14th ICBEN 2023 18 - 22 JUNE BELGRADE

14th ICBEN Congress on Noise as a Public Health Problem

Road, air, and rail traffic noise and the prevalence of hypertension and diabetes in Sofia, Bulgaria: A population-based study

Angel M. Dzhambov[1,2], Veronika Dimitrova[3], Nevena Germanova[4], Angel Burov[2,5], Danail Brezov[6], Reneta Dimitrova[7,8]

[1] Department of Hygiene, Faculty of Public Health, Medical University of Plovdiv, Bulgaria
[2] Research group "Health and quality of life in a green and sustainable environment", SRIPD, Medical University of Plovdiv, Plovdiv, Bulgaria
[3] Department of Sociology, Faculty of Philosophy, Sofia University "St. Kliment Ohridski", Bulgaria
[4] Department of Spatial and Strategic Planning of Sofia Municipality - Sofiaplan, Bulgaria
[5] Department of Urban Planning, Faculty of Architecture, University of Architecture, Civil Engineering and Geodesy, Bulgaria
[6] Department of Mathematics, Faculty of Transportation Engineering, University of Architecture, Civil Engineering and Geodesy, Bulgaria
[7] Department of Meteorology and Geophysics, Faculty of Physics, Sofia University "St. Kliment Ohridski", Bulgaria
[8] National Institute of Geophysics, Geodesy and Geography—Bulgarian Academy of Sciences, Bulgaria

Corresponding author's e-mail address: angelleloti@gmail.com ; angel.dzhambov@mu-plovdiv.bg

ABSTRACT (Font Arial 11 Bold Upper Case)

Traffic noise is a recognized risk factor for cardiometabolic diseases, but there have been no representative epidemiological studies in Bulgaria. Bulgaria has a high background disease prevalence, and the capital city of Sofia has one of the highest percentages of people exposed to and annoyed by high noise levels in Europe. To address this gap in the literature, we undertook a study on the associations between traffic noise and the prevalence of hypertension and diabetes. In the period July-December 2022, we conducted a population-based representative cross-sectional survey in Sofia. A stratified random sample of 917 adult participants (18-65 years; 53.65% female) who had not changed their residential address for at least five years was collected within predefined clusters based on spatial typology. Hypertension and diabetes status was ascertained through self-reported diagnosis and/or medication use. Residential road, air, and rail traffic day–evening–night noise levels were available from the polygon strategic noise maps of Sofia from 2017. We also collected information on potential confounders and effect modifiers including socio-demographics, individual and area-level income, urbanicity level, duration of residence, time spent at home, and family history of the disease. In this paper, we will present the results of a series of main and stratified logistic regression models. Preliminary findings suggest that while effect estimates in the main models are non-significant, in some subgroups, aircraft noise is associated with higher odds of hypertension. These findings will represent the first generalizable evidence on the subject in Bulgaria.

Keywords: Cardiovascular Disease, High Blood Pressure, Residential Noise

INTRODUCTION

Bulgaria has the highest standardized death rate in Europe [1], especially from cardiovascular diseases, for which arterial hypertension and diabetes mellitus are major risk factors [2]. This is largely due to the ageing population and relatively low socioeconomic standard. At the same time, EU noise maps indicate that almost the entire population of major agglomerations is exposed to harmfully high road traffic noise levels above 55 dB(A) [3], above which the WHO considers the risk of cardiovascular diseases and diabetes materially important [4]. The capital Sofia, in particular, has the highest percentage (6.7%) of annual ischemic heart disease deaths attributable to road traffic noise, as well as of highly annoyed citizens in Europe (25%) [3]. Against this background, there have been almost no studies on environmental noise and hypertension/diabetes in the country, and even the few exceptions were of suboptimal design (i.e., small, convenience samples, and poor exposure assessment) [5]. To address this gap in the literature, we undertook a study on the associations between traffic noise and the prevalence of hypertension and diabetes in Sofia, Bulgaria.

MATERIALS AND METHODS

Study Design

We conducted a cross-sectional survey in Sofia, Bulgaria, in the period July 16 – December 7, 2022. Participants were sampled from predefined spatial typology classes, to ensure sufficient variation in environmental exposures. A professional survey company carried out face-to-face interviews among 917 adults (16% response rate) aged 18-65 years who had lived at their address for at least five years.

The study design was approved by the Ethics Commission at Sofia University "St. Kliment Ohridski" (№ 61-13-8/01.07.2022). The study complied with established ethical principles, participants gave verbal informed consent, and their personal information was processed according to the General Data Protection Regulation in the EU.

Health Outcomes

The presence of arterial hypertension and diabetes mellitus was self-reported. Participants were asked whether they had been diagnosed by a physician with the disease and/or whether in the last year they had been prescribed medication for high blood pressure or diabetes.

Traffic Noise

Road traffic, railway, and aircraft L_{den} levels were extracted from the strategic noise maps of

Sofia delivered under the END for the year 2017 (https://cdr.eionet.europa.eu/bg/eu/noise/df8/2017). These maps were delivered in polygon format (5-dB(A) bands) with spatial resolution of 10 m x 10 m, and modeling was done at 4 m above the ground level based on short-term calibration measurements, data on traffic characteristics, infrastructure, urban fabric, and meteorology. Each residential address was intersected with the respective polygon. L_{den} was modelled down to a minimum of 10 dB(A). For aircraft and railway L_{den}, addresses outside the modeled noise contours were assigned a value of < 10 dB(A). As a sensitivity analysis, we merged aircraft and railway Lden values < 30 dB(A), to test whether potentially low accuracy of the acoustic modeling at very low levels has affected the results. Figure 1 shows participants' home addresses overlaying L_{den} maps.

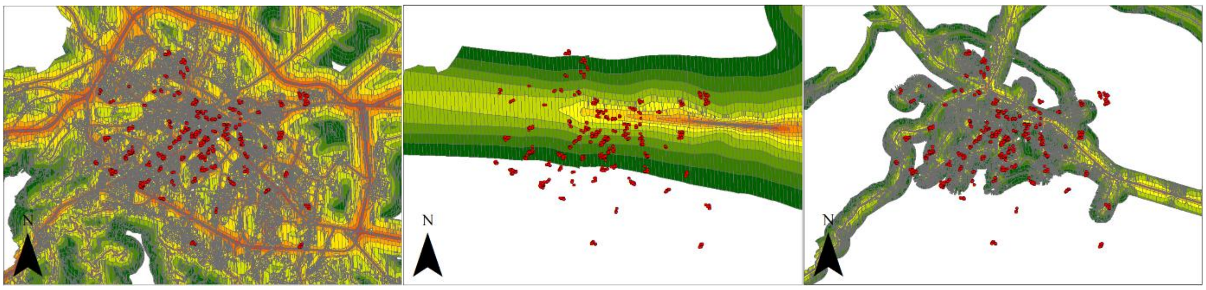

Figure 1. Residential addresses across road (left panel), aircraft (middle panel) and railway (right panel) EU noise maps of Sofia, Bulgaria

Confounders and Effect Modifiers

We also collected information on participant's age, gender, ethnicity, education, and perceived economic struggle. Family history of hypertension and diabetes, orientation of the rooms in the home, and duration of residence were also recorded. City district income and average building height in a 50 m buffer around the address were also available. NO2 was modeled at a resolution of 20 m x 20 m using inverse-distance weighted interpolation from the primary and secondary street network, based on measurement in 2021 with passive diffusion tubes at 27 locations.

Statistical Analysis

Associations between L_{den} and hypertension and diabetes were examined with logistic regressions. L_{den} from different sources was tested in single-exposure models first, and then in multi-exposure models. Model 1 controlled for age and gender, Model 2 was additionally adjusted for other socio-demographics, district-level income and building height, and Model 3 was additionally adjusted for NO_2 instead of district-level income and building height. To account for the complex sampling scheme, standard errors were adjusted for 95 clusters. Effect modifiers and interaction terms were tested with the adjustments from Model 2.

The analyses were conducted in Stata/MP (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC). A p-value of < 0.05 was considered statistically significant, except in effect modification tests, for which we adopted a level of 0.1.

RESULTS

Table 1 shows participants' characteristics. Out of the 917 participants included in the study, the majority were Bulgarians and had at least high school education. In terms of age and gender, the sample was representative of the general population of Sofia. One quarter reported a hypertension diagnosis or taking prescription medication for high blood pressure, and 7% were classified as diabetic. Traffic noise levels ranged 45-80 dB(A) for road traffic L_{den}, 10-65 dB(A) for railway L_{den}, and 10-50 dB(A) for aircraft L_{den}. Figure 2 shows the distribution of L_{den} from different traffic sources. Road traffic and railway were weakly correlated L_{den} (ρ = 0.14), while correlations between aircraft and railway L_{den} were stronger (ρ = 0.33). There was no materially important correlation between and road traffic and aircraft L_{den} (ρ = 0.01).

Table 1. Study population characteristics (N = 917)*

Characteristics		
Age [years] (mean, SD)		44.51 (14.37)
Male (n, %)		425 (46.3)
Bulgarian (n, %)		866 (94.5)
Education (n, %)		
	Basic or lower	50 (5.5)
	High school or vocational	395 (43.1)
	University degree	466 (50.8)
Economic struggle [1-6 scale] (mean, SD)		3.44 (1.04)
Hypertension prevalence (n, %)		221 (24.6)
Diabetes prevalence (n, %)		66 (7.2)

*Some variables contain missing data, therefore valid percentages are reported

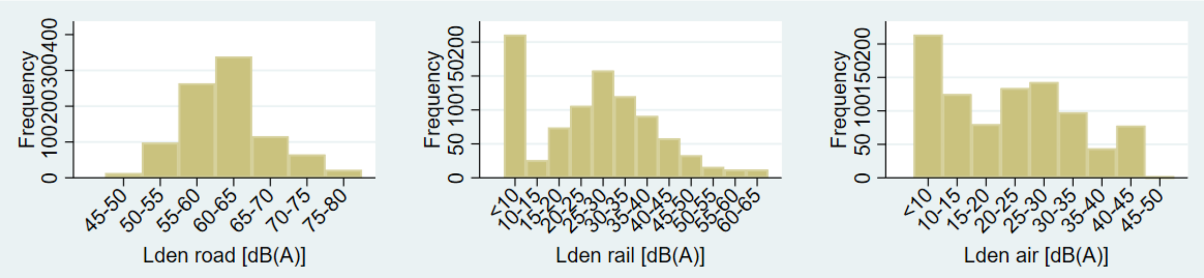

Figure 2. Distribution of traffic noise levels in the study

Table 2 shows results of single- and multi-exposure associations with hypertension and diabetes. Only aircraft L_{den} was consistently positively associated with higher prevalence of hypertension across different model adjustments. In the fully-adjusted multi-exposure model, aircraft L_{den} came close to reaching statistical significance. On the other hand, railway L_{den} was significantly associated with lower odds of hypertension. In the models with diabetes, none of the exposures was associated with prevalent diabetes.

Stratification of the single-exposure Model 2 by participants' characteristics revealed some interesting patterns. With respect to hypertension, road traffic and aircraft noise exposure were associated with higher odds of hypertension in middle-aged people, while railway noise was again associated with lower hypertension prevalence. Accommodation floor was an effect modifier for road traffic noise (p = 0.077), with people living on higher floors having higher odds of hypertension /non-significant though/.

Both accommodation floor and family history acted as effect modifiers (p = 0.061 and 0.023, respectively) in the models with diabetes. Moreover, effect sizes reached statistical significance within some strata – diabetes was related to higher road traffic noise in people with basic or lower education, and with railway noise in those living on lower floors and those having a family history of diabetes.

Table 2. Associations between traffic noise and prevalent hypertension and diabetes

	Model 1	Model 2	Model 3
Single-exposure models		**Hypertension**	
L_{den} road	0.97 (0.85, 1.12)	0.97 (0.84, 1.11)	0.96 (0.83, 1.10)
L_{den} aircraft	1.04 (0.96, 1.14)	1.03 (0.92, 1.13)	1.03 (0.94, 1.14)
L_{der} railway	0.95 (0.88, 1.02)	**0.93 (0.87, 1.00)***	**0.92 (0.86, 0.99)***
Multi-exposure models			
L_{den} road	1.01 (0.87, 1.17)	1.00 (0.86, 1.17)	1.00 (0.86, 1.17)
L_{den} aircraft	1.07 (0.97, 1.17)	1.05 (0.95, 1.16)	1.06 (0.96, 1.18)
L_{den} railway	0.93 (0.86, 1.01)	**0.92 (0.85, 0.99)***	**0.85 (0.85, 0.98)***
Single-exposure models		**Diabetes**	
L_{den} road	0.98 (0.78, 1.22)	0.98 (0.77, 1.23)	0.98 (0.77, 1.24)
L_{den} aircraft	1.00 (0.88, 1.14)	0.96 (0.83, 1.10)	0.98 (0.84, 1.16)
L_{der} railway	1.03 (0.93, 1.13)	1.01 (0.93, 1.10)	1.02 (0.94, 1.11)
Multi-exposure models			
L_{den} road	0.96 (0.77, 1.21)	0.96 (0.76, 1.23)	0.96 (0.75, 1.22)
L_{den} aircraft	0.99 (0.85, 1.15)	0.95 (0.80, 1.12)	0.97 (0.81, 1.17)
L_{den} railway	1.03 (0.92, 1.15)	1.02 (0.92, 1.14)	1.03 (0.93, 1.14)

Model 1 is adjusted for age and gender, Model 2: Model 1 + ethnicity, education, perceived economic struggle, district income, building height; Model 3: Model 1 + ethnicity, education, perceived economic struggle, NO_2. Analysis sample size may vary depending on missing data.

Table 3. Stratified associations between traffic noise and prevalent hypertension

Stratification factors	L_{den} road	L_{den} aircraft	L_{den} railway
Gender			
Male (N=415)	1.02 (0.80, 1.30)	1.05 (0.92, 1.20)	0.92 (0.82, 1.02)
Female (N=478)	0.92 (0.74, 1.14)	1.01 (0.89, 1.15)	0.95 (0.87, 1.05)
Age			
18-29 (N=178)	0.47 (0.21, 1.02)	0.94 (0.69, 1.29)	0.99 (0.84, 1.16)
30-39 (N=167)	**3.28 (1.21, 8.93)***	**1.54 (1.02, 2.33)***	0.78 (0.53, 1.14)
40-49 (N=172)	1.13 (0.81, 1.56)	**1.37 (1.05, 1.78)***	0.99 (0.88, 1.12)
50-59 (N=171)	1.05 (0.78, 1.43)	1.01 (0.87, 1.17)	0.96 (0.84, 1.10)
60-65 (N=201)	0.83 (0.64, 1.07)	0.89 (0.77, 1.02)	**0.84 (0.74, 0.95)***
Education			
Basic or lower (N=50)	1.51 (0.72, 3.17)	0.88 (0.65, 1.20)	0.92 (0.73, 1.17)
High school or vocational (N=381)	0.90 (0.72, 1.14)	1.02 (0.89, 1.19)	0.98 (0.89, 1.09)
University degree (N=454)	0.97 (0.81, 1.18)	1.04 (0.91, 1.20)	**0.89 (0.81, 0.97)***
Quiet room			
No (N=481)	0.97 (0.80, 1.18)	1.07 (0.95, 1.22)	0.98 (0.91, 1.06)
Yes (N=401)	0.98 (0.78, 1.22)	1.02 (0.88, 1.19)	**0.87 (0.77, 0.98)***
Accommodation floor			
1-2 floor (N=437)	**0.80 (0.64, 0.99)***	1.05 (0.93, 1.20)	0.97 (0.88, 1.06)
≥ 3 floor (N=454)	1.10 (0.90, 1.35)	0.98 (0.85, 1.12)	**0.90 (0.81, 0.99)***
Duration of residence			
< 20 yrs. (N=432)	1.07 (0.78, 1.46)	0.94 (0.81, 1.09)	0.96 (0.85, 1.08)
> 20 yrs. (N=461)	0.92 (0.78, 1.10)	1.03 (0.90, 1.17)	**0.91 (0.83, 0.99)***
Family history of hypertension			
No (N=488)	1.04 (0.80, 1.35)	1.08 (0.92, 1.27)	**0.89 (0.80, 1.00)***
Yes (N=383)	0.97 (0.79, 1.19)	1.04 (0.92, 1.17)	0.98 (0.89, 1.08)

Models are adjusted for age, gender, ethnicity, education, perceived economic struggle, district income, and building height 50 m, unless stratified by the respective factor. Analysis sample size may vary depending on missing data.

Table 4. Stratified associations between traffic noise and prevalent diabetes

Stratification factors	L_{den} road	L_{den} aircraft	L_{den} railway
Gender			
Male (N=418)	0.93 (0.68, 1.29)	0.92 (0.76, 1.12)	0.98 (0.86, 1.10)
Female (N=486)	1.04 (0.73, 1.47)	0.98 (0.82, 1.18)	1.05 (0.91, 1.21)
Age			
18-29	-	-	-
30-39 (N=160)	1.81 (0.76, 4.35)	1.89 (0.88, 4.03)	0.95 (0.62, 1.46)
40-49	-	-	-
50-59 (N=176)	1.16 (0.62, 2.15)	1.05 (0.81, 1.37)	1.00 (0.81, 1.22)
60-65 (N=207)	0.89 (0.66, 1.20)	0.85 (0.69, 1.04)	1.01 (0.91, 1.12)
Education			
Basic or lower (N=50)	**2.81 (1.05, 7.50)***	**0.03 (0.001, 0.54)***	1.10 (0.82, 1.48)
High school or vocational (N=393)	0.90 (0.65, 1.23)	0.93 (0.72, 1.21)	1.08 (0.95, 1.24)
University degree (N=455)	1.03 (0.71, 1.51)	1.00 (0.85, 1.19)	0.95 (0.83, 1.09)
Quiet room			
No (N=492)	1.06 (0.75, 1.50)	1.00 (0.79, 1.26)	1.02 (0.87, 1.20)
Yes (N=401)	0.95 (0.67, 1.35)	0.97 (0.76, 1.24)	1.06 (0.92, 1.23)
Accommodation floor			
1-2 floor (N=442)	0.86 (0.60, 1.24)	0.84 (0.68, 1.04)	**1.12 (1.00, 1.25)***
≥ 3 floor (N=460)	1.07 (0.80, 1.43)	1.06 (0.88, 1.28)	0.94 (0.81, 1.09)
Duration of residence			
< 20 yrs. (N=434)	0.95 (0.63, 1.43)	0.74 (0.40, 1.36)	1.17 (0.91, 1.49)
> 20 yrs. (N=470)	0.99 (0.76, 1.28)	0.98 (0.83, 1.17)	0.99 (0.90, 1.10)
Family history of diabetes			
No (N=753)	1.01 (0.73, 1.41)	0.87 (0.67, 1.12)	0.96 (0.85, 1.09)
Yes (N=131)	0.99 (0.63, 1.56)	1.16 (0.89, 1.53)	**1.30 (1.01, 1.67)***

Models are adjusted for age, gender, ethnicity, education, perceived economic struggle, district income, building height, unless stratified by the respective factor. Analysis sample size may vary depending on missing data.

DISCUSSION

This was the first population-based study on the associations between multiple traffic sources and prevalence of hypertension and diabetes in Bulgaria. Overall, we could not find convincing evidence of an association between traffic noise and hypertension and diabetes. While this may seem surprising, the literature is heterogeneous and generally points towards low quality evidence of harmfulness. In their WHO evidence review on traffic noise and cardiometabolic outcomes, van Kempen et al. reported 5% higher risk of hypertension per 10 dB(A) of all three traffic noise sources, based on cross-sectional evidence. However, the effect was only significant for road traffic noise (RR = 1.05; 95% CI: 1.02–1.08) [6]. Another meta-analysis of cohort and case-control studies calculated a 2% risk per 10 dB(A), which was borderline significant [7]. That is not to say that traffic noise does not raise the risk of hypertension, rather that methodological aspects of primary studies may attenuate the observed effect. For example, the use of energetic indicators such as L_{den} may not best capture the effect of other acoustic parameters relevant for cardiovascular disease [8]. Interestingly, for diabetes, a meta-analysis of cohort studies evidenced a pooled risk of 6%, 1%, and 2% per 10 dB(A) increase in road traffic, railway, and aircraft noise, respectively [9]. In the only study on the subject from Bulgaria [10], exposure to road traffic L_{den} of 71-80 dB was associated with OR = 4.49 (95% CI 1.38, 14.68). However, that study was underpowered, used a convenience sample, and even cruder exposure data than what was available here.

In contrast to the main models, we observed some associations, albeit inconsistent, suggesting that in specific subgroups traffic noise might be harmful. It is not straightforward to compare these findings to previous research. It does standard to reason that the association of railway noise with diabetes would be more pronounced in people with family history of diabetes, who are presumably more vulnerable, and in people living on lower floor, given the vibration that goes with railway noise [11]. Interestingly, however, the opposite was found for road traffic noise, where higher floors were associated with larger effect size. We cannot fully explain that beyond accommodation floor acting as a proxy for other unmeasured confounders related to building design or neighborhood infrastructure. It is possible that building characteristics, sound insulation, and window opening habits, which we did not account for here, have confounded the observed associations. It should also be noted that some of our stratified models were underpowered, especially for diabetes, given the sparse number of cases across strata (e.g., in younger age groups). This could have further contributed to our inability to discover important effect modification.

While this study has a number of strengths, such as its population-based design and sufficient range in exposure data, it also has a number of important shortcomings. First, it was of cross-sectional design, preventing causal inference. Even though we had information on both duration of residence and time since diagnosis with hypertension/diabetes, we could not test for time-windows, e.g., by focusing on a subgroup of participants for which the exposure preceded the outcome, since this would have further reduced statistical power even for the main analyses.

Second, given that there is no longer any doubt that traffic noise can cause cardiovascular diseases [12] and plausible evidence suggests that similar mechanisms via oxidative stress and systemic inflammation can lead to diabetes [13], we believe our null findings in the main models can be attributed to exposure and outcome misclassification. On the exposure side, noise data for Sofia was only available in polygon-format maps, meaning that it was rather coarse [3]. More nuanced continuous data may be needed to uncover meaningful associations with our outcomes. As for the outcomes, the sensitivity of self-reported hypertension and diabetes is not outstanding compared with clinical assessments [14,15], therefore, we have likely failed to identify a non-trivial proportion of cases with these conditions in the sample. We also lacked sufficient power to detect significant associations where a trend suggestive of harmfulness was found. While Bulgaria lacks readily available medical registers for linkage to survey data, ongoing advances in the development of an electronic healthcare system are expected to enable the use of validated diagnoses in future studies. Coupled with measurements of blood pressure and laboratory testing, this would improve the validity of disease status classification.

Third, we did not have information on other potential effect modifiers, such as noise sensitivity, hearing impairment, and time-activity patterns, to name a few. And yet, we believe that the present study is an important stepping stone towards generating generalizable evidence on the health impacts of traffic noise in Bulgaria, where the acoustic situation for many urban dwellers is a major cause for concern from a public health perspective [3].

CONCLUSION

There was no overwhelming evidence of an association between traffic noise and prevalent hypertension and diabetes in Sofia, Bulgaria. Only in specific subgroups, traffic noise from different sources might be harmful. Nevertheless, the present study is an important learning experience and thus a steppingstone towards understanding the health impacts of traffic noise in Bulgaria.

Acknowledgements

This study was funded by the Bulgarian National Science Found (BNSF), under project “Development of a methodology for assessing air quality and its impact on human health in an urban environment” (№ КП-06-Н54/2 – 15.11.2021).

REFERENCES

1. EUROSTAT. Cardiovascular diseases statistics. [displayed 23 December 2022]. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Cardiovascular_diseases_statistics
2. Strain WD, Paldánius PM. Diabetes, cardiovascular disease and the microcirculation. Cardiovasc Diabetol 2018;17(1):57.
3. Khomenko S, Cirach M, Barrera-Gómez J *et al*. Impact of road traffic noise on annoyance and preventable mortality in European cities: A health impact assessment. Environ Int 2022;162:107160.
4. World Health Organization. Environmental noise guidelines for the European Region. 2018. ISBN: 978-92-8-905356-3.
5. Dzhambov AM. Environmental noise and health research in Bulgaria (1970 – 2017). Bulgarian Medicine 2017;7(2):41-45.
6. Kempen EV, Casas M, Pershagen G, Foraster M. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cardiovascular and Metabolic Effects: A Summary. Int J Environ Res Public Health 2018;15(2):379.
7. Dzhambov AM, Dimitrova DD. Residential road traffic noise as a risk factor for hypertension in adults: Systematic review and meta-analysis of analytic studies published in the period 2011-2017. Environ Pollut 2018;240:306-318.
8. Lercher P, De Coensel B, Dekonink L, Botteldooren D. Community Response to Multiple Sound Sources: Integrating Acoustic and Contextual Approaches in the Analysis. Int J Environ Res Public Health 2017;14(6):663.
9. Liu C, Li W, Chen X *et al*. Dose-response association between transportation noise exposure and type 2 diabetes: A systematic review and meta-analysis of prospective cohort studies. Diabetes Metab Res Rev 2023;39(2):e3595.
10. Dzhambov AM, Dimitrova DD. Exposures to road traffic, noise, and air pollution as risk factors for type 2 diabetes: A feasibility study in Bulgaria. Noise Health 2016;18(82):133-42.
11. Maclachlan L, Ögren M, van Kempen E, Hussain-Alkhateeb L, Persson Waye K. Annoyance in Response to Vibrations from Railways. Int J Environ Res Public Health 2018;15(9):1887.
12. Münzel T, Sørensen M, Daiber A. Transportation noise pollution and cardiovascular disease. Nat Rev Cardiol 2021;18(9):619-636.
13. Münzel T, Kröller-Schön S, Oelze M *et al*. Adverse Cardiovascular Effects of Traffic Noise with a Focus on Nighttime Noise and the New WHO Noise Guidelines. Annu Rev Public Health 2020;41:309-328.
14. Molenaar EA, Van Ameijden EJ, Grobbee DE, Numans ME. Comparison of routine care self-reported and biometrical data on hypertension and diabetes: results of the Utrecht Health Project. Eur J Public Health 2007;17(2):199-205.
15. Xie D, Wang J. Comparison of self-reports and biomedical measurements on hypertension and diabetes among older adults in China. BMC Public Health 2020;20(1):1664.