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Environmental noise exposure and health outcomes: an umbrella review of systematic reviews and meta-analysis

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Background: Environmental noise is becoming increasingly recognized as an urgent public health problem, but the quality of current studies needs to be assessed. To evaluate the significance, validity and potential biases of the associations between environmental noise exposure and health outcomes. **Methods:** We conducted an umbrella review of the evidence across meta-analyses of environmental noise exposure and any health outcomes. A systematic search was done until November 2021. PubMed, Cochrane, Scopus, Web of Science, Embase and references of eligible studies were searched. Quality was assessed by AMSTAR and Grading of Recommendations, Assessment, Development and Evaluation (GRADE). **Results:** Of the 31 unique health outcomes identified in 23 systematic reviews and meta-analyses, environmental noise exposure was more likely to result in a series of adverse outcomes. Five percent were moderate in methodology quality, the rest were low to very low and the majority of GRADE evidence was graded as low or even lower. The group with occupational noise exposure had the largest risk increment of speech frequency [relative risk (RR): 6.68; 95% confidence interval (CI): 3.41–13.07] and high-frequency (RR: 4.46; 95% CI: 2.80–7.11) noise-induced hearing loss. High noise exposure from different sources was associated with an increased risk of cardiovascular disease (34%) and its mortality (12%), elevated blood pressure (58–72%), diabetes (23%) and adverse reproductive outcomes (22–43%). In addition, the dose–response relationship revealed that the risk of diabetes, ischemic heart disease (IHD), cardiovascular (CV) mortality, stroke, anxiety and depression increases with increasing noise exposure. **Conclusions:** Adverse associations were found for CV disease and mortality, diabetes, hearing impairment, neurological disorders and adverse reproductive outcomes with environmental noise exposure in humans, especially occupational noise. The studies mostly showed low quality and more high-quality longitudinal study designs are needed for further validation in the future.

Introduction

Environmental noise, an overlooked pollutant, is becoming increasingly recognized as an urgent public health problem in modern society.[1,2] Noise pollution from transportation (roads, railways and aircraft), occupations and communities has a wide range of impacts on health and involves a large number of people.[2–6] It is reported that environmental noise exposure may affect human health by influencing hemodynamics, hemostasis, oxidative stress, inflammation, vascular function and autonomic tone.[7–11] Prolonged noise exposure can cause dysregulation of sleep rhythms and lead to adverse psychological and physiological changes in the human body such as distress response, behavioral manifestations, cardiovascular (CV) disease and mortality, etc.[12–19] It is reported that environmental noise is second only to air pollution as a major factor in disability-adjusted life years (DALYs) lost in Europe.[20]

There have been many epidemiological studies and systematic reviews assessing the effects of environmental noise on health, but the quality of the evidence included in these reviews varies due to subjective or inconsistent evaluation criteria. Therefore, it is hard to contextualize the magnitude of the associations across health outcomes according to current reviews. To comprehensively assess the significance, validity and potential biases of existing evidence for any health outcomes associated with environmental noise, we performed an umbrella review of systematic reviews and meta-analyses.[21] The results may provide evidence for decision-makers in clinical and public health practice.

Methods

Search strategy

The umbrella review search followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[22] We searched systematic reviews and meta-analyses of observational or interventional studies studying the relationship between noise exposure and any health outcome from PubMed, Cochrane, Scopus, Web of Science and Embase databases to November 2021 (Supplementary tables S1 and S2). Pre-defined search strategy as follows: noise AND (systematic review* or meta-analysis*). Two researchers (X.C. and M.L.) independently screened qualified literature, and we also manually searched the references of qualified articles. Any discrepancies were resolved by a third investigator for the final decision (L.Z.).

Inclusion and exclusion criteria

Researches meeting the following criteria have been included: (1) Systematic reviews and/or meta-analyses of observational studies (cohort, case–control and cross-sectional studies) or interventional studies [randomized controlled trials (RCTs) and quasi-experimental studies]. (2) The exposure or intervention of meta-analysis and/or systematic reviews is 'noise'. We ruled out the following research: (1) Outcome is not a health outcome, such as students' examination scores. (2) Meta-analysis and/or systematic reviews only evaluated the combined effects of noise exposure and other risk factors on health outcomes and it is not possible to extract the separate effect of noise.

Data extraction

Four researchers (X.C., M.L., L.Z. and X.W.) independently extracted data from each eligible systematic review or meta-analysis. We extracted the following data from original articles: name of the first author; publication time; research population; type of noise and measurement method(s); the dose of noise exposure; study types (RCTs, cohort, case–control studies or cross-sectional); the number of studies included in the meta-analysis; the number of total participants included in each meta-analysis; the number of cases included in each meta-analysis; estimated summary effect (OR, odds ratio; RR, relative risk; HR, hazard ratio), with the 95% confidence intervals (CIs). We also extracted the type of effect model, publication bias by Egger's test, dose–response analyses, I^2, information on funding and conflict of interest. Any disagreement in the process of data extraction was settled through group discussion.

Quality of systematic review and strength of evidence

AMSTAR 2 is a measurement tool to assess the methodological quality of systematic reviews by 16 items.[23] The quality of the method was divided into four grades: 'high', 'moderate', 'low' and 'very low'.

For the quality of evidence for each outcome included in the umbrella review, we adopted the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) to make recommendations and to classify the quality of evidence.[24] The baseline quality of evidence is determined by the research design. The quality of evidence decreases when there is a risk of bias, inconsistency, indirectness, imprecision or publication bias in the article, while it can be elevated when there is the presence of magnitude of effect, plausible confounding and dose–response gradient.[25] The quality of evidence can also be divided into four levels: 'high', 'medium', 'low' or 'very low'.

Data analysis

Noise exposure was divided into six types: (1) transportation noise (combined road, railway or aircraft noise); (2) road noise; (3) railway noise; (4) aircraft noise; (5) occupational noise and (6) combined noise (two or more kinds of noise above or wind turbine noise, etc.). We divided the results into: (1) mortality; (2) CV outcome; (3) metabolic disorders; (4) neurological outcomes; (5) hearing disorder; (6) neonatal/infant/child-related outcomes; (7) pregnancy-related diseases and (8) others. When a systematic review and/or meta-analysis includes different exposures or outcomes, we extracted the data for each of the different types of exposure and health outcomes, respectively. When two or more systematic reviews and/or meta-analyses had the same exposure and health results, we selected the recently published research with the largest number of studies included.

The associations across studies were commonly measured with RR (or OR and HR). We recalculated the adjusted pooled effect values and corresponding 95% CIs by using the random-effects model by DerSimonian and Laird,[26] which takes into account heterogeneity both within and between studies. And all results were reported by RRs for simplicity in our study.

Based on I^2 statistics and the Cochrane Q test, we evaluated the heterogeneity of each study.[27] Due to I^2 being dependent on the study size, we therefore also calculated τ^2, which is independent of study size and describes variability between studies concerning the risk estimates.[28] Publication bias was estimated by Egger's test.[29] Pooled effects were also reanalyzed in articles that included only cohort studies in the sensitivity analysis.

Patient and public involvement

No patients contributed to this research.

Results

Features of meta-analysis

Our initial systematic retrieve recognized 5617 studies from PubMed, EMBASE, Web of Science, Cochrane and Scopus. The search finally yielded 64 meta-analyses of observational research in 23 articles with 31 unique outcomes after excluding duplicates or irrelevant articles,[30–52] and no interventional study was identified. Figure 1 shows the flow diagram of the literature search and study selection. The distribution of health outcomes from noise exposure is displayed in Supplementary figure S1. Most meta-analyses focused on road noise (16 meta-analyses) and the incidence of CV events (18 meta-analyses).

Most of the findings presented were expressed in terms of highest to lowest noise exposure, and statistically significant associations of noise exposure were identified with CV mortality and incidence of diabetes, elevated blood pressure (BP), CV disease, speech-frequency noise-induced hearing loss (SFNIHL), high-frequency noise-induced hearing loss (HFNIHL), work-related injuries, metabolic syndrome, elevated blood glucose, fetal malformations, small for gestational age, acoustic disturbance and acoustic neuroma. The associations of environmental noise exposure with the incidence of other outcomes [angina pectoris, myocardial infarction, ischemic heart disease (IHD), elevated triglyceride, obesity, low high-density lipoprotein cholesterol, perinatal death, preterm birth, gestational hypertension, spontaneous abortion and preeclampsia] were not statistically significant. Similarly, in dose–response analysis, statistical significance was achieved for harmful associations with CV mortality, stroke mortality, IHD mortality, non-accidental mortality and incidence of IHD, diabetes, anxiety, elevated BP, stroke, depression, work-

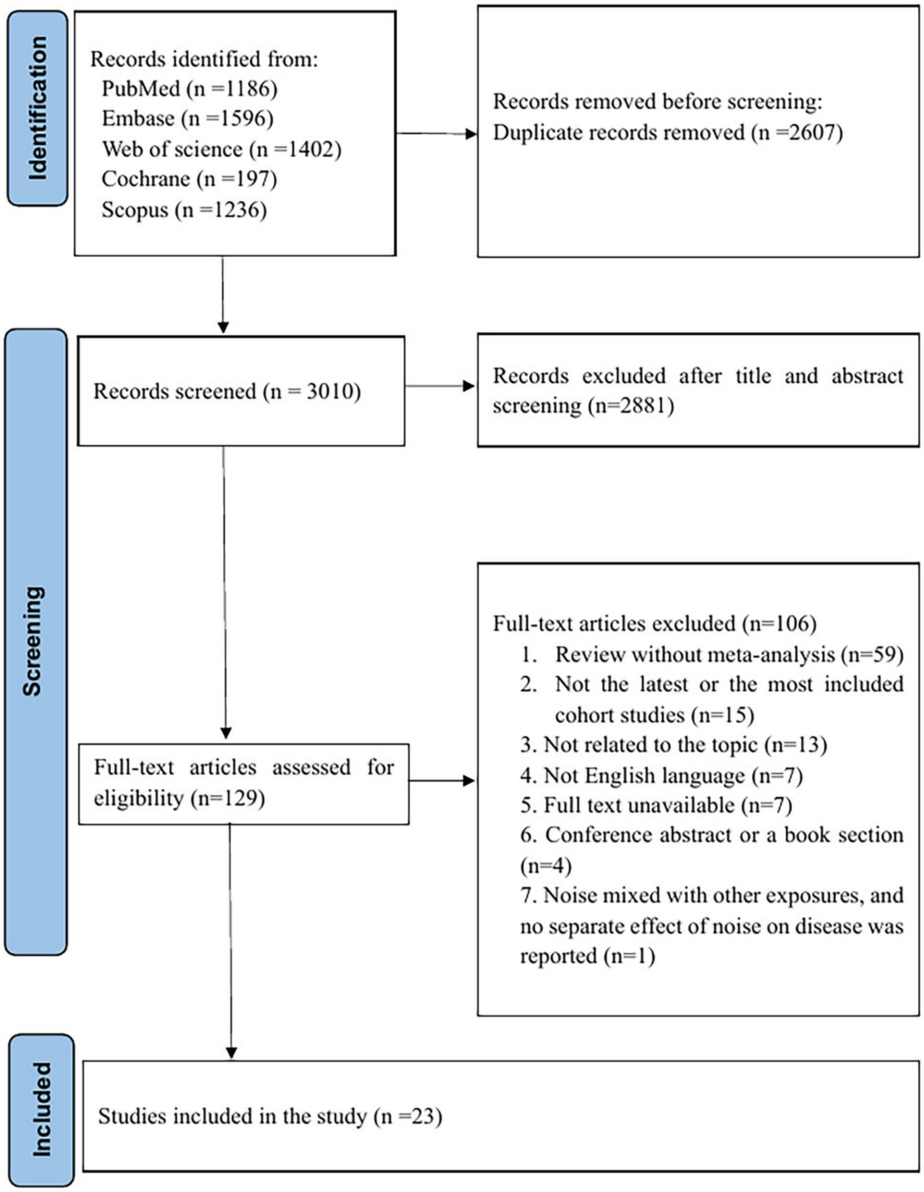

Figure 1 Study flowchart

related injuries, low birth weight, small for gestational age and preterm birth, whereas other outcomes were not significant.

Transportation noise

We identified four studies on transportation noise and health.[32,34,39,48] Transportation noise exposure might increase the risk of developing CV outcomes, metabolic disorders and neurological outcomes. Compared with individuals who had the lowest exposure to transportation noise, those with the highest exposure had a higher risk of diabetes (RR: 1.23; 95% CI: 1.10–1.38).[32] Dose–response analysis showed that an increase of 5 dB was associated with a 25% increase in diabetes risk.[39] When the noise exposure from transportation was per 10 dB increment, the risks of developing IHD[34] and anxiety[48] increased by 6% and 7%, respectively (Supplementary figure S2).

Road noise

Eight studies focused on the associations between road noise and health.[30,35,38,39,43,46,47,50] The highest exposure to road noise, compared with the lowest exposure, was associated with increased risks of developing CV outcomes, including angina pectoris (RR: 1.23; 95% CI: 0.80–1.89),[30] myocardial infarction (RR: 1.06; 95% CI: 0.96–1.16),[47] CV disease (RR: 1.06; 95% CI: 0.96–1.18),[30] and IHD (RR: 1.00; 95% CI: 0.79–1.27).[30] In the analysis of the dose–response relationship, the risk of incidence of diabetes increased by 7% for every 5 dB increase of road noise (RR: 1.07; 95% CI: 1.02–1.12).[39] Every 10 dB road noise increment could increase by 2–8% risk of mortality and incidence of diseases (including CV outcomes, neurological outcomes and neonatal-related outcomes), although the results did not reach statistical significance. The most significant harmful association was shown for stroke mortality (5%)[50] in mortalities, for elevated BP (2%)[35,38] in CV outcomes, for depression (2%)[46] in neurological outcomes and for low birth weight (8%)[43] in neonatal-related outcomes, but the estimates did not reach significance (figure 2).

Railway noise

Three studies focused on railway noise[39,46,50] and the results did not show a significant association with any health outcome (figure 3).

Aircraft noise

Six studies focused on aircraft noise and health.[30,33,39,44,46,50] Current evidence showed that aircraft noise exposure was associated with the

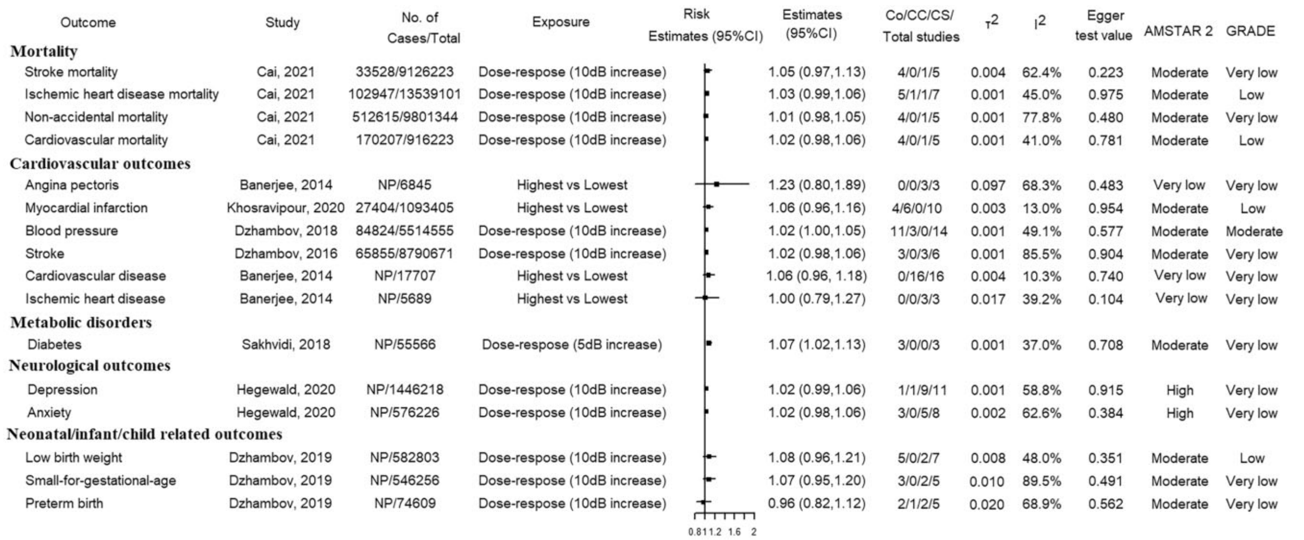

Figure 2 Associations between road noise exposure and health outcomes. Co: cohort; CC: case control; CS: cross-sectional and NP: not provide

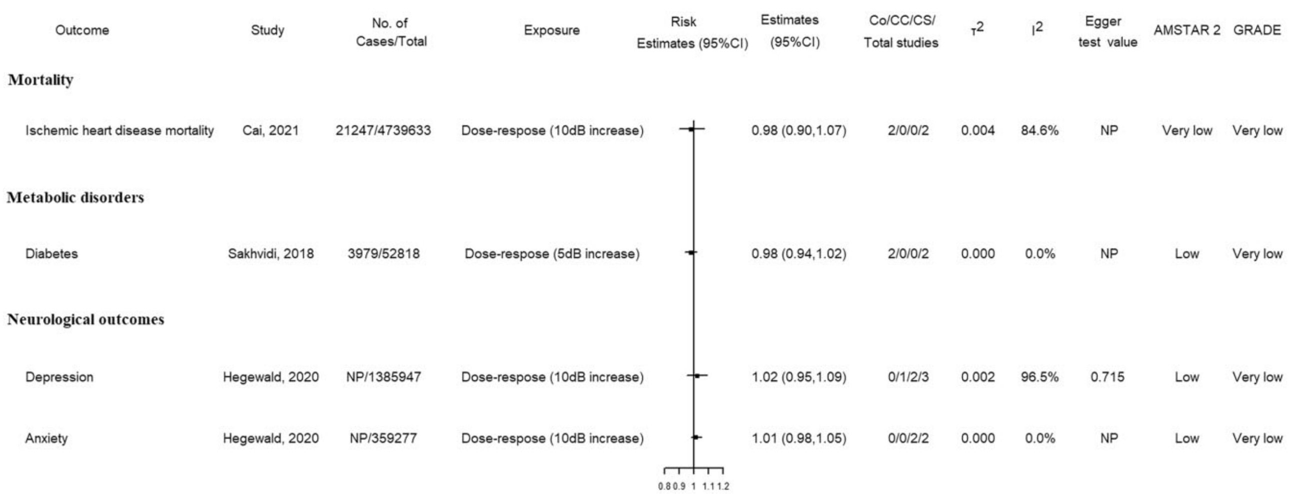

Figure 3 Associations between railway noise exposure and health outcomes. Co: cohort; CC: case control; CS: cross-sectional and NP: not provide

risk of CV mortality, and incidence of elevated BP, stroke, diabetes and neurological outcomes. People exposed to aircraft noise had an elevated BP (RR: 1.63; 95% CI: 1.14–2.33), compared with those non-exposed.[33] A dose–response analysis demonstrated that stroke risk increased by 1% for every 10 dB increase of aircraft noise. The risk of diabetes increased by 17% for every 5 dB increase of aircraft noise (RR: 1.17; 95% CI: 1.06–1.29).[39] With every 10 dB increase in noise, the risk of anxiety[50] and depression[46] increased by 22% and 14%, respectively. We did not find a significant association of aircraft noise exposure with other CV outcomes (figure 4).

Occupational noise

Eight studies focused on occupational noise,[32,36,37,42,45,49,52,53] and the study population of occupational noise exposure mainly came from workers in manufacturing, metals, transportation and mining. Occupational noise exposure increases the risk of mortality, and incidence of CV outcomes, hearing disorders and other diseases. The risk of SFNIHL was greatly attributed to occupational noise exposure (RR: 6.68; 95% CI: 3.41–13.07).[53] Similarly, those exposed to occupational noise showed an increased risk of CV disease (RR: 1.34; 95% CI: 1.15–1.56),[36] HFNIHL (RR: 4.46; 95% CI: 2.80–7.11),[53] and acoustic neuroma (RR: 1.26; 95% CI: 0.78–2.00),[42] compared with the non-exposed group. In addition, the highest exposed group had an increased risk of CV mortality (RR: 1.12; 95% CI: 1.02–1.24),[36] elevated BP (RR: 1.72; 95% CI: 1.46–2.01)[45] and work-related injuries (RR: 2.40; 95% CI: 1.89–3.04).[37] The risk of work-related injuries increased by 22% for every 5 dB increase in occupational noise (RR: 1.22; 95% CI: 1.15–1.29)[37] (Supplementary figure S3).

Combined noise

We identified six studies that combined various noise sources.[31,39–41,51,52] The findings suggested that combined noise or other noise might increase the risk of developing CV disease, metabolic disorders, neonatal-related disease, pregnancy-related and hearing disorders. Hearing impairment was statistically different between the exposed and non-exposed groups.[41,42] Compared with the lowest exposure group, the most harmful association was shown for metabolic syndrome (27%)[51] in metabolic disorders, fetal malformations (43%)[31] in neonatal-related outcomes and gestational hypertension (27%)[31] in pregnancy-related outcomes. Dose–response analysis showed that an increase of 5 dB was associated with a 6% increase in diabetes risk.[39] (Supplementary figure S4).

Outcome	Study	No. of Cases/Total	Exposure	Risk Estimates (95%CI)	Estimates (95%CI)	Co/CC/CS/ Total studies	τ^2	I^2	Egger test value	AMSTAR 2	GRADE
Mortality											
Cardiovascular mortality	Cai, 2021	226183/10100000	Dose-respose (10dB increase)		1.17 (1.10,1.25)	1/0/2/3	0.000	0.0%	0.747	Moderate	Very low
Stroke mortality	Cai, 2021	35034/10100000	Dose-respose (10dB increase)		1.06 (0.93,1.20)	1/0/2/3	0.000	0.0%	0.998	Moderate	Very low
Ischemic heart disease mortality	Cai, 2021	41874/9900000	Dose-respose (10dB increase)		1.14 (0.97,1.33)	1/0/2/3	0.013	81.2%	0.299	Moderate	Very low
Cardiovascular outcomes											
Blood pressure	Huang, 2015	15005/15138	Exposed vs Non-exposed		1.63 (1.14,2.33)	1/0/3/4	0.099	81.2%	0.241	High	Very low
Stroke	Weihofen, 2019	NP/NP	Dose-respose (10dB increase)		1.01 (1.00,1.03)	4/1/2/7	0.000	4.7%	0.415	High	Very low
Ischemic heart disease	Banerjee, 2014	NP/829	Highest vs Lowest		1.35 (0.86,2.12)	0/0/1/1	0.000	NP	NP	Very low	Very low
Angina pectoris	Banerjee, 2014	NP/2135	Highest vs Lowest		1.38 (0.77,2.48)	0/0/2/2	0.000	0.0%	NP	Very low	Very low
Cardiovascular disease	Banerjee, 2014	NP/26377	Highest vs Lowest		1.20 (0.97,1.49)	0/0/7/7	0.028	51.7%	0.195	Very low	Very low
Myocardial infarction	Banerjee, 2014	NP/16878	Highest vs Lowest		1.28 (0.22,7.56)	0/0/2/2	1.039	59.5%	NP	Very low	Very low
Metabolic disorders											
Diabetes	Sakhvidi, 2018	363/9022	Dose-respose (5dB increase)		1.17 (1.06,1.29)	2/0/2/4	0.000	0.0%	0.987	Moderate	Very low
Neurological outcomes											
Anxiety	Hegewald, 2020	NP/4861	Dose-respose (10dB increase)		1.22 (1.03,1.44)	0/0/1/1	0.000	NP	NP	Low	Very low
Depression	Hegewald, 2020	NP/1037786	Dose-respose (10dB increase)		1.14 (1.12,1.16)	0/1/4/5	0.000	0.0%	0.432	High	Very low

Figure 4 Associations between aircraft noise exposure and health outcome. Co: cohort; CC: case control; CS: cross-sectional and NP: not provide

Sensitivity analysis

In the sensitivity analyses of cohort studies, the summary results of recalculating the associations between transportation, road, railway and occupational noise with multiple health outcomes remained similar (Supplementary table S3).

Heterogeneity and publication bias

Heterogeneities across 62 meta-analyses were reanalyzed, of which 15 meta-analyses appeared high heterogeneity, 29 with low heterogeneity and 2 were not able to calculate heterogeneity due to a limited number of individual studies.

Most meta-analyses did not report significant publication bias or a statistical test for publication bias did not publish due to a limited number of studies included, except for the bias found in meta-analyses examining occupational noise and elevated BP.

AMSTAR and GRADE classification

Of the 64 meta-analyses, about 5% were rated as medium quality, 9% as low quality and the rest were graded as extremely low evidence, which was likely rooted in their failure to state that the review methods were established before the review or lack of explanation for publication deviation. The AMSTAR 2 details for every outcome are outlined in Supplementary table S4. In terms of evidence quality, the majority (69%) were classified as extremely low-quality evidence due to the presence of risk of bias, inconsistency and publication bias or lack of statistical tests for publication bias (Supplementary tables S5–S7).

Discussion

Main findings and interpretation

Our umbrella review provides a comprehensive overview of associations between environmental noise and health outcomes by incorporating evidence from systematic reviews and meta-analyses. We identified 23 articles with 64 meta-analyses and 31 health outcomes, and no interventional study was identified. We found significant associations of environmental noise with all-cause mortality, and incidence of CV outcomes, diabetes, hearing disorders, neurological and adverse reproductive outcomes, whereas environmental noise was not associated with the beneficial effect of any health outcome.

Occupational noise is harmful to CV morbidity and mortality, and similar results were found for road noise, railway noise, aircraft noise, transportation noise and combined noise, but the former two did not reach statistical significance. It is worth mentioning that we found that most of the studies reported a harmful association of noise with elevated BP.[54,55] Noise can cause elevated BP and a range of CV-related diseases by activating the hypothalamic–pituitary–adrenal (HPA) axis and sympathetic nervous system,[56,57] or by causing elevated stress hormones such as cortisol and catecholamines through sleep deprivation,[8] leading to vascular endothelial damage.[58] It has also been found that environmental noise, by inducing oxidative stress,[59] can also lead to CV dysfunction.[11] In line with current results, the following large cohort studies also reported that occupational and transportation noises were significantly associated with CV morbidity and mortality.[60–62]

When analyzing the research on noise exposure and diabetes, we found that environmental noise was harmful to diabetes, except for occupational and railway noises. Quality assessments of studies with aircraft, road, traffic and combined noise exposure showed extremely low-quality levels.[32,39] Environmental noise is related to the stress response of human beings and animals,[63] and several studies have confirmed that impaired metabolic function is associated with chronic stress.[64,65] Furthermore, long-term exposure to noise increases the production of glucagon.[66,67] The following studies also found a null association between occupational noise[68,69] or railway noise with diabetes.[70] The non-significant results for railway noise exposure may be due partly to the limited studies and the low level of railway traffic noise compared with other traffic sources.[70] Different types of noise produced varying levels of annoyance, with aircraft noise being reported as the most annoying type of noise.[71,72] Protective equipment use, higher physical activity and healthy worker effects in occupationally exposed populations may account for our findings of invalidity in occupational noise exposure. This hypothesis is further supported by a 10-year prospective study that found that among people with occupational noise, those with high levels of physical activity had a lower risk of developing diabetes.[73] However, recent large cohort studies reported that occupational[74] and railway[75] noise exposure could increase the risk of diabetes by 35% and 2%, respectively.

There is little evidence of the influence of road or railway noise exposure on hearing loss. Noise exposure from occupation increases the risk of hearing disorders, especially occupational noise exposure was observed in our umbrella review. The occupational groups studied mainly come from workers in manufacturing, metals, transportation and mining. It is common for them to be even exposed to more than 85 dB of noise.[3] Some biological mechanisms can explain the damage caused by occupational noise exposure. Occupational noise exposure caused by mechanical injury may damage the hair cells of cortical organs and the eighth Cranial Nerve.[76,77] A series of experiments have demonstrated that exposure to high-intensity noise causes substantial neuronal damage, which in turn causes hearing loss.[78–83] Noise exposure may cause DNA errors in cell division by affecting mechanical damage repair, ultimately leading to cell proliferation disorders.[84] Meanwhile, some animal studies have shown that after noise exposure, free radicals that can cause DNA damage were found in vestibular ganglion cells.[85,86]

The associations of noise exposure with adverse reproductive outcomes such as preeclampsia, preterm birth, perinatal death and spontaneous abortion are still inconclusive. Our analysis found that combined noise exposure significantly increased the risk of birth malformations, small gestational age and gestational hypertension. This is biologically plausible, dysregulation of the HPA axis due to psychological stress[87,88] induced by noise exposure has been shown to impair cortisol rhythms,[89,90] and corticosteroids across the placental barrier stimulate the secretion of adrenotropin-releasing hormone by the placenta, which is toxic to the embryo and leads to adverse reproductive outcomes.[91,92] However, the quality of evidence from studies on the relationship between the two was assessed as extremely low, the association of road noise with neonatal outcomes was not examined in our review. Danish national birth cohort reported that road traffic exposure was not associated with a higher risk of birth defects.[93] A systematic review found associations between road traffic noise and preterm birth, low birth weight and small gestational age, but the quality of evidence was low.[94]

Although most of the current studies showed low quality, current evidence suggested a wide array of harmful effects of environmental noise on human health. Strategies such as limiting vehicle speed, reducing engine noise, building a sound barrier and reducing friction between the air and the ground could be adopted to reduce traffic noise.[11] For occupational noise, it is necessary to educate and train employees to recognize the awareness of noise hazards, equip them with hearing protection devices and monitor the noise exposure level in real-time.[95,96] A study summarizing the latest innovative approaches to noise management in smart cities found dynamic noise mapping, smart sensors for environmental noise monitoring and smartphones and soundscape studies to be the most interesting and promising examples to mitigate environmental noise.[97]

Strengths and limitations

We systematically summarized the current evidence of noise exposure and multiple health outcomes from all published meta-analyses. We conducted a comprehensive search of five scientific literature databases, which ensures the integrity of literature search results. Two researchers screened the literature independently, then four researchers performed the data extraction. We used AMSTAR 2 as a measurement tool to assess the methodological quality of systematic reviews and the GRADE tool to evaluate the quality of evidence.[23,25]

There are some limitations in our umbrella reviews. All meta-analyses included in our umbrella reviews were observational studies, which led to lower evidence quality scores. The studies on occupational and railway noise exposure with some health outcomes were limited. In meta-analyses that we were unable to disentangle the noise types, the presented results were from the combined estimates of all included studies, so these results should be explained cautiously. The dose–response associations of environmental noise exposure with health outcomes should be further investigated.

Conclusion

In a nutshell, the umbrella review suggested that environmental noise has harmful effects on CV mortality and incidence of CV disease, diabetes, hearing impairment, neurological disorders and adverse reproductive outcomes. The results of railway noise are not yet fully defined. More high-quality cohort studies are needed to further clarify the effects of environmental noise in the future.

Supplementary data

Supplementary data are available at *EURPUB* online.

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Ethics approval and consent to participate

Not applicable.

Data availability

The data that support the findings of this study are available in the Supplementary Material of this article.

Conflicts of interest: None declared.

Key points

- The first umbrella meta-analysis of the relationship between noise and multiple health.
- Environmental noise has harmful associations for a range of health outcome.
- The impact of railway noise on health outcomes is inconclusive.
- Most of the current studies showed low methodological and evidence quality.

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