ORIGINAL ARTICLE

The relation of nocturnal exposure to aircraft noise and aircraft noise–induced insomnia with blood pressure

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KEY WORDS

aircraft noise, blood pressure profile, insomnia, noise annoyance, sleep disturbances

ABSTRACT

INTRODUCTION Nighttime environmental noise exposure leads to unconscious stress reactions and autonomic arousals. These may disturb overnight sleep and the diurnal blood pressure (BP) profile, contributing to an increased risk of developing hypertension.

OBJECTIVES This study aimed to investigate the effects of chronic nighttime exposure to aviation noise on sleep disturbances and the relationship with annoyance and the BP profile.

PATIENTS AND METHODS Based on acoustic maps, we selected 2 groups of normotensive participants: exposed (n = 48; mean age, 50.9 years; 29 women) and unexposed (n = 50; mean age, 49.7 years; 35 women) to nocturnal aircraft noise. We collected anthropometric and demographic data using a standardized questionnaire. Insomnia symptoms were evaluated using the Athens Insomnia Scale (AIS). In both study groups, we performed office BP measurements and 24-hour ambulatory BP monitoring.

RESULTS Noise-exposed participants showed distinctive sleep disturbances, higher AIS scores (4.3 vs 2.3; $P = 0.01$), and an increased insomnia risk (odds ratio, 2.62; $P = 0.046$). With increased noise annoyance, a higher AIS score was observed ($P_{ANOVA} = 0.02$). Noise-exposed individuals had higher diastolic BP at night than those unexposed (64.6 mm Hg vs 61.7 mm Hg; $P = 0.03$). Insomnia among noise-exposed participants resulted in higher 24-hour (115.2 mm Hg vs 122.2 mm Hg; $P = 0.03$) and nighttime (103.7 mm Hg vs 112.2 mm Hg; $P = 0.02$) systolic BP. A significant interaction was noted between aircraft noise exposure and the AIS score. The association of the AIS score with 24-hour systolic BP ($P = 0.048$) and pulse pressure ($P = 0.04$) was stronger in the exposed group.

CONCLUSIONS The study results may indicate different pathomechanisms affecting BP in terms of nighttime noise and noise-related insomnia.

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INTRODUCTION We live our lives surrounded by sounds. They become noise when they are unwanted or harmful. There has been growing evidence of the nonauditory effects of environmental noise on public health. Observational and experimental studies have shown that noise exposure leads to annoyance,[1] sleep disruption, daytime sleepiness,[2] increased rates of hypertension and cardiovascular diseases,[3] and impaired cognitive performance in children.[4] Although noise is a product of numerous human activities, the pervasiveness of transportation noise (road traffic, railways, and aircraft) makes the issue highly compelling.[5,6]

While the conscious experience of noise may be the primary source of stress reactions during the day, unconscious biological responses at night have been noted among sleeping individuals.[7] The psychophysiological stress reaction to environmental noise is considered a primary causal link to cardiovascular disease development.[8-10]

WHAT'S NEW?

The study results expand our knowledge about mechanisms involved in arterial hypertension development in response to chronic (over 30-year) aircraft noise exposure. Elevated diastolic blood pressure (BP) was shown to be the direct effect of nighttime aircraft noise exposure, the most probable explanation of which is increased vascular resistance. Insomnia among individuals exposed to nighttime aircraft noise was also associated with noise annoyance and led to increased systolic BP. This sympathetic overactivity represented a mechanism linking insomnia and arterial hypertension. Our findings may suggest that environmental noise exposure increases the risk of developing hypertension by exerting a direct effect on BP rise and as a chronic consequence of insomnia.

Repeated autonomic nervous system arousals caused by nocturnal noise are more relevant for cardiovascular disorders than daytime noise, as they undergo only limited habituation.[11] Sympathetic overdrive may diminish physiological nocturnal blood pressure (BP) dipping and contribute to the risk of developing arterial hypertension in those exposed to high noise levels for prolonged periods of time. Subjective noise perception is crucial, as sound levels and noise annoyance have been associated with cardiovascular disorders.[12] Aircraft noise is pertinent to consider, as it is perceived as the most annoying and sleep-disturbing among all sources of transportation noise.[13] Although recent epidemiological studies have shown stronger relations between nocturnal noise exposure[10,14] and negative health outcomes compared with daytime noise exposure, studies directly investigating the link between noise-induced sleep disturbances and long-term cardiovascular consequences are scarce.

Complex BP regulation mechanisms including responses to stressors, such as aircraft noise, may differ in healthy people versus those with hypertension.[15] To investigate the crude influence of aircraft noise on BP, we excluded individuals with confirmed arterial hypertension from our study to avoid the influence of hypertension-related pathomechanisms and antihypertensive medication.[16]

We aimed to assess the chronic effect of nighttime aircraft noise exposure on self-reported sleep disturbance and noise annoyance. Furthermore, we examined their relationship with the BP profile in normotensive individuals.

PATIENTS AND METHODS

Study population

This observational, cross-sectional study was conducted in a rural area near Kraków, Poland, between June 2015 and June 2016. The study included 2 groups of individuals: exposed (people affected by chronic nighttime aircraft noise) and unexposed (those who were not affected). Based on an acoustic map prepared in 2009 by the Małopolska Regional Council—Resolution no XXXII/470/09[17] (**FIGURE 1**), we selected exposed participants from an area influenced by high nighttime aircraft noise levels (L_N exceeding 50 dB) in the Morawica village located within the deep blue equal-loudness contour at L_N of 50 dB and the red one at an A-weighted long-term average sound level over 24 hours of 60 dB. That area was also selected for noise-exposed participants recruited in our previous study.[18] The unexposed group was recruited from another village (Jeziorzany) located 15 km from an airport outside the light blue equal-loudness contour at L_N of 45 dB in the south, as indicated by the yearly weighted nighttime sound level, L_N.[19] Cutoff levels were consistent with those endorsed by the World Health Organization and European environmental noise guidelines for evaluating the health effects of noise[20,21] and confirmed using field noise measurements. Other environmental conditions did not differ between the selected sites.

Age between 40 and 65 years, which was considered optimal for assessing hypertension-mediated organ damage (hypertension-mediated organ damage was the primary research objective in a previously published paper of this team[18]), length of residence in a given area (a minimum of 3 years), and willingness to participate in the study constituted additional inclusion criteria. The exclusion criteria were as follows: heart failure, coronary artery disease, myocardial infarction, stroke, liver, kidney, or respiratory disease, deafness or serious hearing loss, and obstructive sleep apnea,[22] as classified by the *International Classification of Diseases, Tenth Revision* codes. Shift workers were also excluded from the study.

The total study population primarily considered for study inclusion consisted of 619 inhabitants from 2 locations affected by low and high noise level exposure, as derived from the population registries. All 300 people living in the area of high nocturnal noise level exposure (>50 dB, the Morawica village) were invited to participate in the study. Among them, 143 individuals responded to the invitation (reportability rate, 47.7%), while 101 met the basic inclusion criteria. Of 101 participants, 53 were further excluded due to arterial hypertension defined as previously diagnosed and treated hypertension or BP values during 24-hour ambulatory BP monitoring exceeding: systolic BP (SBP) of 130 mm Hg and / or diastolic BP (DBP) of 80 mm Hg and SBP of 140 mm Hg; and / or DBP of 90 mm Hg in the office setting. Ultimately, for the presented analyses, we included 48 normotensive participants (the exposed group [n = 48]).

A comparison group of individuals exposed to a low nighttime aircraft noise level (<45 dB, the Jeziorzany village) in their place of residence was also recruited. We invited 319 inhabitants, 134 of whom volunteered to participate in the study (reportability rate, 42%), and 100 met the inclusion criteria. Among those, 50 had arterial hypertension and 50 constituted the control normotensive group (the unexposed group [n = 50]).

We obtained anthropometric data and information on lifestyle habits, subjective noise annoyance, and sleep quality from all participants using a dedicated, standardized questionnaire.

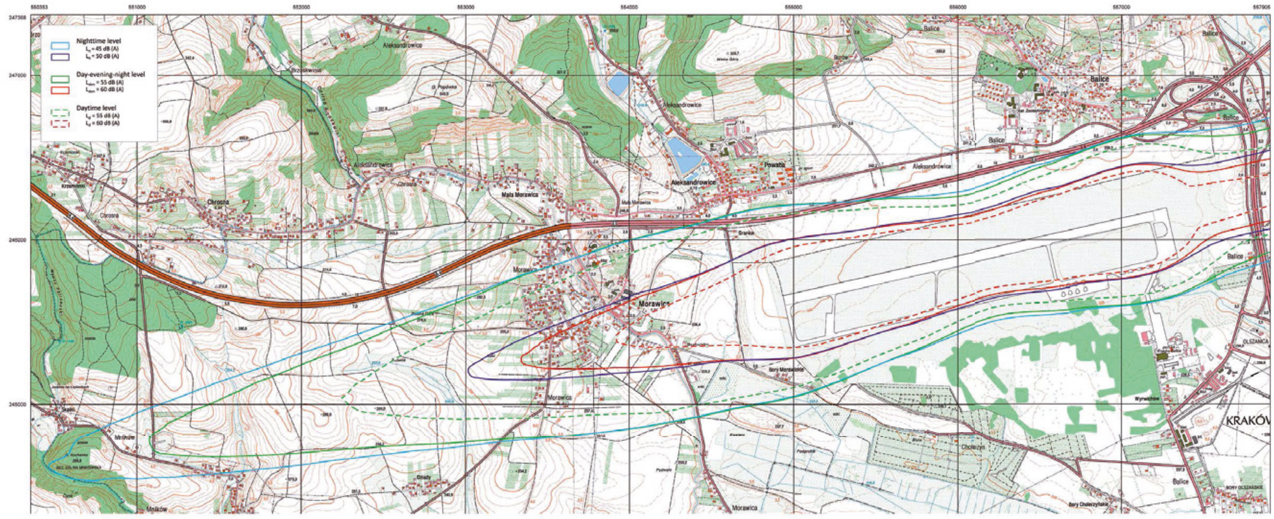


FIGURE 1 Acoustic map of the study region

Noise annoyance was evaluated with a 3-point scale: 0, none; 1, moderate; and 2, high. In addition, on the day of the participant's visit at the outpatient clinic, we performed a physical examination and took their medical history. Study examinations and surveys were consecutively conducted during a single entire day: a standardized questionnaire, BP measurements, and ambulatory BP monitoring setup.

The study complied with the Declaration of Helsinki. The Jagiellonian University Ethics Committee approved the study protocol. All participants were informed about the purpose and methodology of the study and provided written consent to participate in it.

Blood pressure measurement We measured office BP twice in the nondominant arm after 10 minutes of rest, using the Omron M5-I device (Omron, Kyoto, Japan). The mean value of the 2 measurements was used in further analyses. Measured office BP values included SBP and DBP. Pulse pressure (PP) was calculated as SBP minus DBP. Additionally, 24-hour ambulatory BP monitoring was performed using SpaceLabs 90207, a device equipped with the appropriate software (SpaceLabs Healthcare, Snoqualmie, Washington, United States). Measurements were taken every 15 minutes during daily activity (6:00 AM–10:00 PM) and every 20 minutes at night (10:00 PM–6:00 AM). We collected data on 24-hour, daytime, and nighttime BP and heart rate (HR).

The nocturnal dipping of SBP and DBP as well as the night drop of HR were calculated as the difference between the mean daytime BP or HR value and the mean nighttime BP or HR value and expressed as a percentage of the day value.

Sleep quality analysis Insomnia was evaluated using the Athens Insomnia Scale (AIS).[23] Sleep quality was measured by assessing 8 factors, among which the first 5 were related to nocturnal sleep and the last 3, to daytime dysfunction. These were rated on a scale ranging from 0 to 3, and sleep was ultimately evaluated from the cumulative scores of all factors and reported as an individual's sleep outcome. A cutoff score higher than or equal to 6 on the AIS was used to diagnose insomnia.[24]

Statistical analysis Statistical analyses were performed using the SAS software, version 9.1 (SAS Institute, Cary, North Carolina, United States). Results were expressed as numbers and percentages for categorical variables and as mean (SD) for continuous variables.

The exposed and unexposed groups were compared using the *t* test for continuous variables and the χ^2 for qualitative variables. The risk of insomnia in the exposed participants was assessed by calculating the odds ratio (OR) in the univariate LOGISTIC procedure. Differences in the AIS score among participants were grouped according to self-reported noise annoyance degree (0, 1, or 2) and assessed using the Kruskall–Wallis test. The Dunn post hoc test was used to determine differences between the study groups. In order to detect BP differences in response to aircraft noise exposure, noise-induced insomnia, and the interaction of the latter, we implemented the analysis of covariance with BP as a dependent variable and the following independent variables: aircraft noise exposure, AIS score, and their interaction. We used a linear regression model to analyze factors influencing the AIS score. In all analyses, a *P* value less than 0.05 was considered significant.

RESULTS The study participants' background characteristics stratified by the noise exposure level are presented in TABLE 1. Both groups, exposed and unexposed to nighttime aircraft noise, were similar in terms of age, body mass index, and sex. The number of smokers and alcohol consumers, time of residence, and socioeconomic

TABLE 1 Demographic, anthropometric, and socioeconomic characteristics of the study participants

Parameter		All (n = 98)	Unexposed (n = 50)	Exposed (n = 48)	*P* value
Age, y, mean (SD)		50.3 (7.7)	49.7 (8.4)	50.9 (6.9)	0.46
Female sex		64 (65.4)	35 (70)	29 (60.4)	0.32
BMI, kg/m^2, mean (SD)		26.6 (4.5)	26.4 (5)	26.8 (3.9)	0.41
Smoking status		9 (9.2)	4 (8)	5 (10.4)	0.68
Regular alcohol consumption[a]		30 (30.6)	12 (24)	18 (37.5)	0.15
Regular physical activity[b]		27 (27.6)	17 (34)	10 (20.9)	0.14
Time of residence in the selected area, y, median (IQR)		30 (19–46)	29 (13–40)	34 (22–49)	0.13
Time spent at home within 24 h, h, mean (SD)		16 (4.65)	15.8 (4.6)	16.3 (4.7)	0.65
Professional activity	Unemployed	11 (11.2)	7 (14)	4 (8.3)	0.48
	Retired/pensioner	19 (19.4)	11 (22)	8 (16.7)	
	Working person	68 (69.4)	32 (64)	36 (75)	
Education	Primary	22 (22.5)	12 (24)	10 (20.8)	0.11
	Secondary	56 (57.1)	24 (48)	32 (66.7)	
	Higher	20 (20.4)	14 (28)	6 (12.5)	
Aircraft noise annoyance level	None	56 (57.1)	50 (100)	6 (12.5)	<0.001
	Moderate	20 (20.4)	0	20 (41.7)	
	High	22 (22.5)	0	22 (45.8)	

Data are presented as number (percentage) of patients unless otherwise indicated.

a Minimum a single alcohol dose (50 ml of vodka, cognac, or liqueur or 150 ml of wine, or 250 ml of beer) per week

b Minimum once a week

Abbreviations: BMI, body mass index; IQR, interquartile range

TABLE 2 The severity of insomnia in the study cohort according to the Athens Insomnia Scale

Sleep factors	Athens Insomnia Scale								*P* value
	Unexposed (n = 50)				Exposed (n = 48)				
	0	1	2	3	0	1	2	3	
Sleep induction	42 (84)	8 (16)	0	0	37 (77)	11 (23)	0	0	0.38
Waking up at night	37 (74)	13 (26)	0	0	29 (60)	19 (40)	0	0	0.15
Final awakening	40 (80)	9 (18)	1 (2)	0	36 (75)	11 (23)	1 (2)	0	0.59
Total sleep duration	38 (76)	11 (22)	1 (2)	0	38 (79)	7 (15)	2 (4)	1 (2)	0.78
Sleep quality	33 (66)	17 (34)	0	0	16 (33)	32 (67)	0	0	0.001
Well-being during the day	36 (72)	10 (20)	4 (8)	0	28 (58)	14 (29)	6 (13)	0	0.18
Functioning capacity during the day	37 (74)	12 (24)	1 (2)	0	29 (60)	16 (33)	3 (7)	0	0.12
Sleepiness during the day	37 (74)	12 (24)	1 (2)	0	24 (50)	21 (43)	3 (7)	0	0.015
Total score category, median (IQR)	0 (0–5)				3.5 (0–7)				0.014
Sleep duration, h, mean (SD)	7.1 (0.8)				7 (1)				0.92

Data are presented as number (percentage) of patients unless otherwise indicated.

Abbreviations: see TABLE 1

status were similar between the study groups. As expected, most participants exposed to aircraft noise reported it as a nuisance.

The comparison of insomnia severity between the 2 study groups is shown in TABLE 2. Among the parameters analyzed, poor sleep quality, daytime sleepiness, and the total AIS score were significantly higher in the exposed group than in the unexposed one. Of note, the prevalence of insomnia in participants exposed to aircraft noise was 16 (33%), which was 2-fold higher than that observed in the 8 unexposed participants (16%). Also, the risk of insomnia in the exposed participants was higher than in those who were not exposed (OR, 2.62; 95% CI, 1.01–6.89; $P = 0.046$) (FIGURE 2).

FIGURE 2 Insomnia prevalence according to aircraft noise exposure in the normotensive study participants
Abbreviations: OR, odds ratio

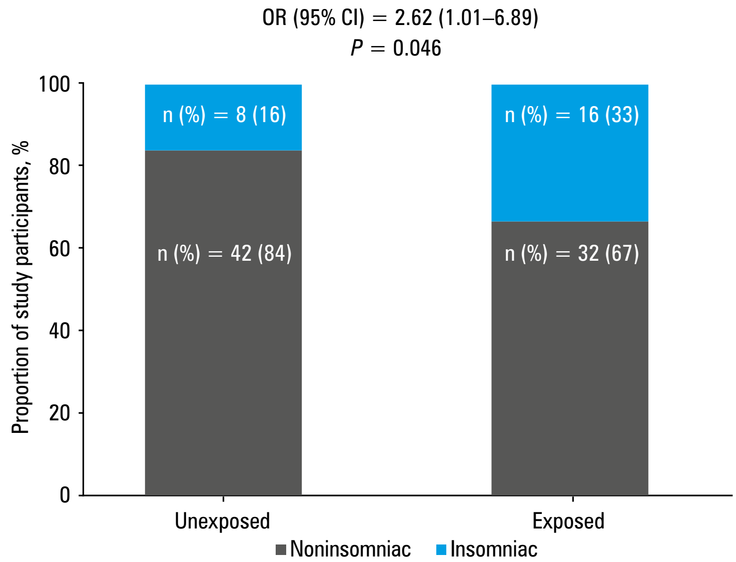
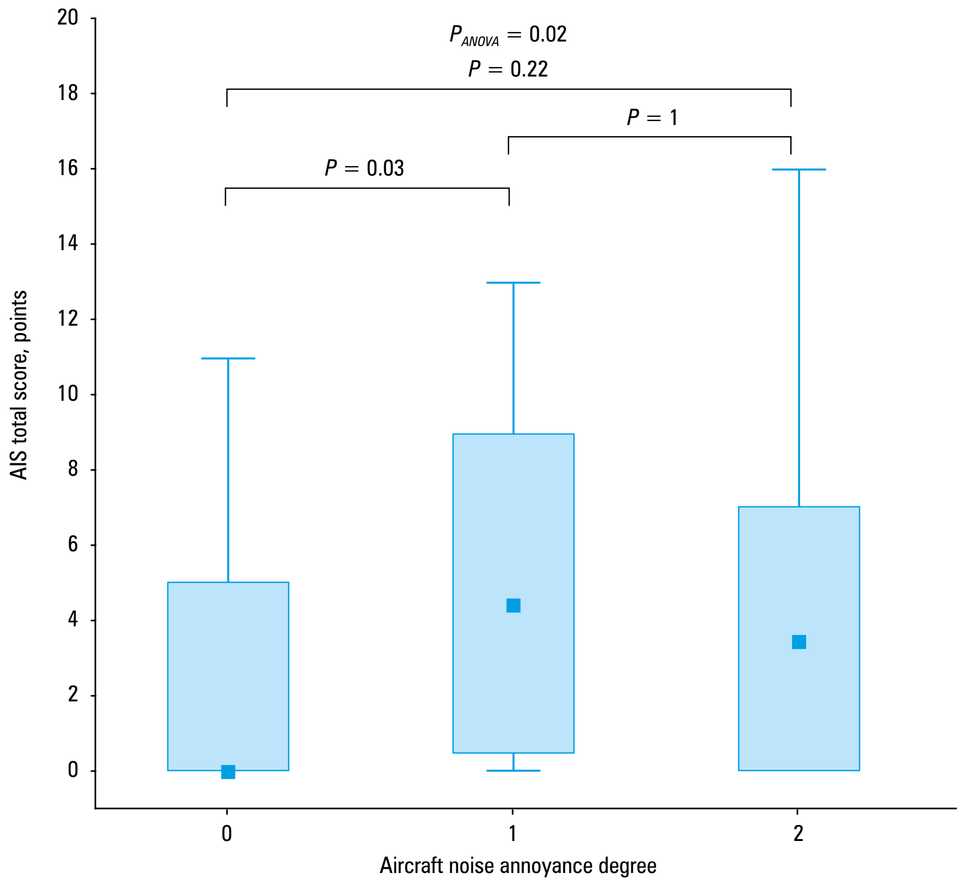


FIGURE 3 Distribution of the total score on the Athens Insomnia Scale (AIS) by the aircraft noise annoyance level (0, none; 1, moderate; and 2, high) in the normotensive study participants. Filled squares represent the median value; boxes, interquartile range; and whiskers, minimum and maximum values. Kruskal–Wallis H test (2; 98) = 8.27 (df = 2, n = 98, χ^2 = 8.27, P = 0.02)
Abbreviations: ANOVA, analysis of variance



As presented in FIGURE 3, the cumulative AIS score was related to self-reported noise annoyance. Importantly, the most annoyed participants had the highest scores on the AIS, but the highest median AIS score was noted in moderately, and not highly, annoyed participants. Time of residence in the study site did not influence the AIS score (R^2 <0.001; P = 0.8) or subjective noise annoyance (R^2 = 0.01; P = 0.62) in the exposed group. The BP parameters of noise-exposed and unexposed participants are shown in TABLE 3. Among the noise-exposed participants, we observed significantly higher office and nighttime DBP than in the unexposed individuals.

The comparison of BP values in participants suffering or not suffering from insomnia among those exposed to aircraft noise is shown in TABLE 4. Of note, significantly higher 24-hour SBP, nighttime SBP, and PP were observed in insomniacs compared with participants without insomnia. These differences remained significant after adjusting for age and sex. Moreover, we observed a significant interaction between aircraft noise exposure and the AIS score, analyzed as a continuous variable in relation to 24-hour SBP and PP (FIGURE 4).

TABLE 3 Blood pressure values in the study cohort

Parameter		All (n = 98)	Unexposed (n = 50)	Exposed (n = 48)	*P* value
Office measurements, mean (SD)	SBP, mm Hg	134.5 (17.3)	133.6 (15.7)	135.4 (18.9)	0.6
	DBP, mm Hg	80.4 (9.3)	77.1 (7.3)	83.9 (9.9)	<0.001
	PP, mm Hg	54.1 (12.7)	56.5 (11.4)	51.5 (13.6)	0.05
	HR, bpm	70.3 (11)	70.6 (9.6)	70 (12.4)	0.80
ABPM measurements, mean (SD)	24-hour SBP, mm Hg	118 (9.9)	118.6 (8.8)	117.5 (11)	0.59
	24-hour DBP, mm Hg	72.2 (5.9)	71.1 (4.6)	73.4 (6.7)	0.05
	24-hour PP, mm Hg	45.8 (7.6)	47.5 (6.5)	44 (8.8)	0.03
	24-hour HR, bpm	72.1(9.1)	71 (8.8)	73.2 (9.4)	0.24
	SBPd, mm Hg	123.8 (10.8)	124.8 (10.1)	122.8 (11.6)	0.36
	DBPd, mm Hg	76.8 (6.3)	76.2 (6.1)	77.4 (6.4)	0.32
	PPd, mm Hg	47.0 (8.3)	48.7 (8)	45.4 (8.4)	0.05
	HRd, bpm	76.3 (9.8)	75.8 (9.4)	76.8 (10.4)	0.62
	SBPn, mm Hg	106.5 (10.1)	106.5 (8.6)	106.5 (11.5)	0.96
	DBPn, mm Hg	63.2 (6.6)	61.7 (4.9)	64.6 (7.7)	0.028
	PPn, mm Hg	43.3 (7.6)	44.7 (6.6)	41.9 (8.4)	0.06
	HRn, bpm	63.7 (9.7)	63.6 (9.8)	63.9 (9.7)	0.89
Nighttime dipping, n (%)	SBP	13.8 (6.4)	14.5 (6.6)	13.2 (6.1)	0.31
	DBP	17.6 (6.9)	18.6 (7.5)	16.6 (6.2)	0.15
	HR	16.4 (7.5)	16.1 (7.7)	16.7 (7.4)	0.70

Abbreviations: ABPM, ambulatory blood pressure monitoring; BP, blood pressure; d, day; DBP, diastolic blood pressure; HR, heart rate; n, night; PP, pulse pressure; SBP, systolic blood pressure

TABLE 4 Blood pressure parameters among the aircraft noise–exposed study participants according to insomnia categories

Parameter	Exposed and AIS <6 (n = 32)	Exposed and AIS ≥6 (n = 16)	*P* value
24-hour SBP, mm Hg	115.2 (11.8)	122.2 (7.5)	0.034[a]
24-hour DBP, mm Hg	72.8 (7.1)	74.6 (6)	0.38
24-hour PP, mm Hg	42.3 (8.6)	47.6 (8.5)	0.05
24-hour HR, bpm	72.3 (10)	73.6 (8.3)	0.81
SBPd, mm Hg	120.6 (12.5)	127.3 (7.8)	0.05
DBPd, mm Hg	76.5 (6.5)	79.2 (6)	0.17
PPd, mm Hg	44 (8.2)	48.1 (8.3)	0.12
HRd, bpm	76.3 (11.2)	77.8 (8.9)	0.66
SBPn, mm Hg	103.7 (11.2)	112.2 (10.2)	0.015[b]
DBPn, mm Hg	63.7 (7.7)	66.4 (7.6)	0.26
PPn, mm Hg	39.9 (6.2)	45.7 (10.7)	0.022[c]
HRn, bpm	63.5 (9.2)	64.6 (10.8)	0.75

Data are presented as mean (SD).

a *P* value after adjustment for age and sex = 0.035

b *P* value after adjustment for age and sex = 0.047

c *P* value after adjustment for age and sex = 0.036

Abbreviations: see TABLE 3

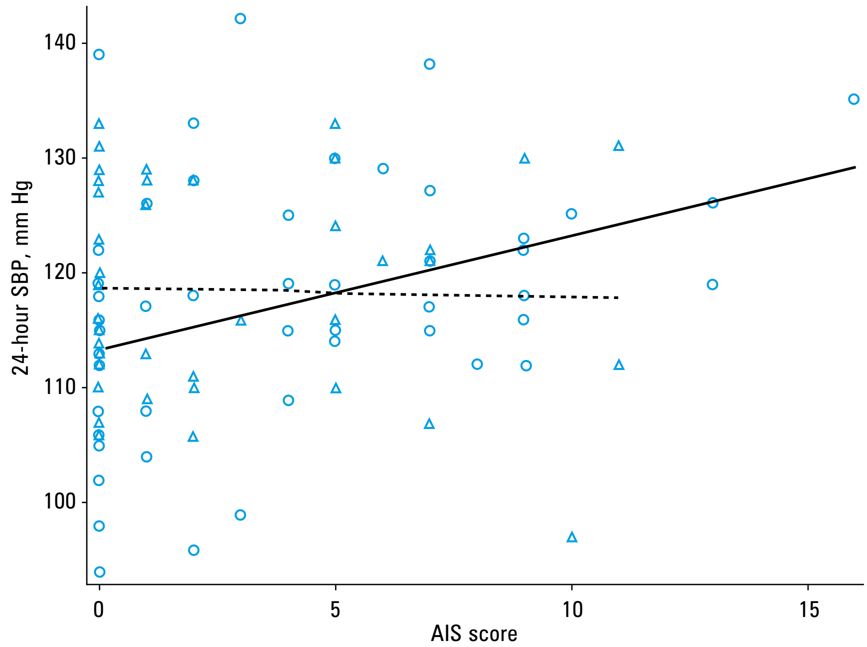
DISCUSSION **Summary of the main findings** In our study, we confirmed poorer sleep quality and higher AIS values in normotensive people living near the airport. The main finding of our study showed that insomnia occurred over 2-fold more frequently among the study participants exposed to aircraft noise during nighttime hours compared with those unexposed. The severity of insomnia measured by the AIS increased with reported noise annoyance. Office and nighttime DBP were significantly higher in the noise-exposed individuals versus the unexposed. Among the noise-exposed participants, significantly higher 24-hour SBP, nighttime SBP, and PP were observed in those with insomnia compared with those without. Moreover, in the noise-exposed participants, a higher AIS score was associated with higher SBP and PP.

Insomnia and noise annoyance Poorer sleep quality in residents living near the Bergamo airport in Italy was reported by Carugno et al,[25] who showed that the severity of sleep disorders was proportional to the aircraft noise level; however, the night noise (L_N) was not addressed. That study showed a relationship between the noise level and BP. However, our findings did not confirm that observation. Nevertheless, we indicated that individuals exposed to aircraft noise were highly annoyed, which partly confirmed the findings of Carugno et al.[25]

Similar to our results, Kwak et al[26] described a positive relationship between insomnia evaluated by the Insomnia Severity Index and the aircraft noise level assessed by the Weighted Equivalent Continuous Perceived Noise Level. The main difference and, in our opinion, the strength of our study compared with Kwak et al,[26] was the adoption of widely used indices of the noise level such as L_N as well as an insomnia index, the AIS.

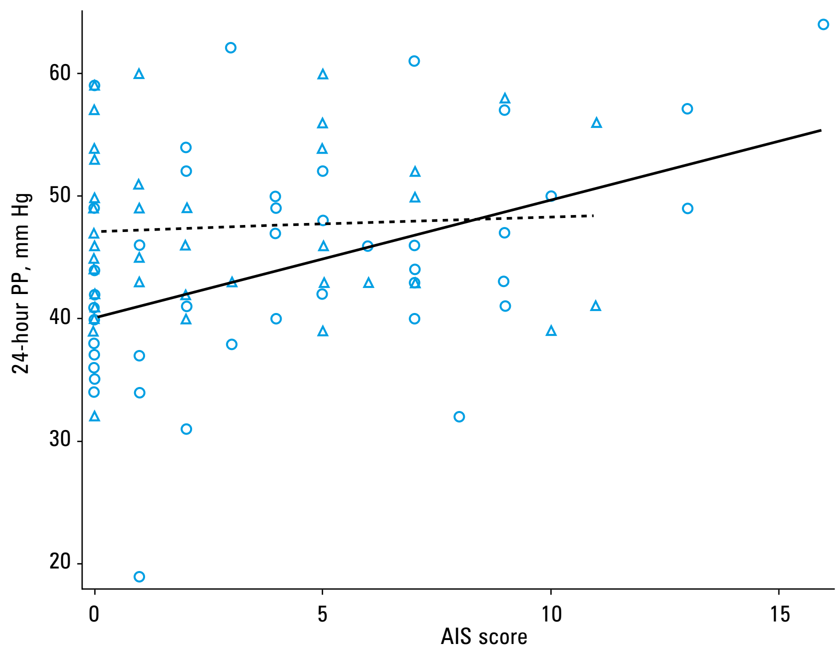
FIGURE 4 Blood pressure parameters (24-hour ambulatory blood pressure monitoring) according to exposure to aircraft noise and insomnia: an analysis of covariance in the general linear model: **A** – model A; **B** – model B. Circles and the solid line represent the data of participants exposed to aircraft noise, whereas triangles and the dotted line, the data of the unexposed participants.
Abbreviations: AIS, Athens Insomnia Scale; CV, coefficient of variation; PP, pulse pressure; RMSE, root-mean-square error; others, see **TABLE 3**

A



	Sum of squares	*F* value	*P* value	R^2	CV	RMSE
Model dependent variable: 24-hour SBP	828.9	2.97	0.04	0.086	8.17	9.6
Independent variables						
Aircraft noise exposure	406.9	4.38	0.04			
AIS score	256.8	2.76	0.09			
Aircraft noise exposure * AIS score	374.1	4.03	0.048			

B



	Sum of squares	*F* value	*P* value	R^2	CV	RMSE
Model-dependent variable: 24-hour PP	1032	6.47	<0.001	0.17	15.9	7.3
Independent variables						
Aircraft noise exposure	700.9	13.2	0.02			
AIS score	368.6	6.94	0.01			
Aircraft noise exposure * AIS score	223.5	4.21	0.04			

Rocha et al,[27] in a pilot study performed near the Atlanta airport, confirmed that L_N was associated with an increased prevalence of severe sleep disruption and annoyance caused by aircraft noise. This was consistent with our findings. Our study indicated a novel association between annoyance and insomnia or sleep disturbances. This constituted the second main finding of our study: the severity of insomnia (as measured by the AIS) increased with reported noise annoyance.

The authors of a large review on the effect of aircraft noise on sleep disturbances in adults suggested that there was a causal relationship between exposure to aircraft noise and sleep disturbances.[28] Detailed analyses of sleep disturbances in our study seem to support this hypothesis.

Blood pressure values In this study, we observed significantly higher DBP, yet not SBP, during nighttime hours among participants exposed to aircraft noise compared with unexposed individuals. Increased SBP and DBP in ambulatory BP monitoring represented the direct strong effect of nighttime aircraft noise exposure in a substudy of Hypertension and Exposure to Noise Near Airports (HYENA).[29] In healthy adults, Schmidt et al[10] demonstrated a worsening sleep quality yet no increase in SBP under the acute influence of aircraft noise. In another study by Schmidt et al,[9] aircraft noise resulted in increased SBP in patients at high cardiovascular risk, decreased sleep quality, and poorer vascular function.

Chronic exposure to aircraft noise was also associated with higher BP in numerous studies.[3,8,18] However, some authors reported the opposite results. Basner et al[30] did not find any significant difference in either systolic or diastolic BP between those living near the airport and those living in the control region. Also, in the population living near the Bergamo airport in Italy, no relationship between noise and BP levels was found.[25]

Therefore, the differences between that study[25] and ours confirm the novelty of our findings: there was a positive relation between insomnia and 24-hour SBP in participants exposed to aircraft noise. This raises the question about the pathomechanism of BP elevation and the subsequent development of arterial hypertension in response to chronic aircraft noise exposure. Of note, according to the literature, insomnia may also cause arterial hypertension.[31-33]

Whereas aircraft noise alone leads to increased DBP during nighttime hours, noise-induced insomnia resulted in increased 24-hour and nighttime SBP. A possible explanation for the different effects of noise versus noise-related insomnia on BP parameters may reflect 2 distinct effects of noise: a direct effect causing physiological stress and an indirect effect leading to emotional stress. The latter seems to depend on annoyance and has been shown to be accompanied by sleep disturbances.[12,34]

Despite significant differences in BP, there was no significant difference in HR between those exposed and unexposed to night aircraft noise in our study. Similar results were obtained by Haralabidis et al[29] and Schmidt et al.[10] One of the possible explanations was the method used for HR measurements in our study, ie, 24-hour ambulatory BP monitoring, which recorded HR during each single BP measurement (about 90 times per day). It was not continuous like in the case of electrocardiographic monitoring. Therefore, it did not reflect the true mean day, night, and 24-hour HR values. The specific character of aircraft noise should also be considered here: a short, repeated event was probably accompanied by a short-term HR increase, which was not necessarily detectable by the ambulatory BP monitoring device. Presumably, BP responses to noise events were more extended over time than the HR increase. Longitudinal studies are needed to thoroughly understand mechanisms and factors influencing BP rise in individuals exposed to nocturnal environmental noise.

Limitations Some limitations of our study should be listed here. First, real aircraft noise exposure and relevant group classification could be an issue. When considering chronic environmental noise exposure, there is always a risk of misclassification as a result of daily movements during the period of analysis. However, the risk in this case was low, as we measured nighttime aircraft noise. Second, a subjective method rather than objective methods such as electroencephalography and polysomnography was used to evaluate sleep disturbances. Therefore, self-report bias may have occurred.

Conclusions In 2 groups of individuals without arterial hypertension, nocturnal aircraft noise was related to sleep disturbances and increased DBP. Insomnia in those exposed to nighttime aircraft noise was associated with noise annoyance and higher SBP and PP. These findings suggested that insomnia might contribute to the development of arterial hypertension in individuals exposed to nighttime aircraft noise.

ARTICLE INFORMATION

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CONTRIBUTION STATEMENT MRo and MRa conceived the concept of the study. All authors contributed to the study design. MRo, MRa, and WW were involved in data collection. MRo and WW analyzed the data. MRa coordinated funding for the project. All authors edited and approved the final version of the manuscript.

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