ARTICLES

RECHERCHES

Étude de l'évaluation de l'impact sanitaire du bruit lié au trafic routier sur la santé des enfants

Feasibility study of HIA (Health Impact Assessment) on road traffic noise induced health effects on children

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Résumé

Le Dr Odile Mekel et ses collègues nous proposent dans cet article de quantifier l'impact du bruit induit par le trafic routier (BTR) sur la santé des enfants. La démarche adoptée par les auteurs s'inscrit dans une réflexion sur la faisabilité et la pertinence de ce type d'évaluation. En effet, l'évaluation de l'impact sanitaire (EIS) du BTR sur la santé des enfants se heurte à un écueil majeur : alors qu'il existe des fonctions exposition risque (FER) liant des expositions au bruit issu du trafic routier à des évènements sanitaires chez les adultes (tels que maladies cardio-vasculaires, gêne, perturbation du sommeil, stress et effets somatiques, altération des capacités cognitives) suffisamment robustes pour réaliser des EIS, trop peu d'études ont jusqu'à présent été menées chez les enfants pour disposer de FER valides. Cependant, étant donné l'importance des expositions au BTR, la plus grande vulnérabilité *a priori* des enfants à ces expositions, et le besoin d'arguments sanitaires pour orienter les politiques de lutte contre le BTR, les auteurs s'attachent dans cet article à rendre compte de l'impact sanitaire du BTR chez les enfants. Cette EIS porte sur la gêne et la perturbation du sommeil chez les enfants de 14 ans et moins, dans deux villes du länder Rhénanie-du-Nord-Westphalie en Allemagne. Ces villes ont été choisies car elles disposaient de données d'expositions au BTR (obtenues par modélisation), qui, intégrées dans un système d'information géographique, permettaient d'estimer le nombre d'enfants exposés par niveaux de 5 dB(A). Ceux-ci variaient entre les villes : 17 à 34 % des enfants étaient exposés à plus de 60 dB(A) durant la journée, et 21 à 34 % à plus de 50 dB(A) durant la nuit. Pour réaliser les EIS, les auteurs ont appliqué les FER obtenues chez les adultes aux enfants, et calculé la part attribuable au bruit. La transposition des FER des adultes aux enfants constitue une hypothèse forte du travail de Mekel *et al.*, dont les limites sont largement discutées dans l'article. Cette discussion constitue un des points forts de l'article, les auteurs ayant par exemple recours à des analyses de sensibilité pour rendre compte de l'impact de certaines hypothèses sur les résultats. Le bénéfice attendu d'une diminution des niveaux de bruit sont également évalués selon deux scénarios. Dans le premier, les niveaux de bruit sont rendus conformes aux recommandations allemandes (niveaux ne dépassant pas 60 dB(A) le jour et 50 dB(A) la nuit). Dans le second, les niveaux de bruit sont diminués uniformément de 5 dB(A) dans les villes.

Au final, les auteurs estiment que, selon la ville, le BTR est responsable d'une gêne forte pour 5 à 10 % des enfants, et que 4,6 à 5,2 % d'entre eux connaissent des perturbations fortes du sommeil. Le premier scénario de réduction des nuisances permettrait de réduire la gêne engendrée par le BTR de 20 à 29 %, les perturbations du sommeil de 19 à 26 %. La diminution de 5 dB(A) examinée dans le second scénario permettrait de réduire de 38 % la gêne induite, et de 25 à 28 % les perturbations du sommeil.

Cette étude montre ainsi qu'il est possible de rendre compte de l'impact du BTR sur la santé des enfants, au prix d'un certain nombre d'hypothèses qui semblent certes raisonnables mais dont la justesse reste à préciser par d'autres travaux épidémiologiques. Elle permet néanmoins de rendre compte du poids du bruit engendré par le trafic routier sur la gêne et les perturbations du sommeil des enfants.

Mots-clés

Bruit environnemental, impacts sanitaires, santé de l'enfant, nuisances, troubles du sommeil.

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Abstract

Environmental noise and especially road traffic noise has a high impact on the European population, affecting ca. 32 % of the population with noise levels exceeding 55 dB(A).

Exposure to road traffic noise is associated e.g. with cardiovascular diseases, annoyance, sleep-disturbance, stress related somatic effects, and impacts on cognitive performance. Quantitative exposure-response-functions (ERFs) are known for adults but have not yet been studied in detail for children. Under the assumption that ERFs derived for adults are valid for children, adult ERFs were used after some adjustments and further evaluation.

For exploring the feasibility of applying quantitative HIA methods for road traffic noise in children, case studies in two cities in North Rhine-Westphalia (NRW) were performed. Based on exposure distribution data of road traffic noise in children (0-14 years) in these cities and the ERFs, the number of children highly annoyed and highly sleep disturbed by road traffic noise was estimated.

The exposure distribution in the case studies varied by city. 17-34 % of the children is likely to be exposed to noise levels > 60 dB(A) during the day, and 21-34 % to noise levels > 50 dB(A) at night. From the total child population in the two cities (> 30 000 children) > 2500 children are estimated to be highly annoyed by road traffic noise, and over 1 500 children to be highly disturbed during sleeping time. Scenario analyses were performed illustrating the health gains that could be achieved by noise abatement measures.

For the two cities our exposure-based calculations were considered to be a good estimate of the local situation. It is not possible to extrapolate the findings to the whole of NRW or of Germany due to the spatial and regional differences in exposure and population structure. In comparison with similar data from other countries (the Netherlands, Norway, Sweden) our findings seem to be plausible.

Improved exposure assessment of road traffic noise as well as studies on exposure-response-relationship especially for health effects in children induced by road traffic noise should help reducing uncertainties in the quantification of health effects.

Keywords

Environmental noise, health impact assessment, children' health, annoyance, sleep-disturbance.

Introduction

Environmental noise ("noise from all sources except noise at the industrial workplace" [4]) has a high impact on the European population. As one of the main sources of environmental noise, road traffic noise affects approximately 32 % of the European Union's population with noise levels exceeding 55 dB(A) daytime. 13 % of the European population are exposed to levels of road traffic noise of more than 65 dB(A) daytime [14, 15]. The WHO ECEH estimates environmental noise becoming one of the major environmental health issues, which concerns policy-makers as well as the public [16, 34, 35]. A reason for the increase of road traffic related noise is an increase of the extent of road traffic in Europe. EUROSTAT-data support this assumption: from 1995 to 2009, the number of cars per inhabitant in the EU-27 increased from 375 to 473 per 1 000 inhabitants.

Due to the increasing transport demands in all EU member states (MS), noise and especially road traffic related noise is an increasing issue, not only in major cities but also in rural areas with heavily trafficked roads crossing. To handle this issue, the EU introduced the EU Directive 2002/49/EC (Environmental Noise Directive – END) [17] which requested the MS to produce noise maps e.g. for cities with more than 250 000 inhabitants as well as for heavily trafficked roads (> 6 million vehicles per year) in stage 1 until 2007 and for all of the cities with more than 100 000 inhabitants ("agglomerations"), major roads (> 3 million vehicles per year) in stage 2 until 2012. Based on these maps, the MS have to set up and implement noise reduction plans. But a link between those exposure-maps and possible health effects is still missing.

Noise exposure at community levels is associated with various health effects. The major effect of environmental noise is annoyance [1, 35]. Beside annoyance, exposure to road traffic noise (the most predominant noise source) is associated with e.g. sleep-disturbance, cardiovascular diseases (such as hypertension, ischemic heart disease, myocardial infarction and stroke), stress related somatic effects, and impacts on concentration and cognitive performance [1-4, 31-35]. Valid quantitative exposure-response-functions (ERFs) are known for annoyance, sleep disturbance, cardiovascular diseases, and cognition [1, 35]. For annoyance and sleep disturbance, ERFs are known for adults [1, 5, 6, 7] but have not yet been studied in detail for children.

Regarding the exposure to noise, children can be defined as a more sensitive group than adults, because

- noise may affect them in critical development periods,
- their coping repertoire may be less developed and
- they are not able to control their environment [1, 8].

But studies on child specific health effects of noise are rare and partly inconsistent [1, 3, 8, 9, 32]. Most studies investigating children's exposure to traffic-related noise mainly focused on the effects of exposure to aircraft noise [10, 11, 32]. Only a few studies have investigated the effects of children's exposure to road traffic noise [9, 12, 32]. Although the findings of studies on children's exposure to traffic noise are difficult to interpret and not consistent, they indicate that road traffic noise related annoyance in children seems to be comparable to noise related annoyance in adults [10, 13]. For sleep disturbance conclusive evidence is still missing. Nevertheless, the studied literature about children indicates that there is a causal

relationship between road traffic noise and sleep disturbance for children, too [9].

The purpose of this study was to assess the feasibility of conducting a quantitative Health Impact Assessment (HIA) on health effects in children (0-14 years) induced by road traffic noise at European level, since children living in the proximity of heavily trafficked roads may be exposed to high ambient air pollutant concentrations and high noise levels. As health outcomes in this HIA study, annoyance and sleep disturbance were assessed.

Methods

Following the "WHO recommendations for the use of epidemiological data for Health Impact Assessment" [18], we assessed in 2007 the feasibility of conducting a HIA on health effects in children induced by road traffic noise. In an exposure-based approach [6, 7, 37] the number of children which are highly annoyed by road traffic noise as well as the number of children highly sleep disturbed can be estimated by combining the exposure distribution with the exposure-response-function (ERF).

It was not feasible to conduct an HIA on health effects in children induced by road traffic noise for all of the European member states due to a lack of suitable noise pollution data. The available data in 2007 were mainly from the 1990s and were based mainly on calculations that differ from those done in the member states for implementation of the EU Directive 2002/49/EC (END) [17] on environmental noise. But unfortunately these results were not available in 2007. As the preparation of the noise exposure data according to the END was still ongoing and not available, we used the noise exposure levels as reported before the introduction of the END.

Exposure assessment

Due to missing data on a national or international level, we examined which data on children were available on a regional level in the German federal state of North Rhine-Westphalia (NRW). It was not possible to get state-wide exposure data. Five cities in NRW were chosen for case-studies and asked for exposure distribution data of road traffic noise in children (0-14 yrs). Two of the cities (city A and city B) supported us with data(1).

Both cities provided data on traffic noise exposure levels for the requested age groups in their populations. The data on traffic noise exposure levels in both cities were based on noise modelling. In these models the noise levels are usually calculated via geographical models of the regarded area including information about buildings and their height, zoning maps, and the distribution of road traffic during 24 hours (based on traffic census) with special regard to lorries. Additionally, the type of paving was included in the modelling for city B, they gave a penalty up to 3 dB(A) for noisy paving. In the modelling for city A, the starting phases of cars at traffic lights were included. The noise levels estimated by these models reflect the highest noise level at 4 metres height at the outdoor façade of buildings.

Total numbers of people exposed to different noise levels per 5 dB classes at daytime (L_{day}, 6-22 hour), at night-time (L_{night}, 22-6 hour) and during 24 hours (L_{DN}) (city B only) were provided. As the noise levels were determined (e.g. modelled) before introduction of the END, these noise levels were not yet reported as L_{DEN}. In case study A, we did not receive data about $L_{(DN)}$. We calculated $L_{(DN)}$ from $L_{(day)}$ and $L_{(night)}$ using Equation 1:

Equation 1 Conversion of $L_{(DN)}$

% of people exposed *day-night* =
(% of people exposed at *daytime* * 16/24)
+ (% people exposed at *night-time* * 8/24)

In line with the recommendations of the END, we shifted the data of people exposed at night within 10 dB(A) before calculating the $L_{(DN)}$, e.g., we subsumed the day's 40-45 dB(A) class with the night's 50-55 dB(A) class and so on.

Data for health outcomes; exposure-response-functions (ERFs)

As health outcomes, annoyance and sleep disturbance were selected. Data on annoyance and (self-reported) sleep disturbance are not collected on a routine basis but measured by standardised questions in population health surveys or specific epidemiologic studies (e.g. RANCH [11, 32]).

A definition of **annoyance** is given in the WHO-Guidelines for community noise [4]: "annoyance is a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them".

For road traffic noise and **sleep disturbance**, exposure-effect relations are only available for adult populations [7, 34, 35]. So we used them very cautiously to get an impression of the effects of road traffic noise in children.

The selected ERFs were derived by Miedema and Vos [5], Miedema and Oudshoorn [6] and Miedema *et al.* [7]. These ERFs are generally accepted and recommended for adults [3, 19, 20, 35, 36]. Even though there are no special ERFs for children, there are indications that road traffic noise related annoyance in children seems to be comparable to noise related annoyance in adults. For sleep disturbance a causal relationship between road traffic noise and sleep disturbance in children is at least probable. Therefore adults ERFs were used for children in our case-study.

(1) The colleagues from the environmental agency of city A preferred to remain anonymous.

The ERF for annoyance was based on pooled data from 26 datasets from studies mainly in Western Europe. After establishing curves for each dataset showing the percentage of people highly annoyed (HA) as a function of $L_{(DN)}$, the authors combined all curves to one curve [5]. For sleep disturbance the ERF was based on pooled data from 15 datasets [7, 20]. In the derived ERFs, annoyance and sleep disturbance both are divided into three categories, dependent on their severity: "lowly annoyed (LA)" and "lowly sleep disturbed (LSD)", "annoyed (A)" and "sleep disturbed (SD)", "highly annoyed (HA)" and "highly sleep disturbed (HSD)". In our case studies we only used the outcomes "highly annoyed" and "highly sleep disturbed" for an "at least"-approach, because we did not want to overestimate the effects. Furthermore we wanted to avoid a discussion on whether mild annoyance is counted as a health issue [35, 37]. In an exposure-based approach, the number of children which are highly annoyed by road traffic noise as well as the number of children which are highly sleep disturbed was estimated by combining the exposure distribution with the ERF.

The proportion of the exposed people (in percent) for $L_{(DN)}$, who are highly annoyed (HA) or highly sleep disturbed (HSD) at a certain noise level can be estimated with the following equations.

Equations 2 for calculating the percentage of highly annoyed or highly sleep-disturbed people by road traffic noise for L(DN)

Health outcome	Exposure Response Function (ERF)	Ref.
% HA	$9.994*10^{-4}\ (L_{DN}-42)^3 - 1.523*10^{-2}\ (L_{DN}-42)^2 + 0.538\ (L_{DN}-42)$	[5],[6]
% HSD	$20.8 - 1.05\ L_{night} + 0.01486\ (L_{night})^2$	[7]

HA = highly annoyed people

HSD = highly sleep-disturbed people

The ERF for annoyance is only valid in the range of L(DN) > 45 dB(A) and $L_{(DN)}$ < 75 dB(A), because the authors of the ERF excluded exposures below 45 dB(A) and over 75 dB(A) [5, 6]. For sleep disturbance, the ERF is valid in the range of > 40 dB(A)-70 dB(A), but extrapolations to lower exposure (40-45 dB(A)) and higher exposure (65-70 dB(A)) are possible in this case [7]. In these ranges, we calculated the percentage of the people highly annoyed and the percentage of highly sleep-disturbed respectively. E.g. at a level of LDN 45 dB(A), 1.5 % of exposed people are highly annoyed (HA); at a level of L_{DN} 47.5 dB(A) = 2.66 % HA; L_{DN} 50 dB(A) = 3.84 %, etc.

Due to the fact that the ERFs are only valid in the described ranges we had to make some assumptions. The proportion of children exposed to noise levels < 45 dB(A) or 40 dB(A) or > 75 dB(A) or 60 dB(A) was set to the noise level 45 dB(A) or 75 dB(A) or 65 dB(A) respectively.

After calculating these percentages of HA and HSD we subsumed the single values to categories (45-50 dB(A), 50-55 dB(A), etc.) by taking the mean of the associated single values. In this way we calculated the number of HA and HSD children per noise level category by combining the number of exposed children in each category with the appropriate percentage value. The total number of HA and HSD children per city is derived by summing up the numbers over all categories.

To assess possible variation in our results, we estimated the range of number of the expected annoyance and the expected number of people sleep disturbed in our case studies making use of the 95% confidence intervals of the ERFs [5-7]. Data points of the confidence intervals were kindly provided by the authors of the exposure-response functions [5-7].

Participating countries, cities, regions

Case study City **A:**

City A has a municipal area of approximately 123 km², about 7.7 km² (6 %) of this area are used for traffic. This city is a core city in an urbanised area, a typical situation for about 9 % of the cities in North Rhine-Westphalia (NRW) [29]. From the 52 538 inhabitants in 2007, 8 589 (16 %) were children between 0-14 years of age.

Case study City **B:**

With its municipal area comprising about 91 km², city B is located in western NRW as part of the largest industrial area in NRW. About 12 km² (13 %) of the municipal area are used for traffic, e.g. roads. City B is a core city in a highly-compressed urban agglomeration. This situation is typical for about 4 % of the NRW cities [29]. In the year 2007, 171 160 inhabitants were living in city B, 22 050 (13 %) of them were children between 0-14 years of age.

Comparisons of the method and results

Based on data of the general population exposed to different noise levels (over 24 hours averaged values) in the Netherlands [3, 21], Norway [22], and in Sweden [23] the number of highly annoyed people was calculated to evaluate our results. As for Germany exposure distribution data for the night was available, the number of highly sleep-disturbed people was calculated additionally [30].

Scenarios

We developed two noise reduction scenarios for the case studies. For each of the case studies, we assumed noise exposure levels not exceeding 50 dB(A) at night and 60 dB(A) daytime (scenario 1). These values are threshold values for noise exposure in residential areas according to the 16. BImSchV (German regulation on noise pollution due to road and railroad traffic) [28]. In a second scenario we examined the effect of decreasing noise levels. We calculated a scenario with a decrease of 5 dB(A) for both cities. The use of low-noise asphalt may lead to a noise reduction of about 7 dB(A) [24]. As we do not know in which ranges this value may vary we selected 5 dB(A) to avoid overestimating of the effects.

Results

Exposure levels

The percentage of children exposed to the different road traffic noise related noise levels (day and night) has been determined for both cities. In comparison, the exposure distribution of road traffic noise in children (0-14 years) for the two cities in North Rhine-Westphalia varied per city. 17 vs. 34 % of the children were exposed to noise levels of more than 60 dB(A) during the day, and 21 vs. 34 % were exposed to noise levels of more than 50 dB(A) at night. Comparing the two cities, the road traffic noise exposure is higher in city B. Hence there are proportionally more children in city B exposed to road traffic noise exposure at higher levels than in city A.

Calculation of health impacts

Based on the exposure levels, for the health outcomes “high annoyance” and “high sleep disturbance” the number of affected children was calculated. While there was only a minor difference in sleep disturbance between the two cities, the estimated percentage of highly annoyed children in city B was twice as much as in city A (see table 1). In comparison with city A, the proportion of highly annoyed children in the noise level classes higher than 55 dB(A) was quite high (see figure 1).

Table I. Estimated number of highly annoyed or highly sleep-disturbed children by road traffic noise in city A and B with the appropriate confidence intervals (CI).

Health outcome	City	
	A	B
Annoyance		
Highly annoyed children (%)	5.4 (3.97-6.53)	10.06 (7.9-12.22)
Highly annoyed children (n)	471 (345-569)	2217 (1742-2695)
Sleep disturbance		
Highly sleep-disturbed children (%)	4.60 (3.27-7.45)	5.21 (3.65-8.17)
Highly sleep-disturbed children (n)	395 (281-640)	1149 (804-1802)

CI = Confidence interval (2)

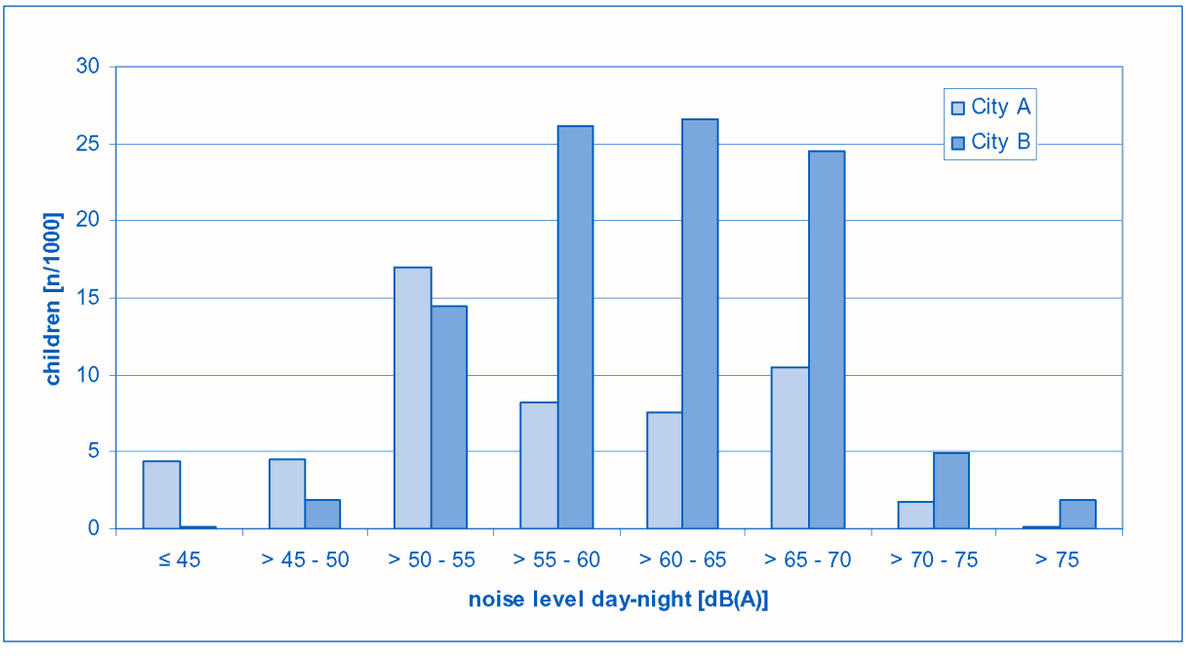

Figure 1. Estimated number of children (per 1 000) highly annoyed by road traffic noise, by noise level category in two NRW cities.

(2) For sleep disturbance only in the range between 45 dB(A) and 65 dB(A).

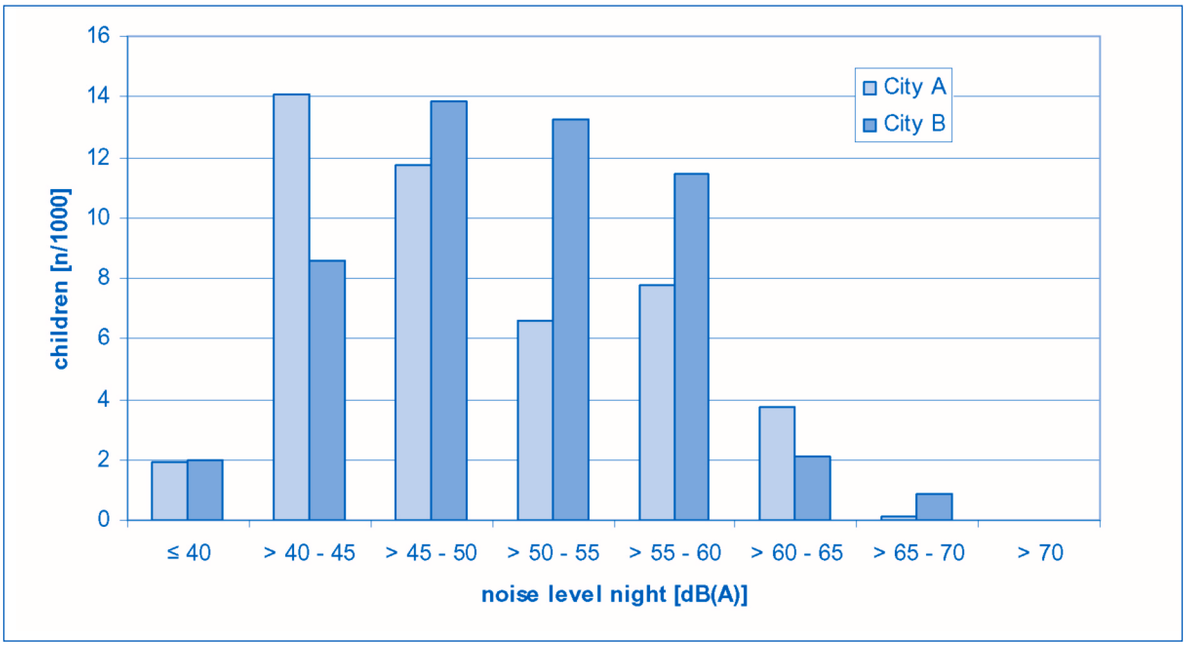

Figure 2. Estimated number of children (per 1 000) highly sleep-disturbed by road traffic noise, by noise level category in two NRW cities.

For the total child population in the two cities of approximately 31 000 (30 759) children in the age up to 14 years, 2 700 children were estimated to be highly annoyed by road traffic noise, and 1 500 children to be highly disturbed during sleeping time. A detailed picture about the estimated distribution of highly annoyed and highly sleep-disturbed children is shown in figures 1 and 2. The 95 % lower and upper confidence limits of the expected annoyance in our case studies are presented in table 3, too. For sleep disturbance they are only available in the range between 45 dB(A) and 65 dB(A).

The accumulation of HA or HSD children in the lowest exposure categories in figures 1 and 2 and in the highest exposure category in figure 1 may be caused by the ranges, in which the ERFs can be applied. The numbers of children exposed to noise levels lower than 40 dB(A) or 45 dB(A) and higher than 70 or 75 dB(A) had to be subsumed to these values.

Comparisons of findings

Our findings are comparable to the results of the calculations we made with data from the Netherlands, Sweden, Norway, and Germany (source: [3, 21-23, 30]). In the Netherlands, there are approximately 2 % of the people highly annoyed because of road traffic noise. These include adults as well as children.

With the same method as used in our HIA study, we calculated approximately 3.1 % of the people living in Sweden and 3.4 % of the people living in Norway may be regarded as highly annoyed because of road traffic noise in the year 2003. The percentage of highly annoyed people varied per city. While in Stockholm (S) and Oslo (N) 7.6 % and 7 % of the inhabitants were estimated to be highly annoyed, the proportion of highly annoyed people in Gothenburg (S) and Akershus (N) was only 3.5 % and 2.8 %.

And also with the same method we calculated approximately 8.9 % of the people living in Germany as highly annoyed because of road traffic noise. 7.8 % of the people living in Germany are estimated as highly sleep disturbed due to road traffic noise.

Scenarios

We calculated the proportion of highly annoyed and highly sleep-disturbed children in the two cities with a noise exposure not exceeding 50 dB(A) during night-time and 60 dB(A) daytime (table 2). In a second scenario, we calculated the situation of the highly annoyed and highly sleep disturbed children in the two cities with the assumption of a noise level decreasing for 5 dB(A) in each noise level category (table 3). The results show a clear decrease of the outcomes in both cities for both scenarios.

Table II. HIA scenario analysis 1 – noise exposure is not exceeding 50 dB(A) (at night) and 60 dB(A) (daytime).

	Current situation		Exposure reduction measure 1		Potential health gain/ Difference	
Health outcome	**City**		**City**		**City**	
	A	**B**	**A**	**B**	**A**	**B**
Annoyance						
Highly annoyed children (%)	5.4	10.1	4.4	7.2	19.1*	28.9*
Highly annoyed children (n)	471	2 217	381	1 576	90	641
Sleep disturbance						
Highly sleep-disturbed children (%)	4.6	5.2	3.7	4.0	19.2*	26.3*
Highly sleep-disturbed children (n)	395	1 149	319	847	76	302

* Proportion (in %) of the HA or HSD children which could be avoided by the exposure reduction measure

Table III. HIA scenario analysis 2 – a 5 dB(A) decrease throughout all categories

	Current situation		Exposure reduction measure 2		Potential health gain/ Difference	
Health outcome	**City**		**City**		**City**	
	A	**B**	**A**	**B**	**A**	**B**
Annoyance						
Highly annoyed children (%)	5.4	10.06	3.36	6.22	38.0*	38.1*
Highly annoyed children (n)	471	2 217	292	1 372	179	845
Sleep disturbance						
Highly sleep-disturbed children (%)	4.60	5.21	3.44	3.77	25.3*	27.7*
Highly sleep-disturbed children (n)	395	1 149	295	831	100	318

* Proportion (in %) of the HA or HSD children which can be avoided by the exposure reduction measure

Discussion

For the two cities investigated in our feasibility study, our exposure-based calculations seem to be a good estimate. Even though it is not possible to extrapolate these findings to the whole area of North Rhine-Westphalia or Germany due to the spatial and regional differences in exposure and population structure, there are some cities which are comparable to the cities in our case study (a total of 13 % of the cities in NRW) [29]. In these comparable cities approximately 5 million inhabitants (5 095 226) were living (28 % of the inhabitants of NRW) in 2006.

In comparison with results of the calculations for Germany, our case study findings seem to be plausible, even though the exposure data for Germany was not complete. We estimated 5 % and 10 % of the children to be highly annoyed in our case studies, for Germany we calculated approximately 9 % of the people highly annoyed. For sleep disturbance, we estimated 5 % for both cities, for Germany we calculated 8 %. The comparison with results from the Netherlands supports our findings, too. Even though there are only 2 % of the people highly annoyed by traffic noise (whereas we estimated 5 % and 10 % of children to be highly annoyed), it has to be noted that in the Netherlands the whole country (including rural areas without heavily trafficked roads) was examined, while we were looking only at cities as was done for the comparison with Norway (3.4 %) and Sweden (3.1 %), too. Furthermore, the comparison with Norwegian and Swedish cities shows a bigger proportion of highly annoyed people (Gothenburg, Stockholm, Oslo, except Akershus). The second difference is, that while in the countries compared (the Netherlands, Norway, Sweden) adults and children were examined, we focussed on children only. For the data from Norway and Sweden there may be an underestimation of the percentage of HA people, because the number of people exposed to noise levels <55 dB(A) was missing in the data source. So this proportion was not included in the estimation.

Our assumption that the ERFs on annoyance for adults were valid for children, too, is not without controversy. Lercher *et al.* [13] demonstrated that road traffic noise induced annoyance in mothers was very comparable with the annoyance of their children. But at the same time Lercher *et al.* [13] showed a difference between children and adults regarding road traffic noise induced annoyance. Children seem to be more annoyed at lower noise levels than adults, while adults seem to be more annoyed at higher levels. Öhrström *et al.* [12] showed similar differences, children seem to be more annoyed at noise levels lower than 55 dB(A) while they are significantly less annoyed at noise levels higher than 64 dB(A). Due to

these differences it is possible that the proportion of highly annoyed children for the lower noise levels may be underestimated, especially in city A, where more than half of the children are exposed to noise levels lower than 55 dB(A). On the other hand, the proportion of highly annoyed children at noise levels higher than 64 dB(A) may be overestimated. But this possible overestimation would not affect as many children as a possible underestimation in the lower exposure levels.

For sleep disturbance the controversy about using the ERFs for children which had been derived for adults is even bigger. As Öhrström *et al.* [9] showed there are indications that children's and adults' sleeping behaviour in relation to noise seems to be similar. But the parameters shown by Öhrström *et al.* (sleep quality, awakenings, tired-alert in the morning) are not necessarily the same as sleep disturbance. So it is not feasible to estimate possible over – or underestimation of our sleep disturbance calculations.

Due to the fact that the ERFs are only valid in the ranges from 40-75 dB(A) for annoyance and 45-70 dB(A) for sleep disturbance, the percentage of HA and HSD children could be overestimated in the lowest noise classes and underestimated in the highest noise classes. Accordingly to these uncertainties the estimated confidence intervals are not the definite range in which the results may vary. For showing the sensitivity of our calculations below the lower end of the ERF, we calculated the number of children highly annoyed and highly sleep-disturbed assuming 0 % high annoyance or high sleep disturbance below noise levels of 40 dB(A) or 45 dB(A). There is a difference of approximately 0.2 % in high sleep disturbance for both cities and of 0.4 % (city A) and 0.01 % (city B) in high annoyance.

Due to the method used for modelling the exposure to road traffic noise in the cities, there might be some uncertainties which could lead to an underestimation of the health impacts. The modelling did not include the vibrations caused by lorries, in city A the type of paving was not differentiated, and in city B starting phases of the traffic were not included. It has to be discussed if the calculation of sleep disturbance with the used ERF based only on $L_{(night)}$ (22-6 hr) could be an underestimation because of the increased sensitivity of children in the evening resulting from earlier sleeping habits in younger ages. Another uncertainty for calculating the highly annoyed children in city A may result from the exposure data for city A. As we did not receive data about $L_{(DN)}$, we calculated the $L_{(DN)}$ from $L_{(day)}$ and $L_{(night)}$ in a very simple way.

The noise exposure is modelled at the façade of houses and not inside. This does not limit these calculations, because the used ERFs are developed for these conditions, too. Another point which may limit the estimations generally is that the location of the bedroom and the bedroom-windows is not being included in the modelling and in estimations. Furthermore information about the socio-economic status of exposed people is useful for a complete estimation but could not be considered [37]. There are some indications that more people with a lower socio-economic status often live near heavily trafficked roads. However, specific ERFs for these populations are not available.

Recommendations

With results from noise mapping according to the END meanwhile available, HIA calculations should be carried out to update the presented preliminary results from this study. This has been done for the overall population in different countries in the EBoDE-project regarding sleep disturbance lately [37]. Furthermore, new calculations could be presented on annoyance and sleep disturbance taking END-data into account [35, 37]. But still, these newer approaches have not accounted for children separately.

Because of the high impact of road traffic noise on children's health, it is important to conduct further HIA making use of standard reported noise exposure distributions. Thus it is crucial to change the report obligations, because currently the stratification of the noise exposure distribution by age groups is not obligatory according to the END.

Using the new noise maps, it could be useful to combine the addresses of primary schools with modelled road traffic noise levels to assess the exposure of children to road traffic noise during the day in a more differentiated way. All in all, exposure-response-relationships for health effects induced by road traffic noise specifically in children need to be improved.

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