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Estimating burden of disease from transportation noise in Switzerland – deriving exposure-response functions

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ABSTRACT

External costs of traffic are regularly estimated for Switzerland, and this includes an estimation of transportation noise induced health impact. To do so, we rated the quality of evidence for various diseases in relation to transportation noise either as sufficient (moderate or high) or not sufficient (very low or low). We used the environmental noise guidelines from the WHO Regional Office for Europe as a starting point and evaluated subsequently published systematic reviews and original research. For diseases rated with sufficient quality evidence, the exposure-response association was determined for the Swiss context.

The quality of evidence was considered sufficient for cardiovascular disease, diabetes and depression, while it was insufficient for obesity, cognitive functions, various birth outcomes, cancer and neurodegenerative diseases. For cardiovascular mortality, we derived age group specific risk estimates from a Swiss nationwide cohort study yielding risk increases of 0.0% (aircraft, ≥80 years) to 8.6% (road, 18-65 years) per 10 dB L_{den} noise increase. For diabetes and depression, pooling Swiss cohort data with international study results yielded risk estimates of 8.0% and 4.9% per 10 dB increase of any type of transportation noise, respectively. Our evaluation of the epidemiologic noise research demonstrated that the quantitative risk assessment approach developed by the WHO Regional Office for Europe needs to be updated to reflect new results in noise research.

Keywords: Health risk assessment; burden of disease; transportation noise; years of life lost; mortality

INTRODUCTION

In a health risk assessment, the exposure distribution of the target population is combined with exposure response functions, which may be derived from a different context, to obtain the number of people affected by the exposure. In general, HRA can be differentiated in burden of disease estimates (BoD) or health impact assessments (HIA). In Switzerland, burden of disease from transportation noise is regularly estimated to obtain the external costs of road, railway and aircraft traffic and this includes an estimation of transportation noise induced health impact. Whereas costs from noise induced annoyance and sleep disturbances is monetarized by means of observed effects on the renting and housing costs, effects on chronic diseases are estimated following an adapted approach from the WHO Environmental Noise Guidelines for the European Region (ENG) (WHO 2018). The aim of this paper is to present the current update of the methods for chronic diseases including the derived exposure-response functions and the number of illnesses and deaths attributed to road, railway and aircraft noise.

MATERIALS AND METHODS

Umbrella Review

We conducted an Umbrella review for evidence rating and deriving exposure-response functions. The starting point was the evidence rating of the WHO guidelines of 2018. In addition to the WHO guidelines, any study results from Switzerland were considered as well as newer meta-analyses after publication of the WHO guidelines, and important original study results that were not included in the respective latest meta-analyses. The literature was identified in scientific databases such as Pubmed and Web of Science. Publications up to the end of July 2021 were included. In addition, the contributions to ICBEN 2021 were reviewed with regard to relevant new findings. The focus was placed on studies that were informative for the derivation of exposure-response relationships.

Evidence rating

The quality of evidence for or against an association for various clinical pictures and noise sources was assessed in the WHO guidelines as "high", "moderate", "low" or "very low". The decisive factor for a high quality of evidence is the existence of at least two prospective cohort studies, which demonstrate an increased risk of disease or death in connection with noise exposure and which show a low risk of bias. If only one high quality prospective study was available, evidence was rated as moderate. These criteria were also used in the current study. A disease was selected for burden of disease quantification if evidence was sufficient, i.e. high or moderate.

Derivation of the exposure-response function

The derivation of the exposure-response function was guided by the following four main principles:

1. Transferability of foreign study results to Switzerland: even more than in the case of other environmental exposures, there are uncertainties in the transferability of foreign noise study results to Swiss conditions. Mostly, exposure-response relationships in large high-quality epidemiological studies on chronic diseases are based on the modelled noise exposure at the house facade (typically the maximum value). Transferability is affected by uncertainties in noise modelling (e.g. accuracy of input data), different noise characteristics (e.g. regulation for night noise, vehicle fleet, road surfaces, etc.) or the attenuation properties of residential buildings relevant for indoor noise. In addition, socio-cultural differences are also expected to play a role, e.g. with regard to possible interactions between noise annoyance, noise exposure and health consequences. Further, the general health risk profile may differ between populations. For these reasons, study data from Switzerland have the highest priority in deriving the exposure-response relationship.

2. Statistical uncertainties: From the above explanations, it would be desirable to use only Swiss data for the determination of the exposure-response function. With regard to cardiovascular mortality, precise exposure-response relationships were derived in the Swiss National Cohort Study (SNC) including the whole Swiss adult population. For diabetes and depression, exposure-response functions are based on only a few thousand participants in the prospective SAPALDIA cohort study. Such a sample size results in substantial uncertainties. Therefore, these Swiss data on diabetes and depression are combined with the available foreign data by means of meta-analyses to obtain more precise exposure-response

functions.
3. Exposure-response functions for specific transportation noise sources: It is plausible that the exposure-response functions for the same disease differ between different transport modes due to different noise characteristics such as tone content, impulsivity and diurnal pattern. For cardiovascular diseases, available data from the SNC allowed to estimate separate exposure-response functions for road, railway and aircraft noise. However, for railway noise little data is available for other outcomes, which limits derivation of specific exposure-response functions, but should not be interpreted as evidence for the absence of effects. On the basis of biological-medical considerations, the pooled exposure-response function over all noise sources is therefore used.
4. Threshold: In epidemiological research, categorical and non-parametric analyses generally find relatively linear exposure-response relationships. This implies that in principle there is no reason to apply a threshold value below which no health impact is considered. Nevertheless, it is not very plausible to expect health effects from noise exposures that are barely distinguishable from the background sound in a quiet residential environment. Therefore, the threshold value is set at a level that is clearly perceptibly higher than a quiet background situation, i.e. an L_{den} of 45 dB.

Calculation of noise induced morbidity and mortality
The calculation of the noise-induced cases of illness is carried out according to the attributable case method. The proportion of noise-related illnesses or deaths (attributable fraction) is estimated based on the exposure-response function, morbidity and mortality rates, and the population weighted mean noise exposure above the threshold.
The number of deaths is calculated in the same manner and the Years of Life Lost (YLL) is determined by comparing life tables with the observed survival probabilities and the adapted survival probabilities without noise exposure. For all calculations, reference year 2019 is taken.

RESULTS

Literature review and quality of evidence rating

Cardiovascular diseases: Effects of transportation noise on cardiovascular diseases have been repeatedly demonstrated and have a high pathophysiological plausibility as shown in several new experimental studies (Schmidt et al. 2021) and on the basis of biomarkers (Osborne et al. 2020). For road traffic noise and ischaemic heart disease, the WHO has classified the quality of evidence as high. Since then, a number of additional international and Swiss studies have been published, showing associations mainly with ischaemic heart disease, hypertension, heart failure and stroke (Munzel et al. 2021). These account for about 70-80% of all cardiovascular diseases. For mortality in particular, there are several studies that have investigated the relationship between transportation noise and all cardiovascular causes of death in aggregate. At ICBEN 2021, several new analyses on various cardiovascular diseases and deaths from Scandinavian cohort studies were presented, which are in line with the previous findings. For this reason, the evidence for a causal relationship between road, rail and aircraft noise and cardiovascular diseases and deaths is considered to be high.
Diabetes: Based on the studies published up to 2015, the WHO has classified the evidence for an association between road traffic noise and incidence of type 2 diabetes as moderate. There was one prospective cohort study of high quality on this topic. In the meantime, there are six other prospective cohort studies, one of them from Switzerland (Eze et al. 2017), which all find associations between road traffic noise and diabetes (Vienneau et al. 2019). Thus, there is no doubt that, according to the WHO's evidence evaluation rules, the evidence for an association between the occurrence of diabetes and road traffic noise must now be judged as high. The biological plausibility is also high. There are fewer studies on aircraft and railway noise. In this respect, the isolated evidence for these sources is lower but overall evidence with transportation noise was rated to be sufficient.
Depression and mental health: In the WHO guidelines, evidence for depression was considered to be low to very low. In the meantime, several cohort studies are available which

demonstrate associations between the occurrence of depression and at least one source of transportation noise (Hegewald et al. 2020). This indicates that, according to the WHO's approach, the evidence for an association is high. In Swiss data, too, there are indications that the risk for depression increases with noise exposure at the place of residence. Moreover, such an association is biologically plausible. The results on depression are also consistent with studies on anxiety and health-related quality of life. A recent review concludes that there is "substantial evidence" for a relationship between noise and depression (Hegewald et al. 2020). In conclusion, there is high evidence for a relationship between depression and transportation noise. For aircraft noise, the association with depression is highly significant, but this result is largely determined by a case-control study (Seidler et al. 2017) and not by a prospective cohort study. For railway noise, there is little data. In conclusion, evidence for an association between transportation noise and depression was rated to be sufficient.

Obesity: The relationship between obesity and exposure to transportation noise is considered plausible, and a new review concludes that the evidence for a relationship with road traffic noise has improved considerably since the WHO guidelines, especially for an increase in waist circumference (Munzel et al. 2021). Nevertheless, the studies are still relatively thin and heterogeneous, so that the association with noise can currently only be quantified with great uncertainty and evidence was considered to be insufficient for burden of disease assessment.

Birth related diseases: The studies on the influence of noise exposure on outcomes related to childbirth are inconsistent. Isolated associations have been observed for preterm birth and low birth weight (Dzhambov and Lercher 2019). Biologically, it is plausible that chronic stress from noise can affect the foetus. However, experimental data to support such an association are missing. The evidence for various birth related outcomes is therefore considered to be insufficient.

Cognition and Behaviour in children and adolescents: The influence of noise exposure on cognition and behavioural problems in children and adolescents is unclear (Clark and Paunovic 2018). In the WHO guidelines, the quality of evidence for a link between cognition in children and aircraft noise was rated as moderate. On this basis, the European Environment Agency (EEA) concludes that 12,400 children in Europe (EEA-33) have cognitive impairment due to aircraft noise (EEA 2020). Due to the heterogeneous nature of the studies and the fact that most of the studies are cross-sectional analyses, the evidence for an association between transportation noise and behavioural problems or cognition in children is rated as insufficient.

Other chronic diseases: For other diseases, such as cancer and neurodegenerative diseases, there are isolated indications for an association with noise. Depending on the disease pattern, there are also biologically plausible hypotheses. Nevertheless, the evidence for an association with exposure to transportation noise is insufficient all these clinical pictures.

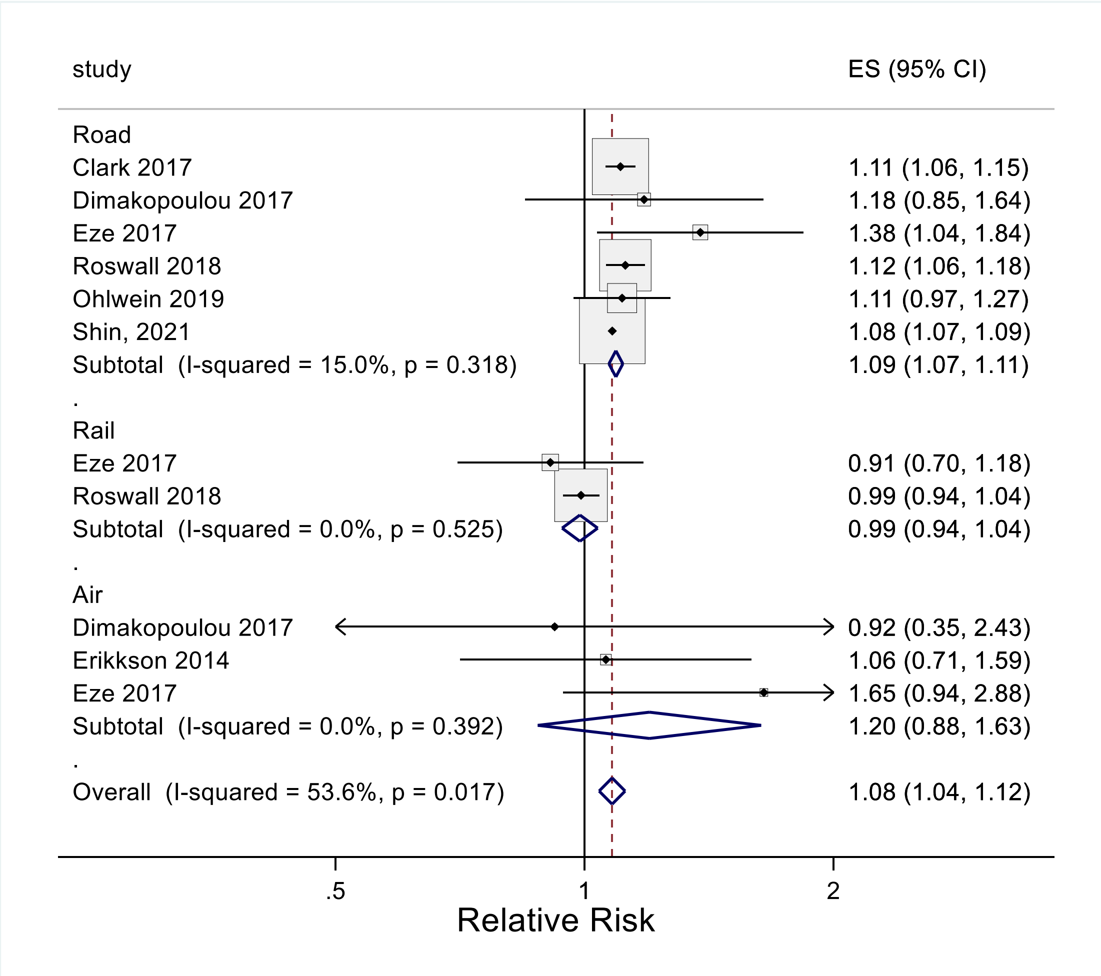
Exposure-response functions

We used exposure-response functions from the SNC, to quantify the relationship between cardiovascular mortality and road, rail and aircraft noise (Table 1). The associations are relatively linear with no discernible threshold value. No consistent gender pattern was seen but the change in relative risk with age was very pronounced. The older the person, the smaller the relative risk of cardiovascular death due to noise. Age-related changes in relative risks have a major influence on the calculation of life years lost, as life expectancy is included in the calculations. For this reason, age-stratified relative risks are used in our project.

In contrast to mortality, there is no Swiss noise study on the incidence of cardiovascular diseases. The existing meta-analyses are heterogeneous and have partly only considered studies on road traffic noise or mixed fatal and non-fatal cases. Basically, there is no evidence from these reviews that the exposure-response relationship differs for fatal and non-fatal cardiovascular cases (Vienneau et al. 2015). Thus, we assumed the same exposure-response relationship for fatal and non-fatal cases, obtained from the SNC.

The latest meta-analysis on the association between type 2 diabetes and transportation noise included all published studies up to February 2019 (Vienneau et al. 2019). Averaged across all traffic sources, the risk of disease increases by 8% (95% CI: 2 to 15%) per 10 dB of noise. Since then, another large prospective cohort study on road traffic noise from Toronto has been published (Shin et al. 2020). All data were combined in a new random effects meta-analysis (Figure 1) that resulted in a diabetes risk increase of 9% per 10 dB of road traffic noise (L_{den}). There are fewer studies on aircraft and railway noise. For aircraft noise, the risk increases by 20% (95% CI: -12 to 63%), although not statistically significantly. For railway noise, no increased risk was observed in the two existing studies within the range of uncertainty. In view of the large differences for the three modes of transport, which are at least partly due to the thin study base for aircraft and railway noise, the same exposure-response relationship is used for all three modes of transport: 8% (95% CI: 4% to 12%) per 10 dB L_{den}.

Figure 1: Association between type 2 diabetes and road, air and rail noise based on studies published by July 2021. ES (95% CI) corresponds to the effect estimate expressed as relative risk per 10 dB L_{den} (including 95% confidence interval, also shown with the horizontal black lines). The small black diamonds correspond to the point estimate; the size of the grey boxes is proportional to the study weights.



In a new meta-analysis on depression and transportation noise all studies up to 11 December 2019 were included (Hegewald et al. 2020). Since then results of the Swiss SAPALDIA study (Eze et al. 2020) were published. Figure 2 shows the pooled estimates based on a random effect meta-analysis. The strongest association was observed with aircraft noise. For road traffic noise, a significant increase in the risk of 3% (95% CI: 0% to 7%) was observed. No association was seen for railway noise, based on a very thin data base. The mean effect estimate across all traffic sources is used for all three types of noise (5%, uncertainty range: 0 to 13%). The lower bound of the confidence interval is censored at the zero value.
Table 1 provides an overview of the derived exposure-response function and the corresponding data sources for the different disease patterns and modes of transport.

Figure 2: Relationship between depression and road, aircraft and railway noise based on the latest meta-analysis by Hegewald et al (2020) and the Swiss SAPALDIA study.

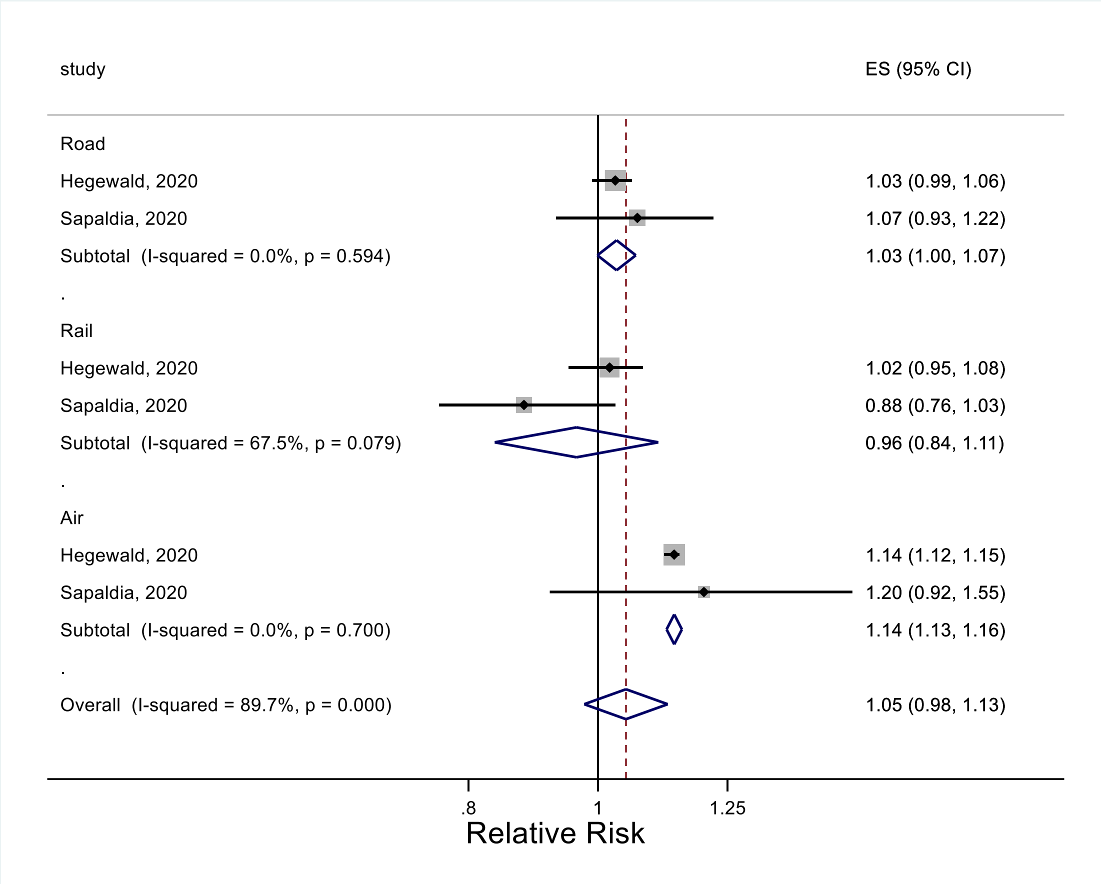


Table 1: Exposure-response relationships for the different clinical pictures: Increase in the risk of disease per 10 dB(A) increase in L_{den} (uncertainty range is given in parentheses)

Outcome	Age group	ICD-10	Road noise	Rail noise	Aircraft noise	Source
Cardiovascular incidence and mortality	≥18 years to <65 years	I00-I99	8.6% (7.3% bis 9.9%)	2.4% (1.5% bis 3.3%)	1.8% (0.1% bis 3.5%)	SNC-SiRENE
	≥65 years to <80 years	I00-I99	2.7% (2.0% bis 3.4%)	1.7% (1.1% bis 2.2%)	0.4% (0% bis 1.4%)[1)]	SNC-SiRENE
	≥80 years	I00-I99	0.8% (0.0% bis 1.6%)	0.4% (0% bis 1.0%)[1)]	0% (0% bis 0.7%)[2)]	SNC-SiRENE
Diabetes Typ 2	≥18 years	E11	8.0% (4.1% - 11.9%)	8.0% (4.1% - 11.9%)	8.0% (4.1% - 11.9%)	Vienneau, 2019 and Shin et al, 2021
Depression	≥18 years	F32-F33	4.9% (0% bis 12.7%)[1)]	4.9% (0% bis 12.7%)[1)]	4.9% (0% bis 12.7%)[1)]	Hegewald, 2020 and Sapaldia

[1)] For the further calculations, the lower bound of the confidence interval was set to the value 0, since protective effects of noise are not plausible.

[2)] In age-stratified models, no correlation was observed for over 80-year-olds. Sensitivity calculations take into account that the upper bound of the confidence interval in this age group is 0.7%.

SNC = Swiss National Cohort (Vienneau et al, 2022)

Baseline disease rates

The observed disease rates were derived from the 2015 hospital statistics of the Swiss Federal Statistical Office. The number of hospital days is calculated by multiplying the number of admissions per diagnosis code by the average length of stay (Table 2). The number of cardiovascular deaths corresponds to the mean value from 2014-2018 (last 5 available years). For the estimation of noise-related deaths among employed persons, the gender-specific labour force participation rates for each year of life were multiplied by the number of observed deaths and summed for the total number. Note that the labour force participation rate above the age of 65 is not zero.

Table 2: Overview of the observed number of cases of disease and deaths

Outcome	ICD Code	Indicator	All age groups	≥18 years	18-64 years	65-79 years	≥80 years
All cardivascular	I00-I99	Hospital admissions	152'139	151'191	46'003	58'772	46'416
diseases	I00-I99	Hospital days	1'329'805	1'321'519	402'100	513'710	405'709
All cardiovascular deaths	I00-I99	death	20'983	20'974	1'370	3'927	15'678
Cardiovascular deaths of labour force	I00-I99	death	1'545	1'545	1'054	309	182
Diabetes Type 2	E11	Hospital admissions	4'668	4'288	1'860	1'517	911
	E11	Hospital days	55'656	51'128	22'171	18'093	10'864
Depression	F32-F33	Hospital admissions	23'083	22'150	17'856	3'205	1'089
	F32-F33	Hospital days	790'175	758'239	611'252	109'707	37'280

Noise-related morbidity and mortality

Table 3 shows the number of noise-related cases of illness per 10 dB(A) increase in noise in 2019. For cardiovascular diseases, road traffic noise has the greatest impact. For every 10 dB(A) increase in average road traffic noise exposure, around 5,800 cardiovascular hospital admissions and 50,600 hospital days are to be expected in Switzerland. For railway and aircraft noise, about 2,400 and 1,100 hospital admissions are expected per 10 dB(A), which corresponds to 20,600 (railway) and 9,500 (aircraft) hospital days. For every 10 dB(A) increase in noise, one expects about 330 hospital admissions due to diabetes and 1,100 hospital admissions due to depression or 3,900 hospital days due to diabetes and 36,700 due to depression for Switzerland as a whole.

Table 3: Number of noise-related hospital admissions and hospital days for cardiovascular diseases, diabetes and depression and breakdown by mode of transport per 10 dB(A) L_{den} in 2019

Number of cases	Road	Railway	Aircraft
Cardiovascular disease			
Hospital admissions (stationary)	5'789	2'358	1'084
Hospital days (stationary)	50'600	20'611	9'479
Diabetes			
Hospital admissions (stationary)	329	329	329
Hospital days (stationary)	3'924	3'924	3'924
Depression			
Hospital admissions (stationary)	1'072	1'072	1'072
Hospital days (stationary)	36'693	36'693	36'693

Table 4 shows the attributable cardiovascular deaths per 10 dB(A) L_{den} for the three modes of transport. Road traffic noise causes 386 deaths per 10 dB(A) L_{den}, railway noise 184 and aircraft noise 48 deaths. The estimated number of deaths in the working population is 112 (road), 37 (rail) and 24 (air) per 10 dB(A) L_{den}. Translating these numbers into YLL by means of life table, road traffic noise causes about 5,200 YLL per 10 dB(A) L_{den}, railway noise 2,200 and aircraft noise 900 YLL. Note that these are discounted values with a discount rate of 1%.

Table 4: Number of noise-related cardiovascular deaths and breakdown by mode of transport per 10 dB(A) L_{den} in 2019

Deaths	Road	Railway	Aircraft
Cardiovascular deaths total	**386**	**184**	**48**
18 to 64 years	130	38	29
65 to 79 years	122	78	19
≥80 years	134	67	-

DISCUSSION

These are preliminary results, which will be updated for the year 2022 using updated noise modelling and possibly new scientific evidence for the health effects from transportation noise. As every burden of disease assessment, the calculations are based on assumption. We adapted the approach proposed by the WHO (2018). Most relevant assumptions in our calculation are the choice of the threshold (counterfactual) below which no health impact from noise was considered (L_{den}=45 dB) and the stronger weighting of Swiss data compared to international data. The latter is expected to be more representative for the Swiss situation and to introduce less uncertainty than international data based on different noise models, noise emission pattern and population's health risk profile. Critical for the use of national data are availability of high quality research that allows deriving reliable exposure-response functions.

CONCLUSION

These burden of diseases assessments demonstrate the impact of noise exposure on the health of the population. The proposed approach may be applied in other contexts as well.

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