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Effects of road traffic noise on health: from Burden of Disease to effectiveness of interventions

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Abstract

Road traffic noise is one of the most ubiquitous urban environmental pollutants. This paper brings together three related works – in which the author has been involved or is currently completing - that together illustrate essential input to good policy development for the management of the health consequences of this pollutant. These include a guidance document on burden of disease from environmental noise; an assessment of exposure, response, and exposure-response, to road traffic noise in a densely-populated Asian city; and a current systematic evidence review of the effectiveness, in health terms, of interventions to control environmental noise. These provide examples of the nature of the quantitative evidence available to promote noise management through policy interventions.

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1. Introduction

Noise is a major environmental issue affecting large numbers of people [1], particularly in urban areas. To date, most assessments of the effects of environmental noise have been based on the annoyance it causes to humans, or the extent to which it disturbs various human activities. Its consideration at a policy level as a problem with specific

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health outcomes has been limited [2]. In recent years, evidence has accumulated regarding health effects of environmental noise. In order to inform future policy, and to develop management strategies and action plans for its control, national and local governments need to understand and consider this new evidence.

2. Burden of disease from environmental noise

Environmental health risk assessment can be based on the Environmental Burden of Disease (EBD) methodology using the metric Disability-Adjusted Life Years, or DALY [3]. The EBD combines the concepts of potential years of life lost due to premature death plus equivalent years of ‘healthy’ life lost by virtue of being in states of poor health or disability. Estimation of EBD for road traffic noise requires knowledge of the distribution of exposure to noise in the population, an exposure-response relationships for each health outcome of interest, and an estimate of a disability weight (DW) for each outcome.

Disability weights allow non-fatal health states and deaths to be measured under a common currency. Disability weights allow time lived in various health states to be valued and quantified. Weights that are commonly used for calculating disability adjusted life years (DALYs) are measured on a scale of 0 to 1 where 1 represents death and 0 represents ideal health. The values of disability weights for various disease states have been the subject of considerable discussion and work – including those for the health outcomes of environmental noise exposure. A detailed introduction to the calculation of EBD is available elsewhere [4].

An example of the use of EBD to compare various environmental health risk factors, including noise, averaged over six countries in Europe, is shown in Fig. 1 (The EBD for noise is significantly underestimated in this diagram as it is calculated on a limited range of health outcomes and sources: severe sleep disturbance only for road, rail and aircraft noise sources, and ischemic heart disease for road sources).

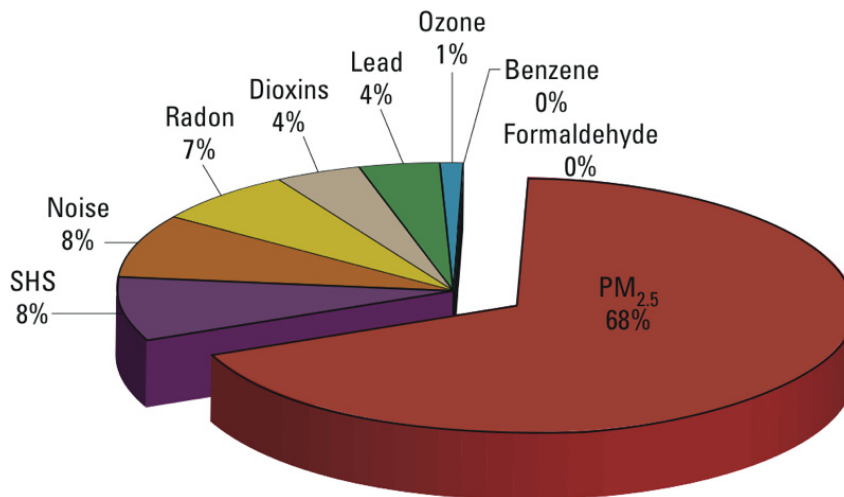


Fig. 1. (Reproduced from Hänninen et al., [5]) Relative contributions of nine targeted risk factors (SHS = secondhand smoke) to the estimated burden of disease attributed to these risk factors, averaged over the six participating countries.

The World Health Organization European Centre for Environment and Health, Bonn, produced a guidance document for quantitative assessment of the health risk of environmental noise [6]. The health effects considered are: cardiovascular diseases, cognitive impairment, sleep disturbance and annoyance. Exposure–response relationships exist for annoyance, sleep disturbance (subjective), cognitive impairment (children) and cardiovascular disease. There are plausible biological models of the relationship between noise exposure and these health effects. The WHO document provides exemplary estimates of the burden of disease of these health impacts - as calculated in Table 1 below. Note that these estimates show the sensitivity of EBD to different Disability Weights; the ranges used reflecting the uncertainty associated with such weights.

Table 1 DALYs for (a) high sleep disturbance and (b) high annoyance, due to road traffic noise in large urban agglomerations of the EU. [6] *Burden of disease from environmental noise: Quantification of healthy life years lost in Europe.* World Health Organization [7]

Exposure category L_{night} (dB(A))	Percentage of population exposed ^a	Percentage of people highly sleep-disturbed ^b	Number of cases per million ^b	DALYs lost in the urban population ^c		
				DW = 0.04	DW = 0.07	DW = 0.10
<45	44 ^d	NA	NA	NA	NA	NA
45-49	20 ^d	4.5	8 906	101 526	177 670	253 814
50-54	20	6.6	13 266	151 230	264 652	378 074
55-59	10	9.6	9 556	108 937	190 640	272 342
60-64	5	13.2	6 611	75 365	131 888	188 412
65-69	1	17.6	1 763	20 099	35 174	50 248
Total	100		40 102	457 156	800 023	1 142 890

Exposure category L_{den} (dB(A))	Percentage of population exposed ^a	Percentage of people highly annoyed ^b	Number of cases per million ^b	DALYs lost in the urban population ^c		
				DW = 0.01	DW = 0.02	DW = 0.12
<55	50	2.77	13 835	39 430	78 859	473 155
55-59	17	8.16	13 868	39 524	79 047	474 285
60-64	19	12.96	24 621	70 170	140 341	842 044
65-69	9	20.08	18 068	51 494	102 989	617 933
70-74	4	30.25	12 100	34 485	68 969	413 815
>75	1	30.25 ^d	3 025	8 621	17 242	103 454
Total	100		85 517	243 724	487 448	2 924 686

Based on more recent estimates of exposure and a wider, but not exhaustive, range of noise-related health outcomes, the European Environment Agency [1] provided the following summary of the extent of effects, and burden of disease, of noise in Europe:

- Noise is a major environmental health problem – with most of the noise from road traffic
- Environmental noise causes 10 000 cases of premature death in Europe per year
- 20 million adults are severely annoyed and 8 million suffer sleep disturbance
- Over 900 000 cases of hypertension are caused by environmental noise per year
- Noise causes 43 000 hospital admissions in Europe per year.

This evidence moves the focus of the adverse effect of transportation noise from a quality-of-life issue, to one firmly on the environmental health agenda.

3. Application in Asia

Urbanization, economic development and growth in motorized transport are drivers of the growing extent and intensity of environmental risk from road traffic noise. There is a global shift in the centre of gravity of urbanization from the developed world. About half of the population already live in cities and this proportion will be two-thirds by 2050 [8]. By 2025, more than half of the twenty-five megacities in the world will be in Asia, and located in the tropics or sub-tropics [9]. In Asia, dense, traffic-intense, and usually high-rise cities are increasingly the norm. Is existing knowledge on exposure to road traffic noise, garnered primarily from studies in western cities, equally applicable in these emerging Asian cities? In particular, are exposure-response relationships for response to road traffic noise similar in Asia and Europe – the latter, again, being where most prior studies of the road traffic noise exposure-response relationships have been conducted.

Exposure-response relationships for annoyance with road traffic noise have been estimated over many decades: There has been considerable variation in the results of individual studies and various syntheses have been performed - the most recent meta-analysis was that by Miedema and Oudshoorn [10] who examined twenty-six studies from six European countries and Canada, consisting of a total of 19,172 individuals. They reported the percentage of people Highly Annoyed (%HA) over an L_{den} exposure range of 45-75 dB. Much of the base data for this meta-analysis is now several decades old. More recent exposure-annoyance studies for road traffic noise have been reported from Europe [11] and from Asia [10] and Phan et al. [13], but there have been no further syntheses conducted.

The effects of noise exposure on sleep have both acute and long-term dimensions, and these are associated with different noise indicators. Acute effects link with event-related measures while overall sleep parameters link with L_{night} , as a whole-of-night indicator. A meta-analysis of 13 subjective self-reported sleep disturbance studies from road traffic noise (9,603 individuals from: 8 studies from Europe, 2 from Canada, 2 from Japan and 1 from Turkey) was reported by Miedema and Vos [14]. It related the percentage of people who self-reported being Highly Sleep Disturbed (%HSD) to L_{night} over a range of 45 to 65 dB. We note that self-reported sleep disturbance is a subjective measure of the effects of noise on sleep often used in surveys, while more objective polysomnographic measures can be used in experimental settings, but are less suitable in large-scale community surveys.

In a major study in Hong Kong, Brown et al. [15] examined if the exposure to road traffic noise in a high-rise Asian city, with high population and traffic densities, is different from that in European cities. They also examined if the exposure-response relationships for annoyance and self-reported sleep disturbance can be considered as drawn from the same population of exposure-response relationships as were those used in the meta-analyses of annoyance and self-reported sleep disturbance responses [10, 14], respectively. In the Hong Kong study, road traffic noise exposure was based on three-dimensional modelling, and residents' responses to traffic noise measured for a sample of 10,077 dwellings.

The distribution of exposures of dwellings in high-rise, high-density, Hong Kong is different from those reported from Europe, but not at the higher noise levels. The proportion of the Hong Kong population exposed to high levels (> 70 dB) is similar to that found in Europe. However, a much higher proportion, compared to European cities, is exposed to L_{den} levels of 60-64 dB, and a much lower proportion to lower levels (< 55 dB). Further, there is no evidence that the exposure-response relationships for annoyance and self-reported sleep disturbance in Hong Kong are different from relationships synthesized from earlier studies - despite the western bias and temperate-climate bias in the studies available in the syntheses. The exposure-annoyance relationship for road traffic noise was from the same population of exposure-response relationships, being well within the tolerance limits of studies used to generate the synthesized Miedema and Oudshoorn curves. The exposure-response curve for self-reported sleep disturbance was also parallel to that of Miedema and Vos, but slightly lower.

These are important findings. They mean that risk assessment of the health effects of environmental noise should be able to be based on the same approaches as used in European EBD calculations [6]. On the basis that the Hong Kong relationships were from the same populations as those in the west, similar exposure-response relations appear applicable in Asia, with EBD calculations additionally requiring only reliable estimates of the population exposures to transport noise.

4. Environmental noise interventions and human health effects

Despite many decades of *environmental noise management* (*noise control*, or *environmental noise interventions*), there is no definitive analysis of whether such interventions have resulted in changes in the health effects of the population exposed to noise. As part of a current World Health Organization systematic evidence review of the effects of environmental noise on people, the current author has commenced a review of the literature reporting the effect of noise interventions on human health.

This work is currently in progress –but to date has led to the development of a model, or framework, of interventions and health outcomes; the review to follow will address the question of the nature and quality of this evidence. The model is applicable across most environmental noise sources, and across most settings. The health outcomes include sleep disturbance, annoyance, cognitive impairment (of children), mental health and wellbeing, cardiovascular diseases, and hearing impairment and tinnitus.

The possible noise interventions are also broad. The intent is that the framework comprehensively incorporates all noise management strategies. Interventions will include, for example, exposure-related actions that aim to change the level of exposure of people, as well as actions that are non-exposure-related. The direct, or indirect, intent of both the exposure-related interventions and the non-exposure-related interventions will be to change the magnitude of adverse health outcomes.

The model has been built on a framework previously adopted in the air pollution field to evaluate whether actions to improve air quality have resulted in reduced air pollution health effects – so-called *air pollution accountability research* (e.g. HEI, [16]). These frameworks put emphasis on *ambient air quality* (the concentrations of air pollutants in the atmosphere) as a key component in the chain of accountability. However, this has less relevance in the environmental noise field because noise exposure is strongly influenced by the length and nature of the propagation paths from sources to receivers. Propagation paths need to be included as a system component in the causal pathway between environmental noise and human health effects. Another difference is air pollution accountability research has tended to focus on regulatory interventions directed at reducing emissions. While regulatory intervention is also used in managing environmental noise, for example by control of road vehicle source levels, there is a much broader set of interventions that is utilized in environmental noise management (e.g. WHO [7]; Chapter 5).

Categorisation of interventions is necessary as synthesis of evidence regarding outcomes from interventions may only be appropriate when conducted across studies that belong to the same intervention category. Five broad categories of intervention (see Table 2) have been identified. Terminologies for two of the technical interventions have been borrowed from the environmental noise control field (*source interventions* and *path interventions*). A third category is termed *infrastructure change intervention*, and others are *indirect interventions*, and *change in behaviour interventions*. The categories of these intervention types are illustrated by the examples in Table 2.

Table 2 Categorization of environmental noise interventions

Type	Intervention Category	Intervention Sub-category	Examples
A	Source interventions	Change in emission levels of sources Time restrictions on source operations	motor vehicle emission regulation; road surface night road curfew, heavy vehicle curfew
B	Path interventions	Change in the path between source and receiver Path control through insulation of receiver/receiver's dwelling	noise barrier; creation of dwelling quiet side insulation of building envelope
C	Infrastructure change interventions	New or removed infrastructure, or change in traffic load on existing infrastructure Distance controls between (new) receivers and sources	construction of town bypass; new wind farm; major changes in road traffic load urban planning control; 'buffer' requirements
D	Indirect Intervention	Change in other dimensions of dwelling/neighbourhood	green space provision in neighbourhood; quiet side
E	Change in behaviour interventions	Change in individual behaviour to reduce exposures; avoidance or duration of exposure. Community education, communication	changing opinions regarding sources, or explaining reason for noise changes. education regarding reducing personal exposure

Evidence of the effect of these interventions on human health should be based primarily on syntheses of studies in which the effect of the intervention has been related directly to a change in health outcome. However, on the assumption that there is a well-established link between exposures and a particular health outcome, evaluation by the intermediate outcome of change in exposure of a population of interest is also appropriate. Change in exposure can be presumed to result in change in health outcome. In addition, certain behavioural environmental noise interventions directed at changing knowledge or attitude may result in changes in health outcomes - a group may report lower annoyance scores if authorities have undertaken a program of communication and explanation.

5. Conclusion

This new evidence on the health effects of environmental noise moves the focus from consideration of transportation noise as a quality-of-life issue only, to one firmly on the environmental health agenda, providing quantitative evidence, even if only a first approximation at this stage, in terms of its Burden of Disease. There is guidance available as to how this burden should be calculated based on knowledge of the distribution of the exposure to environmental noise in the population of interest, an exposure-response relationships for each health outcome, and an estimate of a disability weight (DW) for each health outcome.

In terms of knowledge of exposure-response relationships for noise, there has to date been a Western bias, and a temperate-climate bias, in the studies used in prior meta-analyses of human responses to road traffic noise. However, the exposure-response relationships for annoyance and self-reported sleep disturbance reported from the high-density, high-rise, sub-tropical city of Hong Kong are not inconsistent with the results of previous meta-analyses based on western studies. This is an important finding, as many of the projected mega-cities in the world will be located in non-temperate climatic zones in Asia and elsewhere and their urban forms can be expected to emulate that of Hong Kong. These results will facilitate health-risk assessment of from road transport noise using EBD estimates in Asia.

A conceptual framework has been developed as a tool for further analysis of evidence, arising from a planned systematic search of the literature, of the relationship between environmental noise interventions and human health outcomes. The model will provide a framework for organizing a synthesis of the impacts of environmental noise interventions on human health. We have identified five broad categories of intervention which apply at various points along the system pathway between sources and outcomes. Categorisation is necessary as synthesis of evidence may only be appropriate when conducted across studies that belong to the same intervention category. The systematic review in progress, based on this model, is designed to shed light on whether road transport noise management strategies do, in practice, produce improvements in the health of the community.

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