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UP-TO-DATE EPIDEMIOLOGICAL EVIDENCE ON HEALTH EFFECTS FROM TRANSPORTATION NOISE FOR BURDEN OF DISEASE ASSESSMENT

Martin Röösli[1,2*] **Nicole Engelmann**[1,2] **Xing Jiang**[1,2]
Danielle Vienneau[1,2]
[1] Swiss Tropical and Public Health Institute (Swiss TPH), Kreuzstrasse 2, CH-4123, Allschwil, Switzerland
[2] University of Basel, CH-4003, Basel, Switzerland

ABSTRACT

A growing body of epidemiological research has assessed the association between transportation noise and various diseases. The aim of this paper is to derive exposure-response functions suitable for burden of disease estimation. We reviewed epidemiological research using the Umbrella+ method, which combines a high-quality systematic review with the most recent original studies. We conducted meta-analyses to determine critical health outcomes and derive the latest exposure-response functions. For the following health outcomes, we found moderate or high evidence of an association in adults: all-cause mortality, cardiovascular disease incidence, diabetes, dementia and depression. In children, cognitive performance, behavioural problems, and overweight were observed to be related to transportation noise exposure. A systematic analysis of the lowest effect thresholds for studies on mortality and cardiometabolic outcomes indicates a monotonic risk increase from L_{DEN} levels of 45 dB. These exposure-response functions are used in collaboration with the European Environmental Agency to calculate the burden of disease from transportation noise in Europe.

Keywords: *epidemiology, burden of disease, transportation noise, cardiovascular disease, diabetes, depression.*

[*] ***Corresponding author***: *martin.roosli@swisstph.ch*

1. INTRODUCTION

Exposure to transportation noise is a stressor for the body and activates the sympathetic nervous system (SNS) and the hypothalamic-pituitary-adrenal (HPA) axis, triggering the release of stress hormones like cortisol or adrenaline, eventually increasing oxidative stress and inflammation [1-2]. Further, noise-induced sleep disturbances also contributes to this stress response. Chronic distress is a risk factor for mental and cardiometabolic health.

In 2020, the European Environmental Agency (EEA) calculated the burden of disease from transportation noise [3]. It concluded that long-term exposure to environmental noise causes 12,000 estimated premature deaths and contributes to 48,000 new cases of ischaemic heart disease per year in the European territory. Further, 22 million adults are highly noise-annoyed, 6.5 million people suffer from high sleep disturbance, and 12,500 schoolchildren have learning impairments. These estimates are based on exposure-response functions (ERFs) presented in the Environmental Noise Guidelines for the European Region from the World Health Organization (WHO ENG) [4], which are legally adopted in Annex III of the Environmental Noise Directive (END) in 2020 [5-6]. Since this health risk assessment (HRA) of the EEA, a growing body of evidence on the effects of environmental noise on health has been published.

The aim of this paper is to: i) critically review epidemiological research on various health effects of transportation noise, ii) rate the certainty of evidence for a causal association for these health effects, iii) conduct meta-analyses for relevant health outcomes, and iv) determine the ERFs, which includes the determination of the effect threshold and the relative risk (RR) increase per 10 dB L_{DEN}.

2. METHODS

First, a scoping process, involving a literature search and expert judgement, was used to identify potentially relevant outcomes not included in the END Annex III. Next, an Umbrella+ review was conducted. An Umbrella review is defined as a review of reviews. The "+" allows for the possibility to include very new, high-quality original studies in addition to the identified most recent systematic reviews.
The starting point for the literature search was the WHO Environmental Noise Guidelines for the European Region [4]. Thus, systematic reviews and original studies in English language that were published after 2015 and provide insights into the association of at least one exposure-outcome combination were considered. Outcomes identified to be critical in the scoping process were:

- all-cause mortality,
- cardiovascular diseases (ischaemic heart disease, myocardial Infarction, stroke, hypertension, heart failure, and arrhythmia),
- mental health problems (e.g. depression, anxiety),
- behavioural problems (e.g. hyperactivity/inactivity, peer relationship problems),
- cognition (e.g. reading and oral comprehension in children),
- metabolic diseases including diabetes and overweight
- dementia.

Noise exposures of interest were road, railway and aircraft traffic. Eligible for the review were systematic reviews and original studies of high-quality conducted in Europe. A high-quality original study was defined as having applied reliable exposure assessment methods and accounting for most relevant confounding factors. For incident diseases like ischaemic heart disease, only cohort studies were considered to be eligible. For prevalent diseases such as hypertension, overweight, behavioural problems or cognition, cross-sectional studies were also considered if they were population based, had large sample size and used established methods for outcome measurements. The quality of systematic reviews was rated using adapted AMSTAR 2 criteria [7].
The literature search was conducted in PubMed using predefined search terms (details see: [8-9]). In the meta-analysis, the results from the most recent high-quality systematic review were pooled with the results of subsequent high-quality original studies published using a random effects meta-analysis weighted according to the inverse variance of the effect estimates. Certainty of evidence was rated using the terminology of the WHO ENG classification scheme [4]: strong, moderate, low, and very low. Strong certainty of evidence was obtained if at least two studies with low risk of bias showed an increased risk of disease or death associated with noise and a low risk of bias. The certainty of evidence was classified as moderate if only one high-quality study has demonstrated an association. For all studies, if provided, we extracted information about the lowest effect threshold. Lowest effect threshold was determined as the median over all extracted values.
More details on the methods can be found in Engelmann et al. 2024 and Engelmann et al. 2025 [8-9].

3. RESULTS

3.1 Cardiovascular diseases in adults

In the literature search for studies on cardiovascular disease incidence, a total of 33 reviews and 48 original studies were identified. Thereof, twelve reviews were included for further evaluation and eventually three systematic reviews were used as a starting point for the meta-analysis of at least one specific cardiovascular outcome. Of the 48 original studies, twelve original studies were eligible for the meta-analysis of at least one cardiovascular outcome in relation to road traffic noise, four studies for railways noise and five for aircraft noise.
For ischemic heart disease in relation to road traffic noise exposure, a relative risk of 1.041 (95%-CI: 1.023-1.059) per 10 dB increase in L_{DEN} without noticeable heterogeneity between estimates was observed (Figure 1). Virtually the same association was found for heart failure (1.041, 95%-CI: 1.023-1.059) and similar associations for hypertension (1.045, 95%-CI: 0.970-1.126) and stroke (1.046, 95%-CI: 1.013-1.081). The relative risk for arrhythmia was 1.006, 95%-CI: 1.001-1.011). Pooled effect estimates for all cardiovascular disease was 1.032, 95%-CI: 1.012-1.052) per 10 dB L_{DEN} increase. Certainty of evidence for a causal association with road traffic was rated to be strong for ischemic heart disease, heart failure and stroke, moderate for arrhythmia and low for blood pressure. More detailed results including references of all studies and pooled estimates for railway and aircraft noise are described in Engelmann et al. 2024 [9].

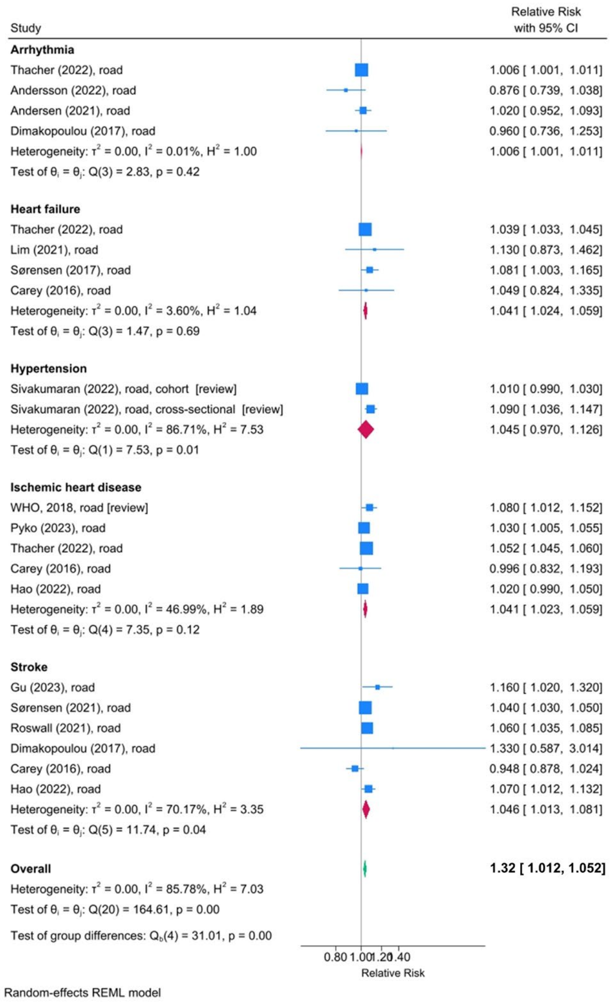

Figure 1. Meta-analysis on various cardiovascular diseases in adults in relation to road traffic noise, stratified by outcome. Relative risks refer to a 10 dB increase in LDEN.

3.2 Death and other diseases in adults

In total, seven eligible studies for the association between all-natural cause mortality and road traffic noise were identified (Figure 2). The pooled effect estimate across the seven European cohort studies was 1.055 (95%-CI: 1.026-1.084) per 10 dB in road traffic noise exposure with high heterogeneity between studies (I^2=99%). The certainty of evidence for this association was considered to be strong. For railway and aircraft noise, only little research has been conducted (details see Engelmann et al. 2024 [9]).

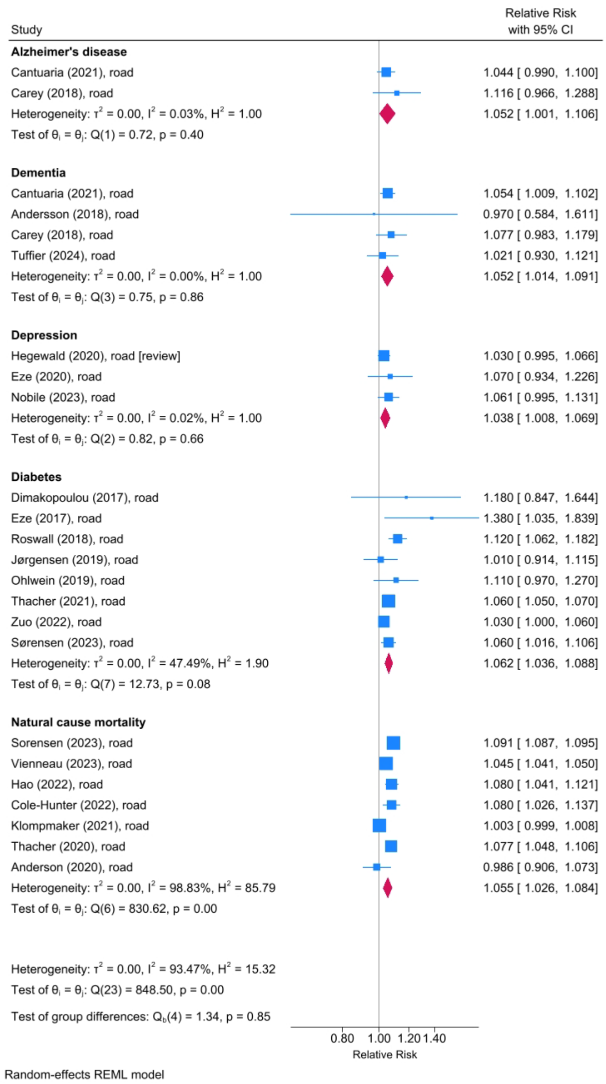

Figure 2. Meta-analysis on mortality and various non-cardiovascular health effects in adults in relation to road traffic noise, stratified by outcome. Relative risks refer to a 10 dB increase in LDEN.

For diabetes incidence, the pooled RR was 1.062 (95%-CI: 1.036-1.88) per 10 dB increase in road traffic noise with little heterogeneity and strong certainty of evidence based on eight cohort studies (Figure 2).

For incidence of depression, one systematic review was identified that included 26 studies on depression and anxiety [10]. Combining the pooled effect estimate of this review, which is based on eleven studies on road traffic noise, with two more recent cohort studies on

depression and road traffic noise provided a RR of 1.038 (95%-CI: 1.008-1.069) per 10 dB increase L_{DEN} (Figure 2). The certainty of evidence for a causal association was rated to be moderate to strong.
Based on four cohort studies, the relative risk to develop dementia was 1.052 (95%-CI: 1.014-1.091) per 10 dB increase in road traffic noise without noticeable heterogeneity (p=0.87) between estimates (Figure 2). Two studies restricted their analysis to Alzheimer's disease, yielding the same RR with wider confidence interval. Certainty of evidence was rated to be moderate to strong for these associations.
More detailed results including reference list of all studies and meta-analyses for railway and aircraft noise are shown in Engelmann et al. 2024 [9].

3.3 Noise effects in children

The most recent systematic review on behavioral problems and/or hyperactivity in children and adolescents included ten studies [11]. We identified another three eligible European studies since this review was published. In total, three studies similar enough to be pooled looked at residential road traffic noise in relation to total behavioural difficulties and five studies for hyperactivity/inattention resulting in RRs of 1.073 (95%-CI: 1.009 to 1.142) and 1.047 (95%-CI: 0.947 to 1.157) per 10 dB increase road traffic noise exposure at home, respectively (Figure 3). For road traffic noise at school, the pooled RR per 10 dB increase was 0.96 (95%-CI: 0.76 to 1.22) for total behavioural difficulties based on two studies and 1.12 (95%-CI: 0.90 to 1.38) for hyperactivity/inattention based on three studies (details in [8]). Based on these study results the certainty of evidence for an association between road traffic noise exposure at home and total behavioural difficulties was rated to be moderate and for hyperactivity/inattention to be low.
We identified three eligible studies on road traffic noise and overweight or obesity. The RR for being overweight in relation to residential road traffic noise was 1.063, (95%-CI: 1.007 to 1.122) per 10 dB increase in L_{DEN}. The certainty of evidence was rated to be moderate.
Substantial research on cognition was identified with the most recent systematic review [12] published in 2022. They rated the certainty of evidence for reading, verbal and language ability in relation to noise as moderate. The heterogeneous tests for measuring the outcome was an obstacle for us to conduct a meta-analysis.
Low or very low certainty of evidence was found for an association between road traffic noise and various birth related outcomes such as low birth weight, preterm birth and small for gestational age (Figure 3). More detailed results for children and adolescents including references to all studies and burden of disease estimates for Europe are published in Engelmann et al. 2025 [8].

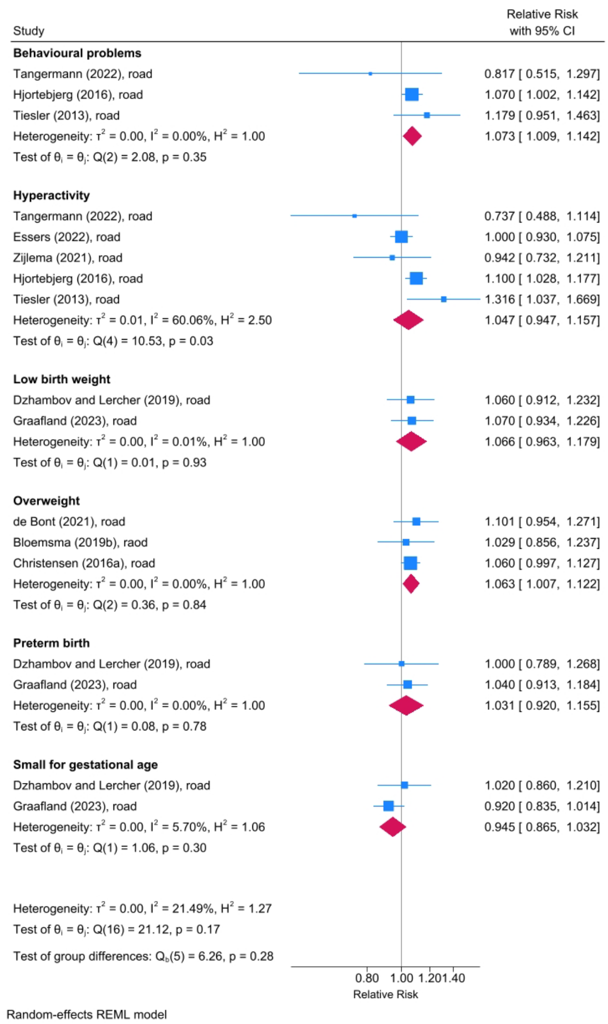

Figure 3. Meta-analysis on various health relevant effects in children in relation to road traffic noise, stratified by outcome. Relative risks refer to a 10 dB increase in L_{DEN}.

4. DISCUSSIONS

These meta-analyses and corresponding ERFs are the basis for an update of the burden of disease from transportation noise in Europe in 2025. The previous 2020 European assessment [3] considered only high noise annoyance, high sleep disturbance, cognitive impairment in children, and ischemic heart disease. Our re-evaluation of the literature found strong certainty of evidence for mortality, the most relevant diagnoses of cardiovascular disease incidence, and diabetes. These outcomes will thus be considered in the next European health risk assessment. Our literature search also found moderate to high certainty of evidence for associations between road traffic noise and depression as well as dementia in adults, and behavioral problems, cognitive impairment, and overweight in children and adolescents. This implies that the evidence for an association between transportation noise and various somatic diseases has substantially increased in the last 5 years.

Based on our analysis, the effect threshold for the quantification of negative health impacts is proposed to be reduced to L_{DEN} of 45 dB. New evidence shows effects at such levels in about 50% of the studies. This lower threshold compared to previous meta-analysis is most likely due to new studies with high-quality exposure models and improved traffic input data relevant for the modeling in the lower exposure range. Such studies tend to find associations with noise at lower levels than earlier epidemiological studies focusing on noise exposure from major roads. Of note, the risk increase per 10 dB of transportation noise for ischemic heart incidence is smaller than previously observed and used in health risk assessments. Possibly this is a direct consequence of the use of better exposure assessments in the low exposure range. Older studies, with a high cut-off for the reference group (e.g. <55 dB), may have actually included people with low exposure in the reference group that resulted in an overestimate of the linear regression slope.

For our critical review of the literature, we applied an Umbrella+ method. Conducting a systematic review for all possible outcomes was beyond our capacity and thus the Umbrella+ review was considered an appropriate compromise that allowed us to capture the most up-to-date literature. However, this type of literature review has some limitations. We relied partly on evidence rating from other authors, which may have resulted in some variability of the criteria related to the evaluation of certainty of evidence. It should also be noted that for most recent studies, we only included high-quality studies whereas the reviews that served as starting point may have been more inclusive. Another challenge in Umbrella+ reviews is to deal with multiple cohorts from the same country. We cannot completely ensure that the same person is not part of multiple cohorts, and thus some may be entered multiple times in our meta-analysis. For instance, there are several studies representing different cohorts in Denmark, including a new nation-wide cohort, that were included on the basis they had different follow-up periods and/or confounder control. However, the overall proportion of potential double-counting is small and would mostly result in a slight underestimation of precision but not affect the point estimate.

In addition to road traffic noise, we also have separately looked at studies on railway and aircraft noise. Effect estimates were sometimes quite different for the three sources of transportation noise. Since the characteristic and the diurnal pattern of noise exposure from different sources varies, it is, in principle, plausible that this translates into differences in the RR per 10 dB increase in L_{DEN}. However, the number of studies for railway and in part also for aircraft noise were mostly scarce, and observed heterogeneity may be mainly introduced by different methods, e.g. the precision of noise exposure assessment. Relatively few people are exposed to railway and aircraft noise compared to road traffic noise and thus the power of these studies is often lower than for road traffic noise studies. Since road traffic noise is much more common it is well possible that moderate levels of railway and aircraft noise were masked by road traffic noise. Such exposure misclassification is expected to lead to an underestimation of the slope in the lower exposure range and this may be another reason why these studies have sometimes failed to observe an association. In this case, absence of evidence may not imply evidence for absence of association. There was consistent high-quality evidence for relationships between road traffic noise and cardiovascular health outcomes, mortality and diabetes. Until more empirical research on railway and aircraft noise is available, and given that the biological mechanisms involved are similar, we propose to use the relationships established for road traffic noise to estimate health risks from railway and aircraft noise.

5. ACKNOWLEDGMENTS

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