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Long-term nighttime aircraft noise exposure and risk of hypertension in a prospective cohort of female nurses

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ABSTRACT

There is growing interest in cardiometabolic outcomes associated with nighttime noise, given that noise can disturb sleep and sleep disturbance can increase cardiometabolic risk such as hypertension. However, there is little empirical research evaluating the association between nighttime aircraft noise and hypertension risk. In this study, we expand on previous work to evaluate associations between nighttime aircraft noise exposure and self-reported hypertension incidence in the Nurses' Health Studies (NHS/NHSII), two US-wide cohorts of female nurses. Annual nighttime average aircraft sound levels (L_{night}) surrounding 90 airports for 1995–2015 (in 5-year intervals) were modeled using the Aviation Environmental Design Tool and assigned to participants' geocoded addresses over time. Hypertension risk was estimated for each cohort using time-varying Cox proportional-hazards models for L_{night} dichotomized at 45 dB (dB), adjusting for individual-level hypertension risk factors, area-level socioeconomic status, region, and air pollution. Random effects meta-analysis was used to combine cohort results. Among 63,229 NHS and 98,880 NHSII participants free of hypertension at study baseline (1994/1995), we observed 33,190 and 28,255 new hypertension cases by 2014/2013, respectively. Although ~1% of participants were exposed to L_{night} ≥45 dB, we observed an adjusted hazard ratio (HR) of 1.10 (95% CI: 0.96, 1.27) in NHS and adjusted HR of 1.12 (95% CI: 0.98, 1.28) in NHSII, comparing exposure to L_{night} ≥45 versus <45 dB(A). In meta-analysis, we observed an adjusted HR of 1.11 (95% CI: 1.01, 1.23). These results were attenuated with adjustment for additional variables such as body mass index. Our findings support a modest positive association between nighttime aircraft noise and hypertension risk across NHS/NHSII, which may reinforce the concept that sleep disturbance contributes to noise-related disease burden.

1. Introduction

Aircraft noise is an unintended consequence of aviation activities and a concern for communities surrounding airports (Guski et al., 2017; Jarup et al., 2008). Among transportation noise sources such as road and rail noise, aircraft noise has been reported to be the most annoying (Brink et al., 2019). According to the World Health Organization (WHO) Regional Office for Europe, noise is "among the top environmental risks to health" (World Health Organization, Regional Office for Europe, 2018). Noise is thought to adversely affect health by activating the

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autonomic and endocrine systems, directly through sleep disturbance and indirectly through cognitive and emotional responses to noise disturbances. Release of stress hormones in response to long-term noise exposure can disturb endothelial function and increase oxidative stress and inflammation, impacting disease risk factors such as blood pressure (Baudin et al., 2021; Charakida and Deanfield, 2013; Kroller-Schon et al., 2018; Munzel et al., 2018; Osborne et al., 2023; Schmidt et al., 2015).

In the most recent reports reviewing trends through 2021, hypertension remained one of the top five risk factors for global burden of disease and is the leading contributor to cardiovascular disease and a major contributor to kidney disease (Collaborators, 2018, 2022, 2024; Fisher and Curfman, 2018; Vaduganathan et al., 2022). Although several studies have found an association between aircraft noise and hypertension (Baudin et al., 2020a; Eriksson et al., 2010; Huang et al., 2015; Pyko et al., 2018), other studies have found little to no association (Carugno et al., 2018; Kim et al., 2022; Zeeb et al., 2017). This lack of consistent results may be due to variations in study designs, noise measurements, and case definitions (Chang et al., 2013; Huang et al., 2015; Kempen et al., 2018). Most studies have used 24-h average sound metrics, which may not capture sleep disturbance accurately, and are case-control or cross-sectional designs (Dimakopoulou et al., 2017; Eriksson et al., 2010; Evrard et al., 2017; Jarup et al., 2008).

The evaluation of the effect of aircraft noise using 24-h average sound metrics, such as day-night or day-evening-night sound levels (DNL and Lden, respectively), is sometimes driven by data availability, ease of measurement, and use in environmental and regulatory assessments (Babisch and Kim, 2011; Correia et al., 2013; Heritier et al., 2017; Jarup et al., 2008; Peters et al., 2018), or informed by the size of the exposed study population (World Health Organization, Regional Office for Europe, 2018). For aircraft noise, the difference between 24-h average sound metrics and nighttime noise may be greater compared to other noise sources such as road traffic (Brink et al., 2018; Heritier et al., 2018; Roosli et al., 2019). And, there is a particular interest in evaluating the association of nighttime noise with hypertension due to its more direct relationship with sleep disturbance (Bozigar et al., 2023; Charakida and Deanfield, 2013; Schmidt et al., 2015; World Health Organization, 2009), which has been associated with cardiometabolic outcomes (Grandner et al., 2012; Kwok et al., 2018; Meng et al., 2013; St-Onge et al., 2016).

There have been a few studies investigating nighttime aircraft noise and its association with hypertension, using different outcome measures – increased prevalence of prescriptions for antihypertensive and cardiovascular drugs (Greiser et al., 2007), cross-sectional short-term elevations in blood pressure (Haralabidis et al., 2008), and incident hypertension (Dimakopoulou et al., 2017). In a study in Greece, Dimakopoulou et al. found a positive relationship with nighttime aircraft noise exposure but not daytime noise exposure (Dimakopoulou et al., 2017). In a cohort of postmenopausal women in the U.S., the Women's Health Initiative (WHI), we did not find an association between noise and incident hypertension, but the effect estimates, though less precise, were higher for nighttime noise compared with DNL (Nguyen et al., 2023).

Given the potential importance of nighttime noise for health outcomes, limited literature including nighttime noise exposure, and possible differences in diurnal patterns of aircraft noise, we build on our previously published work in two prospective cohorts of female nurses, where we investigated the association between aircraft noise characterized as DNL and incident hypertension and found a slight positive association (Kim et al., 2022). Here, we work within the same study population to explore the association between nighttime aircraft noise exposure and incident hypertension. We followed a similar design and analytical strategy as done in our previous paper on DNL and incident hypertension to facilitate comparison, and we were also able to update key spatial variables such as air pollution (for example, adding nitrogen dioxide) and neighborhood socioeconomic variables.

2. Methods

2.1. Study population

Our study population was participants of the Nurses' Health Study (NHS) and the Nurses' Health Study II (NHSII). The NHS began in 1976 and the NHSII in 1989 with the recruitment of female U.S. registered nurses. Participants were followed up biennially with a response rate of 86% overall and 90–94% among those participating over a year (Bao et al., 2016). The follow-up questionnaires updated information on variables such as demographic characteristics, health-related behaviors, incidence of major diseases, medical history, and residential addresses. Participants were included in the current analyses if they were alive and free of hypertension in 1994/1995 - the year the first aircraft noise estimate was available - and had a noise estimate. This study was approved by the Brigham and Women's Institutional Review Board with participant consent assumed with the return of the questionnaire.

2.2. Noise exposure

The methods for estimating aircraft noise exposure have been described in detail elsewhere (Kim et al., 2022; Simon et al., 2022). Briefly, noise was modeled using the U.S. Federal Aviation Administration's (FAA's) Aviation Environmental Design Tool (AEDT) for 90 U. S. airports for 1995, 2000, 2005, and 2010. Nighttime noise was the average A-weighted equivalent continuous sound pressure level from aircraft noise measured in decibels (dB) for the hours of 22:00 to 07:00. The DNL noise metric was also included to allow for direct comparison with nighttime noise within otherwise identical statistical models both including updated air pollution and socioeconomic variables. DNL is cumulative A-weighted equivalent sound level for an average 24-h period with a 10-dB penalty added to nighttime sound levels. Noise levels were modeled down to 45 dB at 1 dB resolution. Contours of modeled nighttime and DNL noise levels were overlaid with participant residential addresses to estimate respective noise exposure. Participants' residential addresses were ascertained at the biennial assessment and noise levels were correspondingly updated if participants moved. Noise exposure estimates were carried forward until the year of the next exposure estimate (updated every five years).

2.3. Outcome

Incident hypertension was assessed using self-report on the biennial questionnaire, where the nurses were asked to report if they had received a hypertension diagnosis since the previous questionnaire. Incident hypertension was defined as reporting new "physician diagnosis of high blood pressure." In validation studies, for those self-reporting hypertension, the sensitivity for comparison with medical records for systolic or diastolic blood pressure readings of >140 or >90 mmHg was 100% and 94% in the NHS and NHSII, respectively, and for those reporting no hypertension, specificity of 93% and 85%, respectively (Colditz et al., 1986; Forman et al., 2007).

2.4. Covariates

We considered similar covariates as reported in Kim et al. which had been selected *a priori* based on previous associations with hypertension or noise exposure (Kim et al., 2022). Covariates were modeled as time-varying except for race (as a social construct of shared experiences of discrimination and segregation that may increase risk (Aggarwal et al., 2021; Hill and Thayer, 2019; Kaufman and Cooper, 2008; Simon et al., 2022), family history of hypertension, and individual-level socioeconomic status (SES). Information on individual-level covariates was obtained from each biennial questionnaire except for dietary information and physical activity, which were assessed every other questionnaire cycle. The full list of covariates were age and calendar year, spouse's educational attainment (<high school, high school, > high school), smoking status (current, former/never), alcohol consumption (quintiles of grams per day), physical activity (quintiles of metabolic equivalent hours (MET) per week), body mass index (BMI; kilograms per meter squared), menopausal status, medication use (statin and nonnarcotic analgesic), and diet (quintiles of the Dietary Approaches to Stop Hypertension (DASH) score) (Harrington et al., 2013). Area-level variables included region of residence (Northeast, South, Midwest, and West), quintiles of neighborhood-level SES (nSES), and quintiles of air pollution exposure. nSES was updated from Kim et al. (2022), with an index (z-score) standardizing and summing nine variables related to income, wealth, educational attainment, employment, and racial composition at the U.S. Census tract level (DeVille et al., 2023; Iyer et al., 2022). Air pollution predicted from spatiotemporal models included fine particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2) (Kirwa et al., 2021; Yanosky et al., 2014; Young et al., 2016).

2.5. Statistics

The eligible participants were followed from 1994 for NHS and 1995 for NHSII to the time of hypertension diagnosis, loss-to follow up, death, or the end of the study period (2014 for NHS and 2013 for NHSII). We used time-varying Cox proportional hazards models to calculate hazard ratios (HR) and 95% confidence intervals (CIs) for the relationship between nighttime aircraft noise exposure and hypertension incidence. Analysis was performed with noise dichotomized at 45 dB to compare hypertension risk comparing those exposed to <45 dB of nighttime noise to those exposed to ≥45 dB. The cut-point corresponds to the lowest value we have modeled although this level is above the WHO guidelines recommendation for nighttime aircraft noise of 40 dB (World Health Organization, Regional Office for Europe, 2018).

Models were performed on a monthly time scale, stratified by age and calendar period. Similar to our previous study assessing DNL exposure and hypertension incidence (Kim et al., 2022), we built three models: basic (adjusting for age and calendar period), parsimonious (basic model adding race, spouse's educational attainment, physical activity, smoking status, alcohol consumption, diet, region of residence, nSES, and air pollution) and extended model (parsimonious model adding related variables that could be potential mediators or colliders including BMI, menopausal status, family history of hypertension, and medications). We first conducted the analyses of the three models separately by cohort (NHS and NHSII) then combined across cohorts using meta-analysis to calculate overall effects using DerSimonian and Laird estimators for random effects and inverse-variance weighting (DerSimonian and Laird, 1986). We calculated p-values for the Q-statistic to examine heterogeneity between NHS and NHSII, as this conservative approach takes into account possible interactions between age and period effects (the cohort effect) that could relate to differences in factors such as population and disease distribution and screening and diagnostic criteria between the cohorts (Jacob and Ganguli, 2016). We reran the previous models with DNL analogous to the nighttime noise analysis for comparative purpose.

We performed sensitivity analyses with shift work and hearing loss. Shift work can introduce misclassification relative to whether nighttime noise exposure is associated with sleep disturbance or potentially heightened sensitivity to nighttime noise related to shift work sleep disorder (Wickwire et al., 2017). Sensitivity analysis with shift work was performed in NHS II only, because during the study period, questions about shift work were only asked of this younger cohort, which was less likely to be retired. Of note, the cohort was asked about rotating night shift work, meaning night shift work only on some nights. We ran the parsimonious and extended models additionally adjusting for shift work and also evaluated effect measure modification by including a multiplicative term of noise exposure category by shift work status. In addition, in both cohorts, we performed sensitivity analyses adjusting for hearing loss and assessing effect measure modification by hearing loss status in parsimonious and extended models. We also performed a sensitivity analysis with parsimonious and extended models only adjusting for NO_2 as the air pollution variable (not including $PM_{2.5}$) to assess overadjustment, choosing the measure most related to road traffic and local air pollution. Lastly, we restricted the sample to individuals living in areas surrounding one of the 90 airports in order to increase homogeneity of other factors related to residing near airports. To define the geographic area, we used a 22.2-mile (35.7 km) radius buffer around each airport, which represents the greatest extent of the noise contours for the 90 airports under study (Bozigar et al., 2023; Grady et al., 2023).

3. Results

In the NHS, 63,229 participants contributed 711,399 person-years and 33,190 new cases of hypertension, and in the NHSII, 98,880 participants contributed 1,267,709 person-years and 28,255 new hypertension cases. The age-adjusted baseline characteristics for the participants overall and for those exposed to L_{night} <45 and ≥ 45 dB for NHS and NHSII are presented in Table 1. The NHS participants, recruited earlier, were about 20 years older than the NHSII participants at baseline, more likely to be postmenopausal, smoke, use statins and aspirin, and less likely to use ibuprofen. Participants exposed to L_{night} ≥45 dB were more likely than those <45 dB to be a race other than White, live in U.S. Census tracts with lower neighborhood-level socioeconomic status, and have higher NO_2 exposure.

Approximately 0.67% of NHS participants and 0.91% of NHSII participants were exposed to L_{night} ≥45 dB. Supplemental Table 1 provides the number of cases and person-years by L_{night} categories (<45, 45–54, 55–64, ≥65 dB). The Spearman correlation (r) between L_{night} and DNL was 0.79 in NHS and 0.74 in NHSII.

Table 2 shows the results of time-varying Cox proportional hazard models examining associations between exposures to L_{night} at the 45-dB cut-point models and risk of hypertension. We observed similar estimates across the three models – basic, parsimonious, and extended (full). In the parsimonious models, adjusted for age, calendar year, race, physical activity, smoking status, alcohol use, DASH, spouse's education attainment, nSES, region of residence, and air pollution ($PM_{2.5}$ and NO_2), the hazard ratios (HRs) for hypertension were 1.10 (95% CI: 0.96, 1.27) and 1.12 (95% CI: 0.98, 1.28) for NHS and NHSII, respectively. For the extended model additionally adjusting for BMI, menopausal status, medications, and family history of hypertension, the HRs were 1.07 (95% CI: 0.93, 1.24) and 1.08 (95% CI: 0.94, 1.24) for NHS and NHSII, respectively. In the meta-analysis of the two cohorts, we observed HRs in the parsimonious model of 1.11 (95% CI: 1.01, 1.23) and in the extended model 1.08 (95% CI: 0.97, 1.19). In all models, no heterogeneity was observed between cohorts.

Fig. 1 shows the results for DNL and L_{night}. We observed comparable results from our previous assessments (Kim et al., 2022) of the association between DNL (average 24-h exposure) and risk of hypertension even with more comprehensive adjustment for air pollution and nSES in the parsimonious and extended models. Supplemental Table 2 provides the effect estimates for DNL. We found a nominally stronger risk of hypertension associated with L_{night} compared to DNL.

Including shift work and hearing loss status did not affect estimates of associations (Supplemental Table 3). There was also no clear evidence of effect measure modification by either shift work or hearing loss (Supplemental Table 4). Including NO_2 as the only air pollution measure did not affect estimates of association (Supplemental Table 5). Lastly, restricting the sample to individuals living within 22.2-mi of one of the 90 airports did not yield different results (Supplemental Table 6).

4. Discussion

We found that higher nighttime aircraft noise was associated with higher risk of hypertension in nationwide prospective studies of female nurses after adjusting for age, calendar year, race, physical activity,

Table 1
Age-standardized characteristics of Nurses' Health Study (1994) and Nurses' Health Study II (1995)participants at baseline who live near 90 major airports, overall and by dichotomized nighttime aircraft noise exposure.

	NHS			NHS II		
	Overall[a]	L_{night} <45 dB[a]	L_{night} ≥45 dB[a]	Overall[a]	L_{night} <45 dB[a]	L_{night} ≥45 dB[a]
N	63,229	62,806	423	98,880	97,978	902
Age, yrs[b]	59.1 ± 7.1	59.1 ± 7.1	59.6 ± 6.9	40.3 ± 4.8	40.3 ± 4.8	40.3 ± 4.8
White, %	94.6	94.6	89.5	93.3	93.4	82.7
Post-Menopausal, %	87.8	87.8	89.3	7.2	7.2	6.0
Spouse's Highest Level of Education Attainment, %						
Less than High School	3.6	3.7	3.0	0.6	0.6	0.2
High School	26.6	26.5	28.0	14.0	14.0	12.4
More than High School	39.9	40.0	34.1	67.1	67.1	66.2
Not Married or Missing	29.9	29.8	34.8	18.4	18.3	21.2
Family History of Hypertension, %	36.1	36.1	37.3	49.3	49.3	50.0
Current Smoker, %	15.2	15.2	15.5	11.3	11.3	13.1
Alcohol Consumption, gm/day	5.1 ± 8.8	5.1 ± 8.8	4.3 ± 7.0	3.5 ± 6.6	3.5 ± 6.6	3.8 ± 6.7
DASH Score	23.9 ± 4.6	23.9 ± 4.6	23.8 ± 4.7	23.7 ± 4.9	23.7 ± 4.9	23.5 ± 4.8
Physical Activity, MET-hr/wk	20.9 ± 26.0	20.9 ± 26.0	18.8 ± 22.0	18.7 ± 23.0	18.7 ± 23.0	19.6 ± 26.3
BMI, kg/m^2						
<18	1.0	1.0	0.5	1.0	1.0	0.6
18-24	51.9	51.9	49.1	58.0	58.0	57.1
25-29	32.4	32.4	33.8	24.7	24.7	24.5
≥30	14.7	14.7	16.6	16.3	16.2	17.8
Statin Use, %	4.5	4.5	4.2	2.3	2.3	2.3
Aspirin Use, %						
<1 day/month	52.9	52.9	49.3	71.0	71.0	69.6
1 day/week	10.4	10.4	10.8	13.2	13.2	11.5
2–3 days/week	8.2	8.2	10.8	3.9	3.9	3.2
4–5 days/week	6.3	6.3	5.6	1.1	1.1	1.9
>5 days/week	13.1	13.0	13.2	2.7	2.7	3.2
Ibuprofen Use, %						
None	69.9	69.9	71.0	32.1	32.0	35.5
1 day/week	4.8	4.8	4.1	35.9	36.0	31.9
2–3 days/week	4.0	4.0	4.2	15.3	15.3	13.5
4–5 days/week	1.7	1.7	1.7	3.2	3.2	3.7
>5 days/week	5.6	5.7	4.4	4.2	4.2	3.6
Acetaminophen Use, %						
<1 day/month	73.2	73.2	70.3	41.6	41.6	42.5
1 day/week	3.8	3.8	3.3	36.8	36.8	36.6
2–3 days/week	3.4	3.4	3.8	9.3	9.3	6.7
4–5 days/week	1.5	1.5	1.2	1.8	1.8	1.6
>5 days/week	2.8	2.7	4.3	1.6	1.6	1.3
nSES Score, %						
Quintile 1 (Low nSES)	18.8	18.8	13.3	18.7	18.7	9.2
Quintile 2	21.1	21.1	19.3	21.3	21.3	17.8
Quintile 3	20.1	20.1	13.8	21.4	21.4	22.4
Quintile 4	20.5	20.5	28.4	20.1	20.1	22.7
Quintile 5 (High nSES)	19.5	19.4	25.2	18.6	18.5	27.9
$PM_{2.5}$, μg/m^3	13.7 ± 2.8	13.7 ± 2.8	14.3 ± 3.0	14.5 ± 3.1	14.5 ± 3.1	15.0 ± 3.1
NO_2, ppb	12.5 ± 7.2	12.5 ± 7.2	19.4 ± 8.0	13.6 ± 7.6	13.5 ± 7.6	19.4 ± 7.9
Region of Residence, %						
Northeast	52.5	52.6	39.8	33.9	33.9	32.5
Midwest	17.3	17.3	15.5	32.7	32.8	19.4
South	16.5	16.5	22.8	18.3	18.2	28.9
West	13.6	13.6	21.9	15.1	15.1	19.1

Abbreviations: DASH, Dietary Approaches to Stop Hypertension; dB, (A-weighted) decibels; L_{night}, nighttime average sound level; MET-hrs/wk, metabolic equivalent hours per week; NHS, Nurses' Health Study; NHSII, Nurses' Health Study II; nSES, neighborhood-level socioeconomic status; ppb, parts per billion; NO_2, nitrogen dioxide; $PM_{2.5}$, fine particulate matter.

[a] Values are means ± standard deviations (SD) for continuous variables; percentages for categorical variables and are standardized to the age distribution of the study population.

[b] Value is not age adjusted.

smoking status, alcohol use, diet, individual and neighborhood SES, air pollution ($PM_{2.5}$ and NO_2), and region of residence. Results were modestly attenuated after additional adjustment for BMI, menopausal status, medications, and family history of hypertensions. Although the number of participants exposed to nighttime aircraft noise above 45 dB was lower than the number exposed to 24-h average noise level (DNL) above 45 dB, the effect estimates of nighttime noise and hypertension were higher than those for DNL.

Our finding of a stronger positive association between nighttime aircraft noise and hypertension risk compared to the association for DNL, a 24-h average metric that adds a 10 dB penalty to nighttime noise, was supported by another U.S. study. In the WHI cohort, including 18,783 post-menopausal women participating in a clinical trial and using the same exposure measures as our study, the authors reported larger but less precise estimates for nighttime noise than for DNL (Lnight HR: 1.06; 95% CI: 0.91, 1.24 compared to DNL HR: 1.00; 95% CI: 0.93, 1.08) (Nguyen et al., 2023). Relatedly, a study of 420 participants surrounding Athens International Airport that compared daytime and nighttime noise found larger, although very imprecise, effect estimates with nighttime noise (Lday [07:00 to 23:00] HR: 1.34; 95% CI: 0.57, 3.16 and Lnight HR: 3.39; 95% CI: 0.87, 13.3) (Dimakopoulou et al., 2017).

Table 2
Cases, person-years, incidence rate (IR), hazard ratios (HR) and 95% confidence intervals (CI) for the association between nighttime aircraft noise exposure and incident hypertension among Nurses' Health Study (NHS) and NHSII participants for the period 1994–2014.

	L_{night} <45 dB	L_{night} ≥45 dB
NHS		
Cases/Person-years	32,996/707,656	194/3743
IR per 100,000 PY	4663	5183
HR (95% CI)		
Basic[a]	ref	1.11 (0.96, 1.28)
Parsimonious[b]	ref	1.10 (0.96, 1.27)
Extended[c]	ref	1.07 (0.93, 1.24)
NHSII		
Cases/Person-years	28,041/1,259,067	214/8642
IR per 100,000 PY	2227	2476
HR (95% CI)		
Basic[a]	ref	1.14 (1.00, 1.31)
Parsimonious[b]	ref	1.12 (0.98, 1.28)
Extended[c]	ref	1.08 (0.94, 1.24)
Meta-analysis		
Cases/Person-years	61,037/1,966,723	408/12,385
IR per 100,000 PY	3103	3294
HR (95% CI)[d]		
Basic[a]	ref	1.13 (1.02, 1.24)
Parsimonious[b]	ref	1.11 (1.01, 1.23)
Extended[c]	ref	1.08 (0.97, 1.19)

Abbreviations: BMI, body mass index; CI, confidence interval; DASH, Dietary Approaches to Stop Hypertension; dB, (A-weighted) decibels; HR, hazard ratio; IR incident ratio; L_{night}, nighttime average sound level; NHS, Nurses' Health Study; NHSII, Nurses' Health Study II; nSES, neighborhood-level socioeconomic status; NO_2, nitrogen dioxide; $PM_{2.5}$, fine particulate matter.

[a] Adjusted for age and calendar year.

[b] Adjusted for age, calendar year, race, physical activity, smoking status, alcohol use, DASH, spouse's education attainment, nSES, region of residence, NO_2, and $PM_{2.5}$.

[c] Adjusted for age, calendar year, race, physical activity, smoking status, alcohol use, DASH, spouse's education attainment, nSES, region of residence, NO_2, $PM_{2.5}$, BMI, menopausal status, medications, and family history of hypertension.

[d] p-values for heterogeneity apply to meta-analyzed associations only, which ranged from 0.78 to 0.94.

Researchers have pointed to the challenges in separating long-term effects of daytime and nighttime noise exposure in epidemiological studies because of potential high correlation between the measures, which is especially true for modeled noise and noise from sources such as road traffic where there is lower potential for restricting nighttime operations (Roosli et al., 2019). We found reasonably high correlation between DNL and L_{night} (r's of 0.74–0.79), which can be expected as DNL includes nighttime noise with a 10-dB penalty and given the common source of noise throughout the day. Similarly, the Hypertension and Exposure to Noise Near Airports (HYENA) study of participants surrounding six European airports found r = 0.80 when comparing daytime (hours) and nighttime noise (Jarup et al., 2008). That said, residential nighttime noise may be a more robust measure of personal exposure for many participants, as exposure misclassification for daytime noise is potentially higher when people are less likely to be at home.

Related to questions of participant circadian activity patterns, when we additionally adjusted for shift work, there was no impact on the association between nighttime noise and hypertension risk. However, there was a suggestion that among those performing shift work, there was a stronger association between noise and hypertension, although the confidence intervals among those who performed shift work and those who did not overlapped. This is conceivable as shift work can alter circadian rhythms resulting in difficulty falling asleep, disrupted sleep patterns, and disturbed sleep (Linton et al., 2015; Wickwire et al., 2017).

Experimental studies have also shown more adverse cardiovascular impacts with nighttime noise compared to daytime noise. These studies have shown that compared to daytime noise, nighttime noise was associated with endothelial dysfunction and increased blood pressure, neurohormones, and markers of oxidative stress (Kroller-Schon et al., 2018; Munzel et al., 2017, 2020). The potential mechanism is through sleep disturbance, as sleep is accompanied by a decrease in blood pressure called "dipping" which when disturbed can increase hypertension risk (Sayk et al., 2007). Sleep deprivation can lead to the release of stress hormones that can activate the renin-angiotensin-aldosterone system, central to hypertension pathogenesis (Bavishi et al., 2016; Kim et al., 2015). Researchers also found an association of noise with endothelial function independent of sleep quality, and endothelial dysfunction has been linked to the development of hypertension (Munzel et al., 2020; Schmidt et al., 2015).

Our study has several limitations. NHS and NHSII were not designed

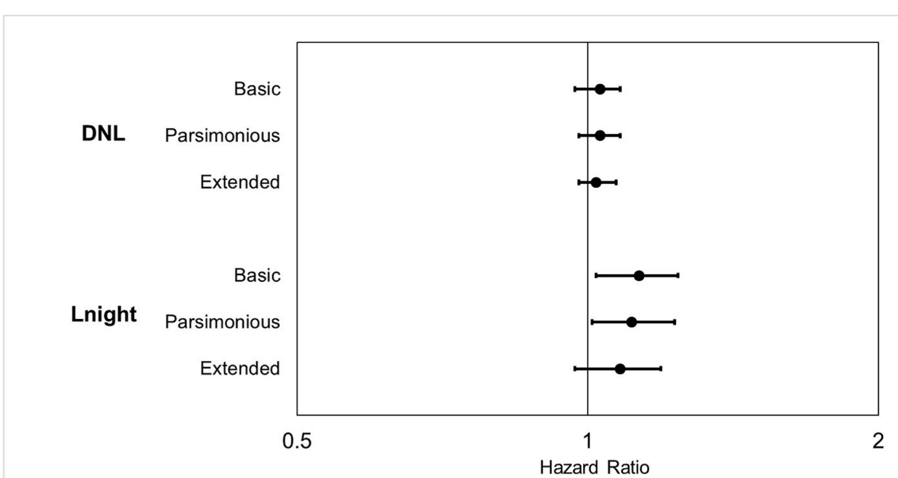

Fig. 1. Results of meta-analysis (combined Nurses' Health Study (NHS) and NHSII cohorts) of noise and hypertension risk for day-night-average level and nighttime noise exposures comparing those exposed to ≥45 dB versus <45 dB.
Basic model adjusted for age and calendar year. Parsimonious model adjusted for age, calendar year, race, physical activity, smoking status, alcohol use, DASH, spouse's education attainment, nSES, region of residence, NO_2, and $PM_{2.5}$. Extended model adjusted for age, calendar year, race, physical activity, smoking status, alcohol use, DASH, spouse's education attainment, nSES, region of residence, NO_2, $PM_{2.5}$, BMI, menopausal status, medications, and family history of hypertension.
Abbreviations: BMI, body mass index; DASH, Dietary Approaches to Stop Hypertension; dB, (A-weighted) decibels; DNL, day-night average sound level; L_{night}, nighttime average sound level; nSES, neighborhood-level socioeconomic status; NO_2, nitrogen dioxide; $PM_{2.5}$, fine particulate matter.

to study noise and health and had very small numbers of participants at nighttime aircraft noise exposure levels above 45 dB. Furthermore, our study participants are all female and from a specific occupation with related SES, occupational exposures, and stressors, and may have lower than average noise exposure; thus, our findings may not be generalizable to the overall U.S. population. In this study, we used annualized average nighttime levels of aircraft noise exposure. It is believed that the intermittent nature of aircraft noise in the nighttime may be of more consequence, and thus, other metrics such as number of flights or intermittency ratio (contribution of an individual noise event above the background noise levels) at night may be more relevant to health outcomes (Basner et al., 2017; Wunderli et al., 2016). In addition, our lowest modeled level of L_{night} of 45 dB (reference group) was above the WHO recommendation for nighttime aircraft noise levels of 40 dB where adverse effects on sleep disturbance were observed (World Health Organization, Regional Office for Europe, 2018). Furthermore, we did not restrict our reference group, for example, by proximity to the airport, and thus this group could be very heterogenous; however, when we restricted the analysis to those in closer proximity to airports, we found that the results did not substantially change. Another limitation is that we only estimate outdoor noise, which does not take into account the penetration of transportation noise indoors that may be affected by factors such as building insulation (Yamagami et al., 2023) and window closing or other noise-reducing behavior (Foraster et al., 2014; Locher et al., 2018). We did not account for noise exposure relative to building façades as is often done with road noise; however, this accounting is less relevant to aircraft noise which primarily emanates from overhead (Bozigar et al., 2023). We adjusted for a number of individual and area-level confounders; however, there still may be residual confounding. Of note, we were not able to adjust for other sources of noise that may correlate with aircraft noise (Floud et al., 2013), or stratify by noise sensitivity or noise annoyance (Baudin et al., 2020b; Park et al., 2017). In addition, although we controlled for ambient air pollution ($PM_{2.5}$ and NO_2), given similarities in associations to adverse outcomes, spatial distribution, and transportation sources (Eze et al., 2017), further investigation into the interrelationship between air pollution and noise may be warranted. Finally, although it has been shown that this population of nurses provides accurate information on hypertension status, this study relied on self-report of hypertension.

In spite of these limitations, this study has several strengths. We used time-varying, comparable aircraft noise estimates across multiple airports, which has not been available in most previous studies. In addition, time-varying data on potential individual and area-level covariates and effect modifiers were available, including an updated database of air pollution measurements. Broadly, our ability to connect noise exposure estimates with a large national cohort study provided considerable advantages relative to smaller studies or cross-sectional epidemiological investigations.

5. Conclusion

In this national U.S. cohort of women, we found a modest positive association between nighttime aircraft noise exposure and hypertension risk, which was stronger than the association with 24-h average aircraft noise. These results were not affected by shift work or hearing loss status. Our findings add to the evidence of the long-term association between noise and cardiometabolic health, potentially through its relationship with disrupted sleep. However, given the small number of participants exposed to high noise levels in this non-representative sample of female nurses, this research should be replicated in more diverse cohorts.

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CRediT authorship contribution statement

Junenette L. Peters: Writing – original draft, Supervision, Investigation, Funding acquisition, Conceptualization. **Stephanie T. Grady:** Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization. **Francine Laden:** Writing – review & editing, Methodology, Conceptualization. **Elizabeth Nelson:** Writing – review & editing, Investigation. **Matthew Bozigar:** Writing – review & editing, Investigation, Conceptualization. **Jaime E. Hart:** Writing – review & editing, Investigation, Data curation, Conceptualization. **JoAnn E. Manson:** Writing – review & editing, Methodology, Funding acquisition, Data curation. **Tianyi Huang:** Writing – review & editing, Investigation. **Susan Redline:** Writing – review & editing, Investigation. **Joel D. Kaufman:** Writing – review & editing, Funding acquisition, Data curation. **John P. Forman:** Writing – review & editing, Data curation. **Kathryn M. Rexrode:** Writing – review & editing, Investigation, Data curation. **Jonathan I. Levy:** Writing – review & editing, Resources, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

Susan Redline reports a relationship with Jazz Pharmaceuticals Inc., Ireland that includes grant and consulting. All other authors declare they have no actual or potential competing financial interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2024.114457.

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16. Abstract

There is growing interest in cardiometabolic outcomes associated with nighttime noise, given that noise can disturb sleep and sleep disturbance can increase cardiometabolic risk such as hypertension. However, there is little empirical research evaluating the association between nighttime aircraft noise and hypertension risk. In this study, we expand on previous work to evaluate associations between nighttime aircraft noise exposure and self-reported hypertension incidence in the Nurses' Health Studies (NHS/NHSII), two US-wide cohorts of female nurses. Annual nighttime average aircraft sound levels (Lnight) surrounding 90 airports for 1995–2015 (in 5-year intervals) were modeled using the Aviation Environmental Design Tool and assigned to participants' geocoded addresses over time. Hypertension risk was estimated for each cohort using time-varying Cox proportional hazards models for Lnight dichotomized at 45 dB (dB), adjusting for individual-level hypertension risk factors, area-level socioeconomic status, region, and air pollution. Random effects meta-analysis was used to combine cohort results. Among 63,229 NHS and 98,880 NHSII participants free of hypertension at study baseline (1994/1995), we observed 33,190 and 28,255 new hypertension cases by 2014/2013, respectively. Although ~1% of participants were exposed to Lnight ≥45 dB, we observed an adjusted hazard ratio (HR) of 1.10 (95% CI: 0.96, 1.27) in NHS and adjusted HR of 1.12 (95% CI: 0.98, 1.28) in NHSII, comparing exposure to Lnight ≥45 versus <45 dB(A). In meta-analysis, we observed an adjusted HR of 1.11 (95% CI: 1.01, 1.23). These results were attenuated with adjustment for additional variables such as body mass index. Our findings support a modest positive association between nighttime aircraft noise and hypertension risk across NHS/NHSII, which may reinforce the concept that sleep disturbance contributes to noise-related disease burden.

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