declining in many developed countries. However, these improvements are more than offset by increases in highly populated, developing, and newly industrialised countries such as China. As a result, the global prevalence of active smoking and passive exposure to tobacco is expected to continue increasing over the next few decades.[55] Currently, ~6 million deaths are attributed to smoking every year, of which 0.6 million are associated with passive smoke exposure.[56] It may be beneficial to enforce the existing global tobacco control interventions to reduce the impact on a wide range of health parameters, including sleep disturbance.

Supplementary data

Supplementary data are available at the *Journal of Public Health online*.

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Conflict of interest

None declared.

Authors' contributions

DB, JPP and DFM designed the study, analysed the data and wrote the draft of the manuscript. CAW, CAM and SD contributed to the statistical analyses and review of the manuscript. SMB, MESB, JMRG and JW reviewed the final draft for submission.

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