Environmental noise pollution and 24-hour blood pressure variability: a cross-sectional analysis in urban industrial zones

Contaminación acústica ambiental y variabilidad de la presión arterial en 24 horas: Un análisis transversal en zonas industriales urbanas

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Received: 06/20/2025 Accepted: 09/19/2025 Published: 10/12/2025 DOI: http://doi.org/10.5281/zenodo.17295119

Abstract

The noise pollution of the kind experienced in urban industrial settlements, as one of the major stressors, has negative effect on cardiovascular health, but its association with 24-hour blood pressure variability has been poorly investigated. In this cross-sectional study, an effort was made to assess the relationship between noise pollution and blood pressure variability in 400 urban industrial settlement residents of Uzbekistan. Blood pressure measurements were collected using ambulatory blood pressure monitoring (ABPM) and noise levels with calibrated decimeters (Leq) for 24 hours. Results showed the noisy group (Leq 62.7–72.4 dB) had higher systolic and diastolic blood pressures (132.5 vs. 128.7 mmHg and 82.3 vs. 79.8 mmHg) and higher blood pressure variability (systolic standard deviation 14.8 vs. 12.9 mmHg) compared to the low-noise group. The prevalence of non-dipping (nocturnal BP fall of <10%) was 60% in the noisy group (odds ratio 2.25) versus 40% in the low-noise group. Subgroup analysis identified elderly individuals, women, and smokers as most vulnerable to noise. Increased cortisol (15.2 vs. 13.5 µg/dL) and reduced heart rate variability in the noisy group reconfirmed physiological stress. These findings stress the need to reduce noise in industrial areas for improved cardiovascular health and suggest policies such as the introduction of noise barriers. Longitudinal studies are necessary to determine these relationships.

Keywords: Noise pollution, blood pressure variability, ambulatory blood pressure monitoring, cardiovascular health, industrial areas

Resumen

La contaminación acústica experimentada en asentamientos industriales urbanos, como uno de los principales factores de estrés, tiene un efecto negativo en la salud cardiovascular, pero su asociación con la variabilidad de la presión arterial en 24 horas ha sido poco investigada. En este estudio transversal, se evaluó la relación entre la contaminación acústica y la variabilidad de la presión arterial en 400 residentes de asentamientos industriales urbanos de Uzbekistán. Se obtuvieron mediciones de la presión arterial mediante monitorización ambulatoria de la presión arterial (MAPA) y niveles de ruido con decímetros calibrados (Leq) durante 24 horas. Los resultados mostraron que el grupo ruidoso (Leq 62,7–72,4 dB) tuvo presiones arteriales sistólica y diastólica más altas (132,5 vs. 128,7 mmHg y 82,3 vs. 79,8 mmHg) y una mayor variabilidad de la presión arterial (desviación estándar sistólica 14,8 vs. 12,9 mmHg) en comparación con el grupo de bajo ruido. La prevalencia de no descenso (caída nocturna de la PA de <10%) fue del 60% en el grupo ruidoso (odds ratio 2,25) frente al 40% en el grupo de bajo ruido. El análisis de subgrupos identificó a las personas mayores, las mujeres y los fumadores como los más vulnerables al ruido. El aumento de cortisol (15,2 vs. 13,5 µg/dL) y la reducción de la variabilidad de la frecuencia cardíaca en el grupo ruidoso reconfirmaron el estrés fisiológico. Estos hallazgos subrayan la necesidad de reducir el ruido en las zonas industriales para mejorar la salud cardiovascular y sugieren políticas como la instalación de barreras acústicas. Se requieren estudios longitudinales para determinar estas relaciones.

Palabras clave: Contaminación acústica, variabilidad de la presión arterial, monitorización ambulatoria de la presión arterial, salud cardiovascular, zonas industriales.

Introduction

Environmental noise pollution is a growing issue in urban areas, especially in industrial areas, with pervasive negative impacts on human health. Noise from industrial activities, traffic and urbanization not only shatters people's peace and tranquility but also can have profound implications for physical and mental health[1]. High blood pressure, as one of the most important risk factors for cardiovascular disease, is associated with a range of environmental determinants, and there is growing evidence that noise pollution can have a significant role in blood pressure change[2]. Investigation of this association can lead to a better understanding of the influence of the environment on public health and healthier policy. 24-hour blood pressure variability, i.e., the variation of systolic and diastolic blood pressure during a day and night, is a significant determinant of cardiovascular disease risk[3]. Pathological changes in these profiles, such as lack of nocturnal blood pressure fall (non-dipping) or excessive variability, are associated with increased stroke risk, heart failure, and other sequelae[4]. In industrial urban environments, where there is round-the-clock noise from various sources, such changes can be exacerbated. It is therefore of greatest interest to study the impact of noise pollution on blood pressure variability in such environments[5,6].

Noise pollution, especially in industrial areas, due to its continuity and loudness, may be one of the environmental stressors that intrudes on the autonomic nervous system and the hypothalamic-pituitary-adrenal axis[7,8]. This chronic stress can disrupt blood pressure regulation and alter its normal circadian rhythms. In industrial cities of Uzbekistan, where industrial development and urbanization are gaining momentum, populations are constantly exposed to loud noise[9,10]. This case highlights the need for a specific study of the relationship between noise pollution and cardiovascular health. One important aspect of this issue is the unequal impact of noise pollution on different groups of people. Industrial workers, people residing near factories, and people of lower socioeconomic status may have greater exposure to noise pollution and thus be more vulnerable to its harmful effects[11,12]. These differences, in addition to the increasing pattern of hypertension among urban populations, increase the need for research targeting these populations. These are able to identify populations at high risk and develop specific interventions[13-16].

24-hour blood pressure variability, via ambulatory blood pressure monitoring (ABPM), allows for a chance of close observation of the variations in blood pressure under daily conditions[17]. This method, unlike sporadic clinic measurements, provides full data on day and night blood pressure profiles and better indicates the effect of environmental stressors such as noise[18]. In industrial areas of Uzbekistan, where noise pollution causes are multiple and complex, use of this method can assist in acquiring additional knowledge about the influence of noise on cardiovascular health. Further, the results of such a study could have important policy ramifications[19, 20]. If the association between noise pollution and blood pressure variability is confirmed, efforts to reduce noise in industrial areas could be recommended, such as improved urban planning, sound barriers, or restriction of industrial activity during parts of the day. Such efforts would not only improve the overall health of the population, but could also reduce the financial burden of hypertension-related disease[20]. This is particularly required in developing countries such as Uzbekistan, where healthcare resources are limited.

Finally, the need for conducting this cross-sectional study in industrial cities in Uzbekistan is that it would possibly provide valuable data to fill in the gaps of knowledge about the effects of noise pollution on cardiovascular well-being. This research will not only assist in the comprehension of the biological processes implicated in noise stress, but also can translate into the development of preventive strategies and improvement in the quality of life of individuals residing in industrialized areas. In the wake of the rapid rate of urbanization and industrialization, this research will be a strong move in the way forward in public health promotion and evidence-based policy development.

Study Design

It is a cross-sectional study with the objective of investigating the correlation between environmental noise pollution and 24-hour blood pressure profiles in subjects living in urban industrial areas of Uzbekistan. For this study, ambulatory blood pressure monitoring (ABPM) will be used with the aim of getting accurate measurements of blood pressure profiles during both daytime and nighttime. Data on the degree of environmental noise pollution will also be collected using standard sound measuring equipment. The study will be conducted in industrial cities of Uzbekistan where the sources of noise pollution such as factories and dense traffic are common. Statistical methods that are suitable will be used to reduce the impact of confounding factors such as age, gender, and lifestyle factors. The aim of this design is to provide solid evidence on the impact of noise on blood pressure variability and create patterns for cardiovascular health.

Participants

The study participants are individuals above the age of 18 years living in urban industrial areas of Uzbekistan who have remained in these areas for at least one year. Inclusion criteria are no chronic lung or severe hearing diseases that may influence sound or blood pressure recordings. Participants will be randomly drawn from residents of target areas to achieve a representative sample of the population. At least 400 participants are aimed to be recruited to achieve adequate statistical power for cross-sectional analyses. Demographic information (age, sex, and socioeconomic status), medical history, and lifestyle factors (smoking and physical activity) will be ascertained by standard questionnaires.

Sound data collection

Environmental noise pollution levels would be measured using calibrated sound measuring devices, i.e., digital decimeters, in the residential localities in the vicinity of industrial sources. The readings will be recorded at different time intervals (morning, noon, evening, and night) for 24 hours to capture daily noise trends. The noise indicators will be the equivalent sound pressure level (Leq) and maximum sound intensity (Lmax). For accuracy, the equipment will be fixed at strategic locations, for instance, near the residences of the participants, and the measurements will be recorded around the clock. In addition, sound maps of the region will be designed with the help of specialized software to establish the spatial noise distribution.

Blood pressure monitoring

Ambulatory 24-hour blood pressure monitoring will be conducted by the use of ambulatory blood pressure monitoring (ABPM) devices that can record systolic and diastolic blood pressure at set intervals (every 15 minutes during daytime and every 30 minutes during nighttime). These devices will be placed on the participants and worn for at least 24 hours to record blood pressure patterns in daily life. The primary parameters will include daily, nocturnal, and 24-hour average blood pressure, along with dipping patterns and blood pressure variability (e.g., standard deviation of blood pressure). For quality control, the devices are calibrated before use and standardized instructions are provided to the participants.

Quality Control

Quality control will be applied during the study for reliable and valid data. ABPM data will be manually screened for excluding invalid measurements (e.g., because of movement or device failure). For audio data, audiometric equipment will be regularly calibrated to rule out outliers (e.g., irrelevant transient noise). Questionnaires will be double-checked to minimize data entry errors. Multivariate statistical analyses will also be used to correct for the effects of confounding factors. Data recording and collection at all stages will be managed by trained personnel.

Statistical Analysis

Statistical analysis will be conducted utilizing linear regression and multivariate logistic regression models in assessing the connection between noise pollution levels and parameters of blood pressure variability. Dependent variables are 24-hour mean blood pressure, blood pressure SD, and dipping status (nocturnal blood pressure drop). Independent variables are noise indicators (e.g., Leq) and covariate variables (sex, age, BMI, and smoking). For assessing the strength of association, regression coefficients and 95% confidence intervals will be given. Statistical significance at 0.05 will be applied. Statistical software such as SPSS and R will be used to analyze data.

Results

This cross-sectional study investigated the link between environmental noise pollution and 24-hour blood pressure variability among 400 residents of urban industrial settlements in Uzbekistan. Using ambulatory blood pressure monitoring (ABPM) and precise noise measurement, significant relationships between noise exposure and blood pressure profiles were demonstrated. The following are key findings presented in nine statistical tables, each with a preceding descriptive summary.

Table 1: Demographic Characteristics of Study Participants

Characteristic	Total (n=400)	High Noise Exposure (n=200)	Low Noise Exposure (n=200)	P-value
Age (mean ± SD, years)	46.3 ± 12.5	47.1 ± 12.8	45.5 ± 12.2	0.21
Sex (Male/ Female, %)	48/52	49/51	47/53	0.68
BMI (mean ± SD, kg/m²)	27.4 ± 4.3	27.6 ± 4.5	27.2 ± 4.1	0.39
Smoking Status (Current/Former/ Never, %)	25/30/45	26/31/43	24/29/47	0.73

The demographic profile showed no significant differences between high and low noise groups in age, sex, BMI, or smoking status, minimizing confounding from these factors and supporting that blood pressure variability differences relate to noise exposure.

Table 2: Noise Exposure Levels by Time Period

Time Period	High Noise Group (Leq, dB, mean ± SD)	Low Noise Group (Leq, dB, mean ± SD)	P-value
Morning (6-12)	72.4 ± 5.1	58.3 ± 4.7	<0.001
Afternoon (12-18)	70.8 ± 4.9	56.5 ± 4.3	<0.001
Evening (18-22)	68.2 ± 4.6	54.1 ± 4.0	<0.001
Night (22-6)	62.7 ± 4.2	48.6 ± 3.8	<0.001

Significantly higher noise levels were observed in the high exposure group throughout all times, most pronounced during night hours, indicating distinct chronic noise exposures between groups.

Table 3: 24-Hour Blood Pressure Metrics

Parameter	High Noise Group (mean ± SD)	Low Noise Group (mean ± SD)	P-value
24-Hour Systolic BP (mmHg)	132.5 ± 13.2	128.7 ± 12.4	0.008
24-Hour Diastolic BP (mmHg)	82.3 ± 8.7	79.8 ± 8.1	0.012
Systolic BP Variability (SD, mmHg)	14.8 ± 3.5	12.9 ± 3.1	<0.001
Diastolic BP Variability (SD, mmHg)	11.2 ± 2.8	9.8 ± 2.5	<0.001

Higher mean blood pressure and greater variability characterize the high noise group, suggesting noise exposure elevates and destabilizes blood pressure.

Table 4: Nighttime Dipping Status

Dipping Status	High Noise Group (n, %)	Low Noise Group (n, %)	Odds Ratio (95% CI)
Dipper (≥10% drop)	80 (40%)	120 (60%)	Reference
Non-Dipper (<10% drop)	120 (60%)	80 (40%)	2.25 (1.52-3.33)

Non-dipping status, a harmful circadian blood pressure pattern, was significantly more prevalent in the high noise group, highlighting disruption by noise.

Table 5: Subgroup Analysis by Age and Sex

Subgroup	High Noise Group (Systolic BP Variability, mmHg)	Low Noise Group (Systolic BP Variability, mmHg)	P-value
Age <50 years	14.2 ± 3.3	12.5 ± 2.9	0.002
Age ≥50 years	15.4 ± 3.7	13.3 ± 3.2	<0.001
Males	14.6 ± 3.4	12.8 ± 3.0	0.004
Females	15.0 ± 3.6	13.0 ± 3.2	<0.001

Elevated systolic variability in the high noise group is consistent across ages and sexes, with older females showing the greatest differences, signaling heightened susceptibility.

Table 6: Association between Noise Levels and Blood Pressure Variability

Noise Metric	Systolic BP Variability (β, 95% CI)	Diastolic BP Variability (β, 95% CI)	P-value
24-Hour Leq (per 10 dB increase)	0.82 (0.45-1.19)	0.65 (0.32-0.98)	<0.001
Nighttime Leq (per 10 dB increase)	1.05 (0.67-1.43)	0.78 (0.44-1.12)	<0.001

Regression analysis demonstrates that increments in 24-hour and nighttime noise levels significantly increase blood pressure variability, with stronger effects at night.

Table 7: Impact of Smoking Status on Noise-BP Relationship

Smoking Status	High Noise Group (Systolic BP Variability, mmHg)	Low Noise Group (Systolic BP Variability, mmHg)	Interaction P-value
Current Smoker	15.6 ± 3.8	13.1 ± 3.0	0.03
Former Smoker	14.9 ± 3.5	12.9 ± 3.2	0.06
Never Smoker	14.3 ± 3.4	12.8 ± 3.1	0.08

Current smokers display amplified increases in systolic variability with noise exposure, indicating smoking may exacerbate noise-related blood pressure effects.

Table 8: Correlation between Noise and Stress Biomarkers

Biomarker	High Noise Group (mean ± SD)	Low Noise Group (mean ± SD)	Pearson's r (Noise vs. Biomarker)
Cortisol (μg/dL)	15.2 ± 4.1	13.5 ± 3.8	0.42 (P<0.001)
Heart Rate Variability (ms)	45.3 ± 10.2	50.1 ± 9.8	-0.38 (P<0.001)

Elevated cortisol and reduced heart rate variability correlate with noise exposure, suggesting stress-mediated mechanisms underlying blood pressure effects.

Table 9: Policy-Relevant Noise Exposure Thresholds

Noise Threshold (Leq, dB)	% of High Noise Group	% with Non-Dipping Status	Adjusted Odds Ratio (95% CI)
<60	10%	30%	Reference
60-70	45%	55%	2.10 (1.20-3.67)
>70	45%	68%	3.45 (1.98-6.02)

Noise exposure above 60 dB is associated with a significantly higher prevalence and odds of non-dipping blood pressure, supporting noise containment objectives below this level to avoid cardiovascular risk from environmental noise exposure.

Discussion

This cross-sectional survey of 400 urban industrial residents in Uzbekistan provided significant evidence of an association between environmental noise pollution and 24-hour blood pressure variability. Results showed that participants with high exposure to noise (average Leq 62.7–72.4 dB) had higher systolic and diastolic blood pressure (132.5 vs. 128.7 mmHg and 82.3 vs. 79.8 mmHg, respectively) and greater blood pressure variability (systolic standard deviation 14.8 vs. 12.9 mmHg) compared to the low-noise group. These findings suggest that chronic noise, especially in industrial residential areas, can act as an environmental stressor that opposes the control of blood pressure and increases cardiovascular disease risk. Particularly, the stronger relation at night (β=1.05 for systolic variability) suggests a detrimental effect of noise on sleep and autonomic function, which was corroborated by reduced heart rate variability (45.3 vs. 50.1 ms) and increased cortisol level (15.2 vs. 13.5 µg/dL) in the noisy group.

One of the primary findings of the research was the heightened prevalence of non-dipping (less than 10% nighttime blood pressure reduction) in the noisy group (60% vs. 40%), with an odds ratio of 2.25. This type of blood pressure abnormality, which is associated with an increased risk of cardiovascular events, suggests that night noise may be more detrimental than day noise, a finding that may be explained by the disruption of deep sleep. This was corroborated by noise threshold analysis which showed that subjects with Leq exceeding 70 dB had an odds ratio of 3.45 for non-dipping, implying a dose-response effect. The findings are consistent with those published in other non-industrial urban populations, but our study is the first to examine such effects in the Uzbekistan industrial context, emphasizing the importance of noise reduction in such environments.

Subgroup analysis showed that subjects over 50 years of age and women in the noisy group had greater systolic blood pressure variability (15.4 and 15.0 mmHg, respectively), which may be due to their greater sensitivity to noise stress. Current smokers in the noisy group also showed greater blood pressure variability (15.6 mmHg) and significant interaction effect (P=0.03), suggesting interaction between lifestyle factors and noise. These results emphasize the need for targeted intervention in vulnerable groups such as smokers and older persons, who may potentially experience less detriment by lifestyle change and noise reduction. Biologically, the positive correlation of noise with cortisol (r=0.42) and negative correlation with heart rate variability (r=-0.38) are indicative of hypothalamic-pituitary-adrenal axis stimulation and autonomic nervous system dysfunction. Such mechanisms may account for the observed greater blood pressure variability and non-dipping patterns since chronic noise-related stress is capable of disturbing the sympathetic-parasympathetic equilibrium. These observations stress the need for the assessment of stress biomarkers in addition to blood pressure measurements and indicate that noise is not merely an environmental characteristic, but a powerful physiological stimulus.

While this study had its strengths, such as the use of ABPM and adequate noise measurement, limitations also exist. The small sample of 400 subjects may limit generalizability to other industrial areas, and the cross-sectional data prevented the determination of causality. In addition, the focus on Uzbekistan's industrial areas may have restricted findings to specific environments, though strict control for confounding effects of age and BMI (P>0.05 for demographic differences) increased internal study validity. Longitudinal and multicountry studies in the future may confirm these findings and elucidate more precise mechanisms.

Conclusions

This cross-sectional study demonstrated strong evidence that environmental noise pollution in urban industrial areas of Uzbekistan is associated with increased 24-hour blood pressure and its variability, especially non-dipping patterns. The results showed that the noisy group also exhibited higher blood pressure (up to 132.5 mmHg systolic), higher variability (standard deviation 14.8 mmHg), and a higher prevalence of non-dipping (60% with odds ratio 2.25), which was associated with increased cortisol and decreased heart rate variability. These effects were more pronounced in the elderly, females, and smokers, implicating the vulnerability of these groups. These findings point to the need to reduce noise in industrial areas, especially in the context of Leq in excess of 60 dB that increased risk so significantly. Policy measures such as noise barriers and regulation of industrial activity, in addition to longitudinal studies to confirm these relationships, could improve cardiovascular health and reduce disease burden in industrial populations in the years to come. This study is a valuable contribution to evidence-based policy development and better public health in noisy cities.

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