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The association between aircraft noise and sleep disturbance: evidence from four major airports in the UK

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ABSTRACT

A recently published update to the WHO systematic review and meta-analysis by Smith et al. (2022) found a negative association between aircraft noise exposure at night and self-reported sleep disturbance. This study further investigates the association between aircraft noise exposure and sleep disturbance using a large-scale sample size of 105,773 participants of the UK Biobank cohort living near four major airports in England. Both self-reported (N=105,773) and actimetric measures (N=24,050 for average proportion of time spent on sleep within 7 days and N=22,102 for other actimetric measures) were used to assess sleep disturbance, with a focus on circadian rhythm as an outcome, which has rarely been studied previously. Analyses using longitudinal research design (only possible for self-reported outcomes) suggested that aircraft noise exposure is associated with increased daytime dozing (OR 1.25; 95% CI 1.09–1.42; N=85,624). Cross-sectional analyses (N=18,481) showed night-time aircraft noise can be related to movements during the least active continuous 8-hour (coefficient: 0.13, 95% CI 0.04–0.21), and

5-hour periods (coefficient: 0.07, 95% CI 0.02–0.11) (proxy for sleep window), and disrupted circadian rhythms as measured by relative amplitude (coefficient: -0.004, 95% CI (-0.01– -0.00), inter-daily stability (coefficient: -0.01, 95% CI -0.01– -0.00)), and intra-daily variability (coefficient 0.01, 95% CI (0.00 –0.02)). However, no significant association was found with self-reported sleeplessness or sleep duration as well as actimetrically measured average proportion of time spent on sleep. This study contributes to the literature by providing evidence from a very large cohort study on noise impacts on circadian rhythm, a potential mechanism linking night-time noise pollution to various health outcomes. These findings have important implications for policymakers on negative impacts of aircraft noise on sleep disturbance.

Keywords: night-time aircraft noise, sleep disturbance, circadian rhythm, actimetry, accelerometery

INTRODUCTION

Aircraft noise is a persistent problem that negatively impacts the well-being of an ever-growing population. A significant outcome of noise exposure, particularly during the night, is sleep disturbance. The mechanism through which noise disrupts sleep may be due to noise evoking physiological signals in the auditory system, as the sleeping body continues to react to environmental stimuli [1]. Sleep is a crucial physiological state that is essential for normal recuperation [2], and therefore, the relationship between aircraft noise exposure and sleep disturbance has been widely studied [3, 4]. However, recent literature reviews have identified significant gaps in the literature regarding large-scale studies that use objective measures to evaluate sleep disturbance [4, 5].

Polysomnography (PSG) is the gold standard in sleep research [6], but it is relatively intrusive as subjects typically need to sleep in a laboratory, which limits the scalability of a study. An alternative method that is less intrusive is actimetry, which has been extensively used and validated [7]. Actimetry involves using wrist-worn devices to monitor sleep-wake rhythms and has been found to be more reliable than sleep logs [8]. However, there is limited evidence on aircraft noise and sleep studies using actimetric measures.

To address these gaps, we conducted a large-scale study using data obtained from the UK Biobank, a population-based biomedical database. We focused on 105,773 participants living near four major airports in England and used both self-reported and actimetric measures to investigate the association between aircraft noise exposure and sleep disturbance. In particular, we used circadian rhythm as a sleep outcome, which has rarely been examined in previous studies.

MATERIALS AND METHODS

Study Population

We analysed data obtained on 105,773 participants who reside near the four airports (London Heathrow, London Gatwick, Birmingham, and Manchester) in England. These participants were a subset of UK Biobank, a large-scale, population-based biomedical database that has collected comprehensive health, lifestyle, and genetic information from 502,413 volunteer participants aged 40-69 years at recruitment. The UK Biobank has ethical approval to function as a research database from the North West Multi-centre Research Ethics Committee (MREC) approval and project approval for this specific research is covered by UK Biobank project #59129. UK Biobank has conducted baseline and multiple follow-up assessment visits.
For our study, we used both baseline assessments, instance 0 (2006-2010) and follow-up instance 1 (2012-2013) data.

Sleep disturbance definition
To assess sleep disturbance, we utilised both self-reported measures and actimetric measures.

Self-reported measures
We extracted three self-reported outcomes. The first outcome was related to sleeplessness/insomnia and was obtained through the question, "Do you have trouble falling asleep at night or do you wake up in the middle of the night?" Response options included never/rarely, sometimes, usually, and prefer not to say. Another outcome was daytime dozing/sleeping, which we obtained from the question "How likely are you to doze off or fall asleep during the daytime when you don't mean to? (e.g. when working, reading or driving)?" Participants were provided with response options including never/rarely, sometimes, often, all of the time, do not know, and prefer not to say. Lastly, we extracted sleep duration as the final self-reported outcome, which was obtained from the question "About how many hours sleep do you get in every 24 hours? (please include naps)". We categorised sleep duration into less than 6 hours, between 6 and 8 hours, and more than 8 hours. Each of the self-reported outcomes had a baseline measurement (instance 0) and a corresponding repeated measurement (instance 1)

Actimetric measures
Between 01/06/2013 and 23/12/2015, 236,519 participants from the UK Biobank were invited to measure their physical activity using the Axivity AX3 wrist-worn triaxial accelerometer [9]. Of those invited, 106,053 participants agreed to wear the physical activity monitor, and valid physical activity data from 96,600 participants (93.3%) were obtained [9], of whom 24,050 (sleep duration) and 22,102 (other actimetric measures) participants were living near the 4 major airports in this study.

We obtained actimetrically measured sleep outcomes from two sources. The first was the overall average proportion of time spent sleeping during the monitoring period, which was computed using a specific methodology described in a previous paper [10]. The second source of sleep outcomes was from derived accelerometery data [11], and it included three outcomes that could measure a participant's circadian rhythms: relative amplitude (RA), intra-daily variability (IV), and inter-daily stability (IS). RA measures the contrast in activity levels between the most active 10 hours and the least active 5 hours within a 24-hour period. A higher RA value indicates greater activity during the day and reduced activity during sleep. IV measures the fragmentation of the 24-hour rest-activity rhythm, and a high IV suggests a more fragmented rhythm indicative of circadian dysfunction. IS measures the stability of the rest-activity rhythm, and a higher IS score indicates a strong alignment with light and other environmental cues that regulate the biological clock [11]. In addition, we used the average acceleration during the least active continuous 8-hour, 6-hour, and 5-hour periods within a 24-hour period. These were used to measure participants' movement or arousals during the least active periods, with a low level of movement suggesting a more peaceful rest during those periods. We also used the start time of the least active 8-hour, 6-hour, and 5-hour periods within a 24-hour period. Each of these outcome measurements were only available at baseline measurement (instance 0).

Aircraft noise
Aircraft noise exposure was obtained from the UK Civil Aviation Authority (CAA). We used the night-time noise levels (Lnight) for 105,773 participant's residential address that fall inside 44 local authority districts (2020 version) near four major airports (London Heathrow, London Gatwick, Birmingham and Manchester) in England.

Lnight is the A-weighted equivalent noise level (Leq) over the 8-hour night period of 23:00 to

07:00 hours, also known as the night noise indicator.

Participants were categorized into three categories based on a 5 dB increase: <45 dB, >=45 dB and <50 dB, and >=50 dB.

The noise data were available for 2006 and 2011. We matched 2006 data with UK Biobank instance 0 (2006-2010) and 2011 with instance 1 (2012-2013).

Covariates

The covariates used in this study were selected based on a directed acyclic graph, as depicted in Figure 1. Covariates include sex, ethnicity, age at 2006 and 2011, mental health diagnosis by a professional or psychiatrist, hearing difficulty, smoking status, alcohol consumption, BMI, average yearly household income before tax, Townsend deprivation index at recruitment, night-time road traffic noise, night-time rail traffic noise, total NO2 emission and greenspace percentage within a buffer of 1000m, and PM2.5 emission.

Given that chronotype and night shift had a significantly lower number of respondents, we decided not to adjust for these variables.

Statistical Analysis

Descriptive statistics were used to provide a summary of the sleep outcomes, environmental variables, and covariates.

A longitudinal research design was employed to investigate the association between night-time aircraft noise and self-reported sleep outcomes, as both the self-reported sleep outcomes and aircraft noise levels had baseline (instance 0) and follow-up measures (instance 1). Some covariates, including sex, ethnicity, household income, and environmental variables (road noise levels, rail noise levels, NO2, greenspace proportion and PM2.5) were only available at the baseline, and these baseline measures were repeated for instance 1.

Random effects ordered logit regression models were used to examine the associations between noise exposure levels and self-reported sleep measures, adjusting for covariates. The results were presented as odds ratios (ORs) and 95% confidence intervals (CIs).

For actimetric measures, which only had baseline data, a cross-sectional research design based on instance 0 was used. Multivariate linear regression models were employed to examine the associations between noise exposure levels and actimetric sleep measures, adjusting for potential confounders. To account for group effects, we clustered variance at the local authority district level. The results were presented as beta coefficients and 95% confidence intervals (CIs).

We employed a complete case approach to analyse the data. Any observations that have missing values in any of the variables included in the regression analysis were excluded.

All statistical analyses were conducted using Stata software version 17, and the significance level was set at $p<0.05$.

RESULTS

Descriptive summary

The descriptive summary is presented in Table 1

Main results

We used a longitudinal design to analyse the association between aircraft noise and self-reported outcomes (Figure 3). We found non-significant associations between night-time aircraft noise and self-reported sleeplessness and sleep duration. However, individuals exposed to aircraft noise levels above 55 dB Lnight experienced a 1.25 odds ratio (95% CI 1.09-1.42; N=85,624) for reporting daytime dozing.

Cross-sectional research design was used to analyse the association between night-time aircraft noise and all actimetric outcomes. In Figure 4, based on 18,481 participants with complete dataset, we found that individuals exposed to night-time aircraft noise above 50 dB experienced a significantly higher average acceleration during the least active continuous 8-hour of 0.13 mg (95% CI 0.04–0.21), and 0.07mg (95% CI 0.02–0.11). However, no significant differences were observed in the least active continuous 6-hour average accelerations. Individuals exposed to higher levels of aircraft noise at night demonstrated non-significant differences in the start times for the least active continuous 8 hours, 6 hours, and 5 hours.

Figure 5 shows no significant association between night-time aircraft noise and proportion of time spent on sleep within 7 days. When looking at circadian rhythm outcomes (N=18,481), we found significant associations between night-time aircraft noise and relative amplitude (coefficient: -0.004, 95% CI (-0.01– -0.00))), inter-daily stability (coefficient: -0.01, 95% CI -0.01– -0.00))), and intra-daily variability (coefficient 0.01, 95% CI (0.00–0.02)).

DISCUSSION

Our study, which included a large sample size, found no significant association between night-time aircraft noise and self-reported sleeplessness or (self-reported or actimeter measured) sleep duration. This is consistent with some previous studies [12, 13] but not others [4]. Methodological differences, such as sample size, different questions and recall bias, may account for discrepancies in effect sizes. It is important to note that the self-reported sleep duration was assessed over a 24-hour period, while the actimetrically measured average proportion of time spent sleeping was calculated based on data averaged over a 7-day period.

Interestingly, our findings suggest that night-time aircraft noise exposure may be associated with daytime dozing, which could be a result of poor night-time sleep [14].

We did find some evidence for disturbances of sleep quality from the actimetry data. Our study found that exposure to night-time aircraft noise may be linked to increased average accelerations during the least active continuous 8-, and 5-hour periods, indicating potential movements or arousals during the least active periods (proxy for a sleep window) [15, 16]. However, we did not find significant associations during the least active continuous 6-hour period, the average timing of which corresponds to periods of lowest flight activity, which may be a factor, and/or it may relate to different thresholds for awakening at various stages of sleep. We also found evidence suggesting that night-time aircraft noise may be related to disrupted circadian rhythms, with individuals exposed to noise levels above 50 dB exhibiting lower relative amplitude and inter-daily stability as well as higher intra-daily variability. These outcomes imply that participants experienced increased restlessness during the night, an inconsistent rest-activity pattern [15] and fragmented rhythm [17].

Our findings suggest possible mechanisms linking nocturnal noise pollution to diverse health outcomes through disrupted circadian rhythm, which may be relevant to cardiovascular disease [18, 19], metabolic disorders [20], breast cancer [21-23], and neurodegenerative diseases [24-27].

However, our study has limitations, such as the potential for misclassification of noise levels and biases in self-reported and actimetric sleep outcomes [7]. We adopted a complete case approach to analyse the data, which could introduce bias [28].

CONCLUSION

Our study investigated the relationship between night-time aircraft noise and sleep disturbance using self-reported measures and actimetrically assessed outcomes. We found that aircraft noise is associated with increased movement during the least active continuous 8-, and 5-hour periods (suggestive of increased arousals during sleep), increased daytime dozing, and disrupted circadian rhythms. Our large sample size of 105,770 participants and the inclusion of both subjective and objective measures contribute to the existing literature. Additionally, our study highlights the importance of considering the role of circadian rhythm in the mechanisms linking night-time noise pollution to various health outcomes.

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Tables and Figures

	Instance 0 (2006-2010)		Instance 1 (2012-2013)	
	N.	Mean±SD [range] (for continuous variables) or % (for categorical variables)	N.	Mean±SD [range] (for continuous variables) or % (for categorical variables)
Demographic information				
Sex				
Female	57,381	54.25		
Male	48,387	45.75		
Total	105,768	100		
Ethnicity				
White	91,251	87.12		
Mixed	1,120	1.07		
Asian or Asian British	5,194	4.96		
Black or Black British	4,386	4.19		
Chinese	612	0.58		
Other	2,176	2.08		
Total	104,739	100		
Age at 2006 (instance 0) and 2011 (instance 1)	105,768	53.700±8.279 [35 to 72]	105,768	58.700±8.279 [40 to 77]
Sleep variables				
Actimetric measures				
Proportion of time spent on sleep (7-day average)	24,050	0.382±0.122 [0 to 1]		
Relative amplitude	22,102	0.875±0.047 [0.280 to 0.973]		
Intra-daily variability (IV)	22,102	0.655±0.177 [0.219 to 2.039]		
Inter-daily stability (IS)	22,102	0.662±0.111 [0.039 to 0.982]		
Average acceleration over least active continuous 8-hour (L8)	22,102	4.460±1.842 [1.608 to 39.222]		
Average acceleration over least active continuous 6-hour (L6)	22,102	3.017±1.011 [1.072 to 35.224]		
Average acceleration over least active continuous 5-hour (L5)	22,102	2.911±0.930 [0.901 to 33.801]		
Time of start of least active continuous 8-hour	22,102	23.116 (23:06:58)±1.002 (01:00:07) [13.250 (13:15:00) to 34.694 (+1 day 10:41:38)]		
Time of start of least active continuous 6-hour	22,102	24.202 (24:12:07)±1.042 (01:02:31) [13.944 (13:56:38) to [34.028 (+1 day 10:01:41)]		
Time of start of least active continuous 5-hour	22,102	25.223 (+1day 01:13:23)±1.160 (01:09:36) [14.333 (14:19:59) to 34.500 (+1 day 10:30:00)]		
Self-reported measures				
Sleep duration				
<6 hours	27,041	25.86	1,343	21.92
6-8 hours	70,343	67.28	4,246	69.31
>8 hours	7,166	6.85	537	8.77
Total	104,550	100	6,126	100
Sleeplessness/insomnia				
Never/rarely	27,308	25.98	1,403	22.85
Sometimes	50,034	47.6	2,924	47.62

Usually	27,772	26.42	1,813	29.53
Total	105,114	100		6,140
Daytime dozing/sleeping				
Never/rarely	77,783	74.51	4,594	74.96
Sometimes	23,396	22.41	1,390	22.68
Often	3,189	3.05	145	2.37
All of the time	24	0.02		
Total	104,392	100	4,594	74.96
Environmental variables				
Night-time aircraft noise 2006 (instance 0) and 2011 (instance 1)				
<=45	92,367	87.33	93,491	88.39
>45, <50	7,850	7.42	7,394	6.99
>50	5,553	5.25	4,885	4.62
Total	105,770	100	105,770	100
Night-time road traffic noise				
<=45	47,617	45.02		
>45, <50	35,899	33.94		
>50	22,254	21.04		
Total	105,770	100		
Night-time rail traffic noise				
<=45	102,627	97.05		
>45, <50	1,672	1.58		
>50	1,448	1.37		
Total	105,747	100		
Total No2 emission	105,770	37.392±10.116 [4.5 to 79.16]		
Greenspace percentage, buffer 1000m	104,795	34.016±17.503 [4.415 to 98.084]		
PM2.5	104,318	10.19±1.05 [8.17 to 20.71]		
Covariates				
Mental health				
No	69,598	67.04	4,057	66.52
Yes	34,223	32.96	2,042	33.48
Total	103,821	100	6,099	100
Hearing difficulty				
No	73,468	75.75	3,899	67.05
Yes	23,470	24.2	1,912	32.88
Completely deaf	54	0.06	4	0.07
Total	96,992	100	5,815	100
Smoke				
Never	56,981	54.36	3,616	59
Previous	35,914	34.27	2,189	35.72
Current	11,917	11.37	324	5.29
Total	104,812	100	6,129	100
Alcohol consumption				
Daily or almost daily	23,671	22.52	1,185	19.29
3 or 4 times a week	22,887	21.77	1,594	25.95
once or twice a week	23,862	22.7	1,566	25.5
1-3 times a month	11,164	10.62	676	11.01
Special occasions only	13,104	12.47	682	11.1
Never	10,437	9.93	439	7.15
Total	105,125	100	6,142	100
Average household income before tax				
<18,000	17,083	19.81	1,076	19.35
18,000-30,999	19,213	22.28	1,638	29.46
31,000-51,999	21,678	25.14	1,497	26.92
52,000-100,000	20,328	23.57	1,042	18.74
>100,000	7,941	9.21	307	5.52
Total	86,243	100	5,560	100
Townsend deprivation index at recruitment	105,648	-0.413±3.406 [-6.258 to 10.157]		
BMI	104,731	27.189±4.844 [12.646 to 68.130]	6,127	26.943±4.724 [14.901 to 58.884]

Table 1 Descriptive summary of data

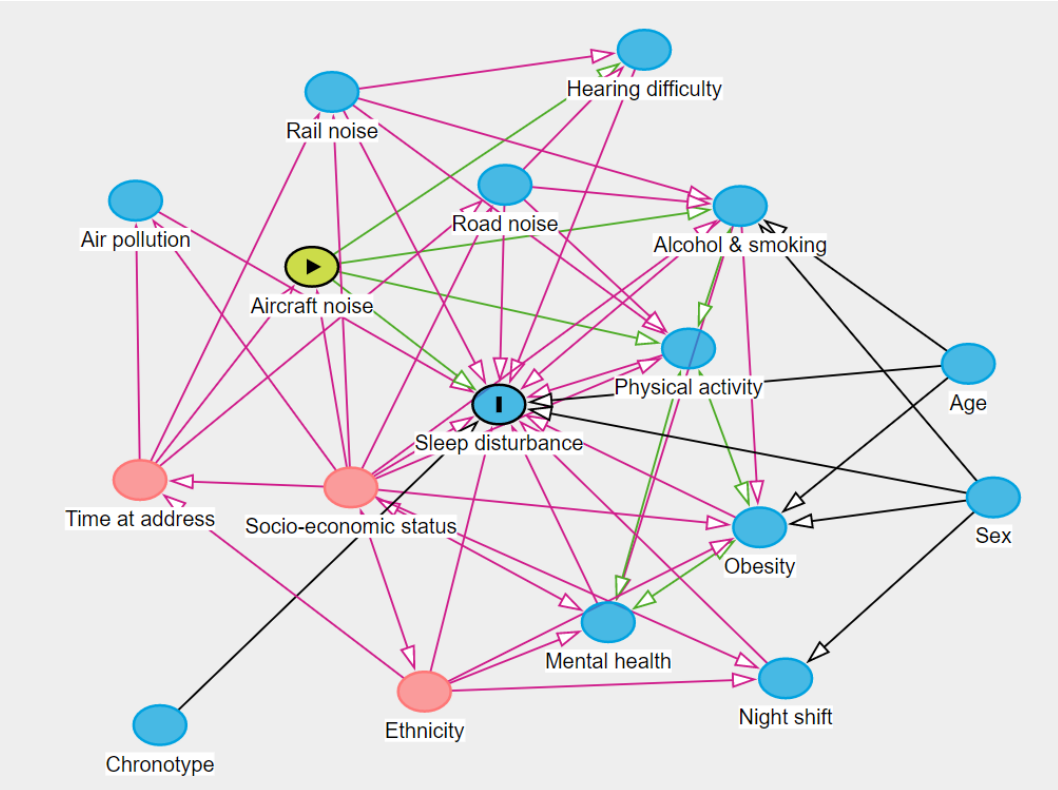

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Figure 1 Directed Acyclic Graph (DAG) identifying potential confounders for the relationship between night-time aircraft noise exposure and sleep disturbance.

Note: The DAG depicted a graphical model where each factor was represented as a node and the arrows between them suggested possible associations. In the graph, red circles were used to indicate ancestor of exposure and outcome while blue circles denote ancestor of outcome.

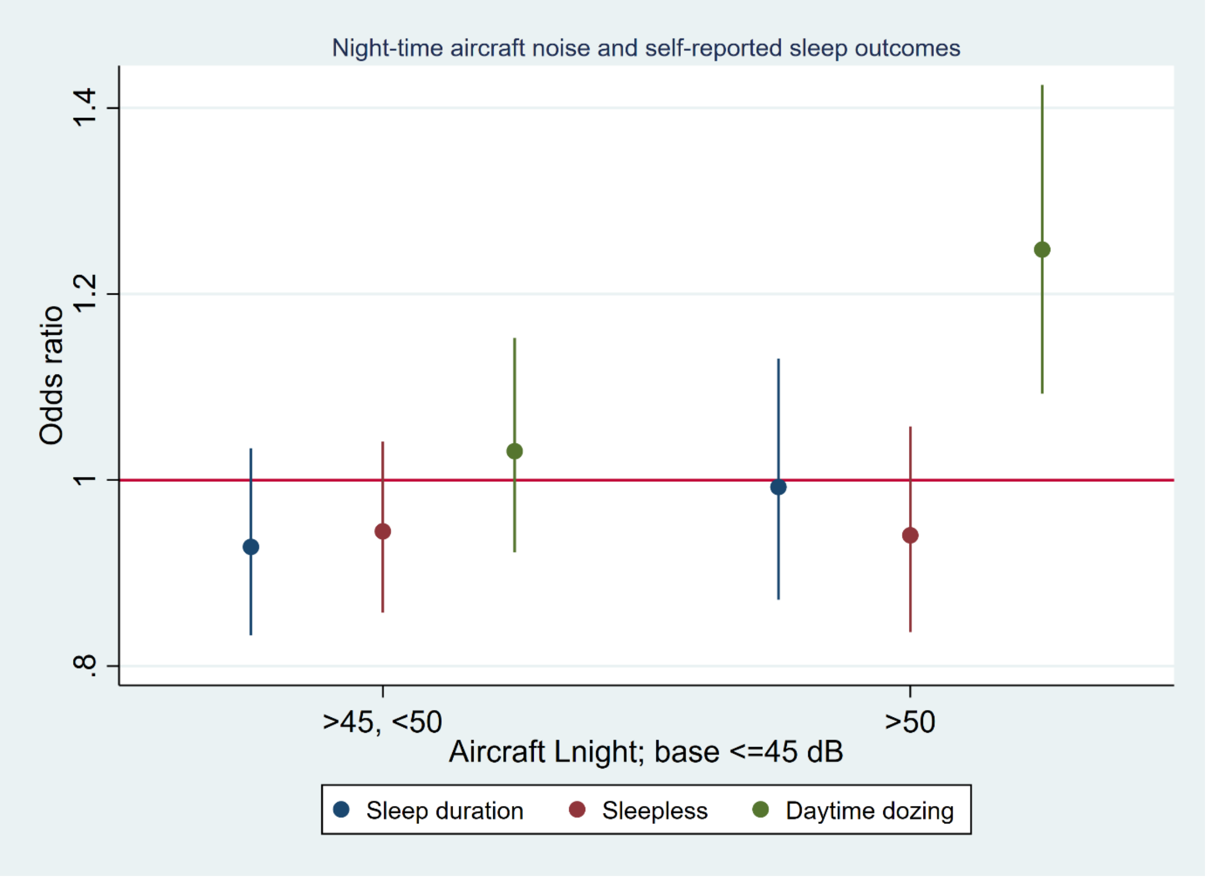

Figure 2 Association between night-time aircraft noise and self-reported sleep outcomes
Note: Random effects ordered logit regression models were used to examine the associations between noise exposure levels and self-reported sleep measures, adjusting for all covariates. The results were presented as odds ratios (ORs) and 95% confidence intervals (CIs).

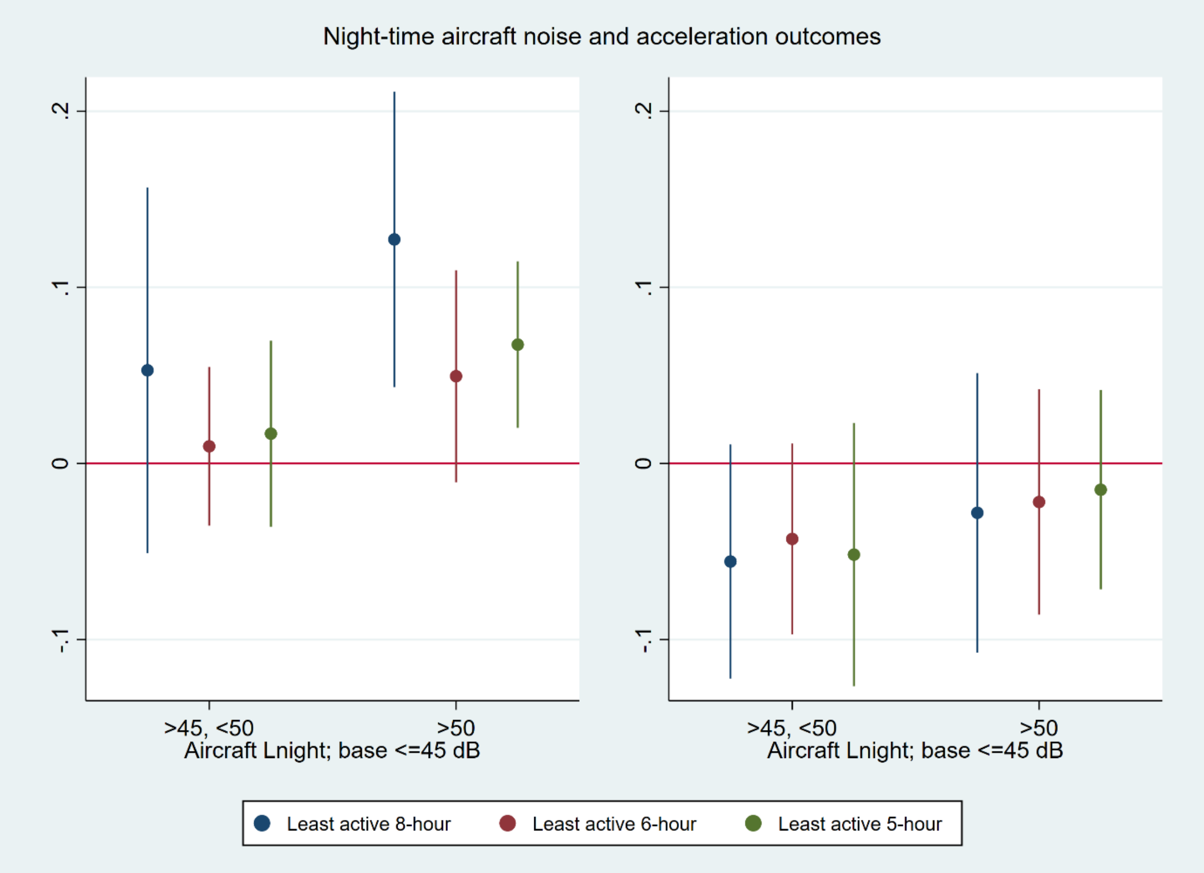

Figure 3 Association between night-time aircraft noise and average accelerations during (left) and start time of (right) the least active periods.

Note: Linear regression models were used to examine the associations between noise exposure levels and average accelerations during (left) and start time of (right) the least active periods, adjusting for all covariates. Variance was clustered at local authority district level. The results were presented as coefficient and 95% confidence intervals (CIs).

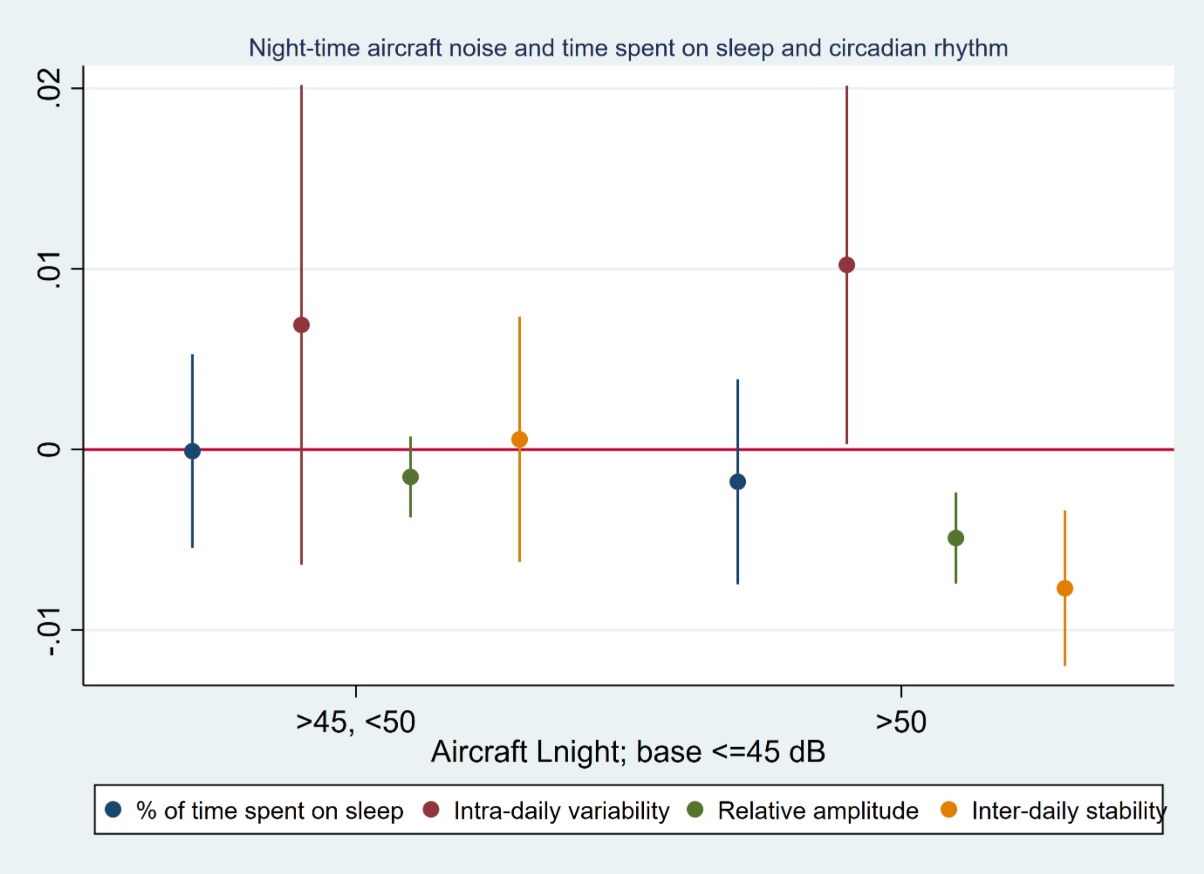

Figure 4 Association between night-time aircraft noise and proportion of time spent on sleep and circadian rhythm.
Note: Linear regression models were used to examine the associations between noise exposure levels and proportion of time spent on sleep within 7 days, and circadian rhythm, adjusting for all covariates. Variance was clustered at local authority district level. The results were presented as coefficient and 95% confidence intervals (CIs).

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